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Essays on Derivatives and Risk Management on Freight and Commodity: An Attempt to Anticipate and Hedge the Market Volatilities

by

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Declaration of Original Authorship

I confirm that this is my work and the use of all material from other sources has been properly and fully acknowledged.

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Abstract

This thesis investigates three unexplored areas in maritime freight and commodity markets; 1) the relationship between commodity and freight markets; 2) the interaction of freight options market with the freight futures and underlying freight rate markets; 3) improving the hedging performance of freight futures contracts by cross hedge technique. Details provided as follows: Firstly, information flows between commodity and shipping freight markets are essential for the participants of the international shipping industry for optimising ship chartering strategies, investment positioning and risk management. This study investigates the economic relationships between commodities corresponding shipping freight rate markets, along with both their futures contracts, through a comprehensive dataset of 65 variables analysed simultaneously through a dynamic factor model. In contrast, previous literature has only investigated the bi-variate framework which limits some of the cross-market information. Commodity markets (especially the crude oil and other oil derivative products) lead the freight rates driving price movements. Secondly, the study fills the gap by investigating the economic spillovers of both returns and volatilities between time-charter rates, freight futures, and the un-investigated freight options in the international dry-bulk shipping industry. Empirical results indicate the existence of significant information transmission in both returns and volatilities between the three related markets, which we attribute to varying trading activity and market liquidity. The results also point out that, consistent with theory, the freight futures market informationally leads the freight rate market, though surprisingly, freight options lag both futures and physical freight rates. Lastly, the international shipping freight rates are susceptible to high market volatilities demanding diversifying and hedging the associated risks. This study develops a portfolio-based methodological framework aiming to improve freight rate risk management to create market stability. The study also offers, for the first time, evidence of the hedging performance of the recently developed container freight futures market. The approach utilises portfolios of the container, dry bulk and tanker freight futures along with corresponding portfolios of physical freight rates to improve the efficacy of risk diversification for shipping market practitioners. The results of this thesis provide not only commercial and financial risk management solutions but also offer valuable insights for economic development policymakers and regulators. The empirical findings uncover necessary implications for overall business, commercial, and hedging strategies in the shipping industry, while they can ultimately lead to a more liquid and efficient freight futures market.

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Part I - Introduction to the Thesis

1. Overview and Contribution

Maritime trade is the major source of international trade and transportation. Currently, more than 90% of international trade by volume is carried by ships, as reported by the International Maritime Organization (IMO). The major reason for such a high percentage of trade through ships is attributed to the very low ocean freight rates as compared to those associated with other modes of transportation such as land and air. The total volume of goods carried by ships is more than 10 billion tons with a gross ton-mileage of over 56 ton-miles in 2016. Despite the high volume of trade through ships, ocean freight rates are subject to high volatilities. The slightest fluctuation in freight rates has major implications for international trade and commodity prices. Further, investment in shipping assets acts as an important source of diversification, as shipping has a very low correlation with stocks (Grelck et al., 2009). So, institutional investors like investment banks, hedge funds, private equities are very interested in holding shipping portfolio for hedging their exposures. Though shipping industry serves the purpose of the good diversifiable sector, it is highly interlinked and very sensitive to the global economy (Grammenos and Arkoulis, 2002, Kavussanos and Marcoulis, 2005). This makes it an interesting, though risky, business to venture into, as the international market information spillover into the shipping industry business means that an understanding of the business cycle can yield high profitability. This drives practitioners to invest in this market with the intention of getting higher returns and academics to develop high-impact research works.

The shipping industry is regarded as one of the most volatile industries (Kavussanos and Visvikis, 2006a). Dry bulk freight within the shipping industry is notorious for its high fluctuation. Industry practitioners (including shipowners and charterers) utilise various models to anticipate the dry bulk freight rates which can not only offer better risk management solutions and improve their profitability but also can provide an edge over their competitors. Determining the information spillover effects from the leading market to anticipate the price movements of the lagging market is one of the standard models to forecast market prices. Freight futures contracts act as a forward-looking curve which helps to predict the underlying freight rates, as futures contracts react faster to any new market information than the physical freight rates (Kavussanos and Visvikis, 2004b). Though there exists literature investigating the lead-lag relationship between freight futures and underlying freight rates, there exist no studies of freight options price movements. Since freight is a type of non-storable commodity, its options are priced using Black (1976), where the underlying asset (on which the option contract is priced) is the futures contract, instead of Black and Scholes (1973), which utilises spot prices. The spillover effect of dry-bulk (Capesize, Panamax and Supramax) freight rates, with their corresponding freight futures and options contracts, will be investigated in Chapter 3. Further, it also presented the lead-lag relationship between the freight rates and freight options markets without even having any theoretical linkage between them.

The academic and industry contributions of Chapter 3 are multifaceted, as follows: firstly, dry-bulk freight rates and their corresponding futures and options contracts are investigated in a tri-variant framework to understand the lead-lag relationships of both returns and variance for Capesize, Panamax and Supramax markets. This provides valuable information for hedgers, including shipowners and charterers and investors who can take a position on the lagging market by observing the leading markets; secondly, it is also the first study to investigate the price movements of freight options contracts. This research provides a base on which researchers can build various trading strategies on freight market price movements such as investigating whether there exists an arbitrage opportunity in freight options markets, etc.

The results indicate that the freight futures contracts react fastest to new information followed by freight rates and lastly by freight options contracts. This is attributed to the increasing level of market friction – freight futures contracts have the lowest market friction due to low transaction costs and high market liquidity, physical freight rates have relatively high market friction due to the high transaction costs involved in re-adjusting the contracts and, finally, freight options contracts experience the highest market friction caused by the very low market liquidity. This chapter also presents interesting trading and hedging strategies using freight options contracts that not only provide important risk management strategies for hedgers using options contracts but also establish an enriched model for investment using freight options contracts. This can help in improving the market liquidity of such contracts. Various risk management strategies concerning freight rates are also presented by observing the freight futures contracts that can benefit shipowners and charterers in improving their returns, even in the present slow moving dry bulk market.

The spillover effects within dry bulk freight rates and the corresponding derivatives contracts are extended to tanker and commodity markets and their corresponding futures markets in Chapter 4. An exhaustive list of commodity and freight rate variables utilize various tanker and dry bulk freight rates and the major maritime commodities carried by ships, including crude oil and its derivatives products, coal, iron ore, wheat, corn, soybeans, sugar and fertilizers, amongst others, along with their corresponding futures contacts, constituting a total of 65 variables in a multi-factor framework that can help to understand the lead–lag relationship between the commodity prices and their costs of carriage by ship. This study contributes to the existing literature in the follow ways: (a) This is the first study to combine a wide range of dry and liquid commodities and, along with their corresponding freights rates, to investigate the lead–lag relationship between the commodity and freight markets which can help investors to understand the price movement of the maritime transportation sector; (b) The study also considers the spillover effect between the commodity and freight futures' contracts which provides a forward-looking curve for the underlying commodity and freight markets; (c) The study presents the relationship between the liquid energy commodities such as crude oil and its derivative products and the tanker freight rates which has not so far been investigated, validating the economic relationship between them. This research will directly benefit practitioners by extensively demonstrating the price movement of various commodity prices and freight rates. Examining the price variation and tracing the leading variables to efficiently anticipate the lagging variables can provide effective risk management strategies.

The concept of the freight market is the derived demand of the commodity market is validated in this research – that is, freight rates are observed to lag commodity prices. More specifically, crude oil and oil product prices can act as a price discovery instrument for tanker freight rates, whereas iron ore and agricultural products help in anticipating the dry bulk freight rates. It is also observed that the futures prices lead the underlying commodity or freight rates, which is in line with the existing literature. Overall, it is observed that crude oil prices drive the prices of other commodity and freight rates, indicating that energy (as crude oil is still the major source of energy) prices determine global commodity prices. This research has economic implication: (a) Macroeconomic implication: its export and import determines the gross domestic product (GDP) of a country. As transportation cost and commodity prices are two major factors of export and import, this research can help to understand the economic growth of major exporting nations by elucidating their trading activities. This calls for policy implications to take advantage of any price dynamics facilitating international trade; (b) Microeconomic implication: commodity houses, charterers and shipowners who are directly affected by freight and commodity price fluctuations can take positions in the market to improve their returns. Forwarding agents, ship brokers and other third-party service providers can also benefit from these findings by taking action to prepare for future business activities.

The risk management strategy is finally completed in Chapter 5 by providing a freight rate hedging solution. Hedging freight rate fluctuations through the usage of freight futures contracts have not been very effective. The hedging performance of both dry bulk and tanker freight futures has been historically low (Alizadeh et al., 2015a, Kavussanos and Visvikis, 2010). Further, there has been no study investigating the hedging performance of the newly developed container futures contracts. As there exists a strong information spillover between the dry bulk, tanker and container freight markets (Tsouknidis, 2016), this study creates a diversified portfolio of freight rates using a Markowitz (1952) mean-variance portfolio. This is unique research and the first of its kind to provide a traditional mode of hedging freight rate volatilities by diversifying freight rate contracts to secure the cash-flow generated through chartering ships covering the three major internal shipping sectors: dry bulk, tanker and container freight rates. The freight rate fluctuations of the well-diversified portfolio (using dry bulk, tanker and container freight rates) are further minimised by the use of a portfolio of freight futures contracts. This study thus contributes to academic and industry practice in the following ways: Firstly, it is the first study to investigate the hedging performance of container futures' contacts and thereby provide a strategy to hedge the newly developed freight futures contracts. The results will be useful for container liners, forwarding agents and charterers who are exposed to container freight rate fluctuations Secondly, the study provides a traditional mode of hedging freight rate volatilities through diversification. As some of the traditional shipowners do not have expertise on freight derivatives contracts to hedge their freight rates' volatilities, this study provides a model that they can use to diversify their investments effectively. Thirdly, the approach of hedging the underlying portfolio of freight rates through the use of a portfolio of future contracts attempts to improve the hedging performance of such contracts. Understanding the correlation between freight futures contracts can improvise the hedging strategies that can be developed in future studies.

The results suggest that, though the container freight futures contracts have developed recently, their effectiveness is comparable to other matured freight derivatives contracts such as dry bulk and tanker futures. It is also observed that the traditional hedging through diversification can help to reduce the freight rate variances by up to 48%. Up to 10% could further reduce these freight rate fluctuations by financially hedging the well-diversified portfolio of freight rates. It is also seen that financial hedging with the use of freight futures contracts outperforms the hedging performance of direct hedging.

Overall, the three empirical chapters in this thesis (Chapters 3–5) can help industry practitioners to develop better risk management strategies by (a) market anticipation – spillover information between the markets and (b) hedging freight rate risks – the use of both traditional hedging techniques through efficient diversification and a financial hedging model by using freight futures' contracts.

The remaining of the thesis is structured as follows: Chapter 2 presents a general literature review on freight derivative markets, information transmission of general futures and options markets with their corresponding underlying assets, including commodity markets, hedging performances of general and commodity futures and information spillover of commodity and freight markets along with their futures contracts. This is followed by the three empirical chapters that have just been described. Lastly, the thesis is concluded in Chapter 6 by summarising the results and implications including suggestions for future research work.

2. General Literature Review

2.1. Introduction

Freight derivatives play a significant role in developing risk management solutions for international shipping markets. Freight derivatives have not only gained interest amongst market practitioners such as shipowners, charterers, brokers and banks, but also amongst academics. This is highlighted by the fact that, despite shipping being one of the most matured and established industries, freight derivatives are a relatively new and emerging sector which allows the scope for constant improvement. In February 2008, the total value of market trade was about 1000 billion USD (Alizadeh, 2013), as compared to the 560 billion USD trade for the underlying physical freight rate trade.[1] This indicates that the freight derivative markets also suffer from market liquidity. This could be attributed due to the lack of knowledge about this emerging market amongst market practitioners (Kavussanos and Visvikis, 2006b). This should further encourage academics and researchers to investigate this sector of the industry, not only to create industry awareness but also to develop extensive and valuable literature.

The following review offers extensive literature on the freight and commodity derivatives markets but is by no means exhaustive. This section of the thesis may not be apparently related to the areas investigated in the empirical Chapters 3–5, as its own literature review accompanies each empirical chapter. The purpose of this chapter is to offer a contextual understanding of freight and commodity derivatives, which will allow for a more pleasant experience for the scholarly reader.

[1] This includes only the dry-bulk and tanker markets.

2.2. Development of Freight Derivatives and their Underlying Assets

The Baltic Exchange was first established in 1744 that later became the first organised maritime exchange. In 1985, the first index of freight rates was developed, known as the Baltic Freight Index (BFI), which was a composite index of dry-bulk freight rates comprising Capesize, Panamax, Supramax and Handysize freight rates. The Baltic Exchange started trading dry-bulk freight futures contracts known as Baltic International Freight Futures Exchange (BIFFEX) in 1985, settled against the Baltic Freight Index and cleared at the International Commodity Clearing House (ICCH), which is presently known as LCH.Clearnet. This type of futures contracts introduced was successful until 1992 when Clarksons introduced the over-the-counter (OTC) contracts, known as freight forward agreements (FFAs). FFAs were successful compared to freight futures contracts, as they were tailor-made to their users' requirement. Later, several sub-indexes of dry-bulk freight rates were introduced to track the sub-market prices more accurately, such as (a) the Baltic Capesize Index (BCI) introduced in 1999, (b) the Baltic Panamax Index (BPI) introduced in 1998, (c) the Baltic Supramax Index (BSI) introduced in 2005 and (d) the Baltic Handymax Index (BHMI) introduced in 2000. Details of the present route constituents of those indexes are presented in Tables 2.1–2.4.

Table 2.1 Baltic Exchange Capesize Index (BCI) Composition, 2017

Route	Vessel Size (dwt)	Cargo	Route Description	Weight (%)
C8_14	180,000	Iron Ore	Gibraltar/Hamburg transatlantic round voyage	25
C9_14	180,000	Iron Ore	Continent/Mediterranean trip China–Japan	12.50
C10_14	180,000	Iron Ore	China–Japan transpacific round voyage	12.50
C14	180,000	Iron Ore	China–Brazil round voyage	12.50
C16	180,000	Iron Ore	Revised backhaul[2]	12.50

Source: Baltic Exchange.

[2] Delivery Qingdao–Beilun range, 3–10 days from index date for a trip via Australia or Indonesia or US west coast or South Africa or Brazil, redelivery UK–Cont–Med within Skaw–Passero range, duration to be adjusted to 65 days. Basis: the Baltic Capesize vessel.

Table 2.2 Baltic Exchange Panamax Index (BPI) Composition, 2017

Route	Vessel Size (dwt)	Cargo	Route Description	Weight (%)
P1A_03	74,000	Grain/Ore/Coal	Skaw–Gibraltar transatlantic round voyage	25
P2A_03	74,000	Grain/Ore/Coal	Skaw–Gibraltar trip to Taiwan–Japan	25
P3A_03	74,000	Grain/Ore/Coal	Japan–South Korea transpacific round voyage	25
P4_03	74,000	Grain/Ore/Coal	Japan–South Korea trip to Skaw Passero	25

Source: Baltic Exchange.

Table 2.3 Baltic Exchange Supramax Index (BSI) Composition, 2017

Route	Vessel Size (dwt)	Route Description	Weight (%)
S1B_58	58,328	Canakkale trip via Med or the Black Sea to China–South Korea	5
S1C_58	58,328	US Gulf trip to China–South Japan	5
S2_58	58,328	North China one Australian or Pacific round voyage	20
S3_58	58,328	North China trip to West Africa	15
S4A_58	58,328	US Gulf trip to Skaw–Passero	7.50
S4B_58	58,328	Skaw–Passero trip to US Gulf	10
S5_58	58,328	West Africa trip via east coast South America to north China	5
S8_58	58,328	South China trip via Indonesia to east coast India	15
S9_58	58,328	West Africa trip via east coast South America to Skaw–Passero	7.50
S10_58	58,328	South China trip via Indonesia to south China	10

Source: Baltic Exchange.

Table 2.4 Baltic Exchange Handysize Index (BHSI) Composition, 2017

Route	Vessel Size (dwt)	Route Description	Weight (%)
HS1	28,000	Skaw–Passero trip to Rio de Janeiro–Recalada	12.50
HS2	28,000	Skaw–Passero trip to Boston-Galveston	12.50
HS3	28,000	Rio de Janeiro–Recalada trip to Skaw–Passero	12.50
HS4	28,000	US Gulf trip to Skaw–Passero	12.50
HS5	28,000	South East Asia trip via Australia to Singapore–Japan	25
HS6	28,000	South Korea–Japan trip via North Pacific to Singapore–Japan	25

Source: Baltic Exchange.

After the establishment of sub-indexes, BFI was abolished, and the Baltic Dry Index (BDI) was started which is the arithmetic average of BCI, BPI, BSI and BHSI. Due to the development of sub-indexes that reflects the freight rates of four main sizes of bulk carried individually – that is, for Capesize, Panamax, Supramax and Handysize vessels – the use BIFFEX with a composite index of dry freight rate (BFI) lost its importance. The BIFFEX contracts also had very low hedging performances as the underlying index (BFI) was a composite index comprising various sizes of dry-bulk vessels instead of sector-specific (Kavussanos and Nomikos, 2000a; Kavussanos and Nomikos, 2000b). BIFFEX contracts stopped trading in 2002. Figure 2.1 shows the yearly volume trade of BIFFEX.

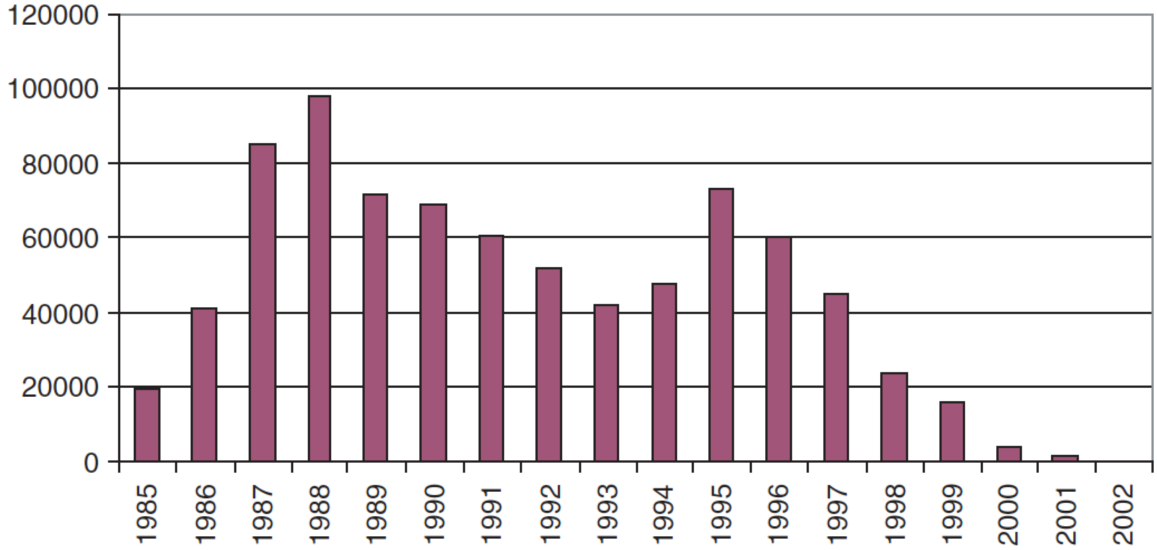

Figure 2.1 Yearly Volume of BIFFEX Contracts (May 1985–April 2002)
Source: Kavussanos and Visvikis (2006b).

The cessation of the BIFFEX contracts in 2002 was followed by the developed of sub-index-specific FFA contracts. Table 2.5 presents the gradual increase in the volume of FFA trade since 1992. The total dry-bulk FFA trade was about 1,200,000 contracts in 2016 (Source: Baltic Exchange)

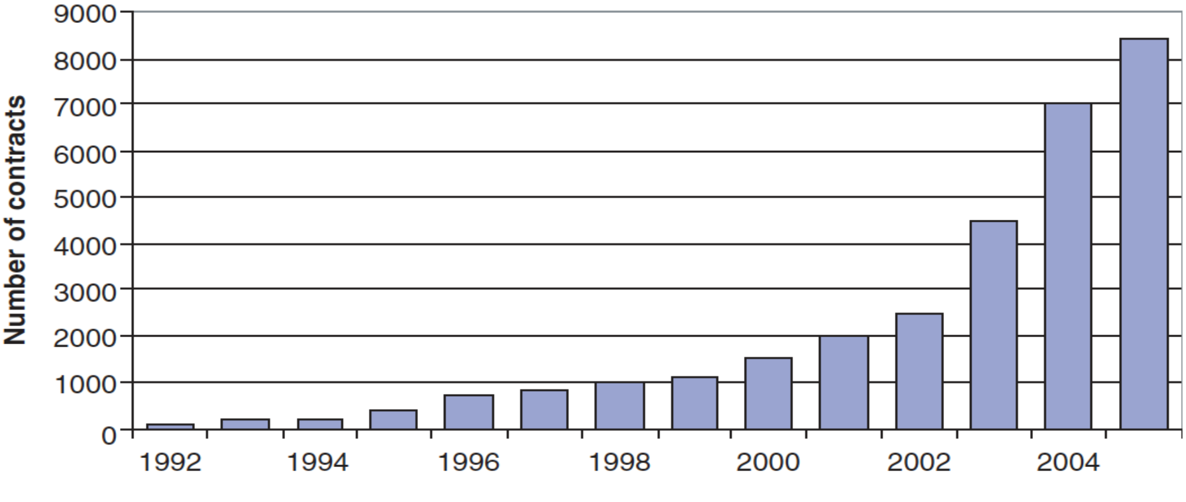

Figure 2.2 Yearly Volumes of Dry-Bulk FFA Contracts (January 1992–September 2005)
Source: Kavussanos and Visvikis (2006b).

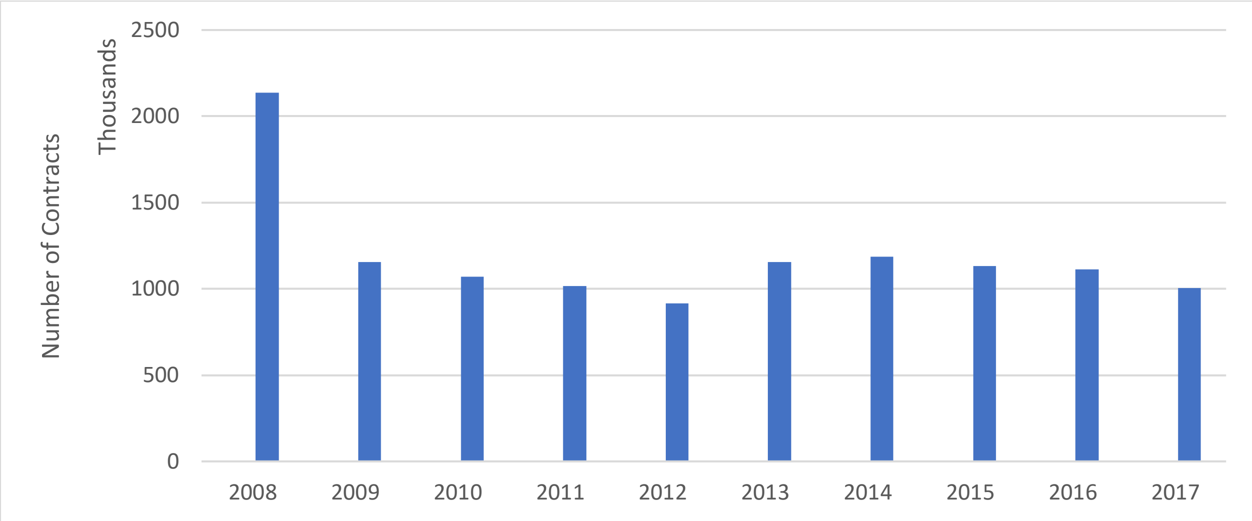

Figure 2.3 Yearly Volumes of Dry-Bulk FFA Contracts (Jan 2008 - Oct 2017)
Source: Baltic Exchange

As compared to dry-bulk FFA contracts, tanker FFAs were not initially that popular.. Similar to the use of BIFFEX for hedging dry-bulk freight rates, the Tanker International Freight Futures Exchange (TIFFEX) was introduced in 1986 for hedging tanker freight rates, but ceased in the same year due to lack of liquidity. After the launch of Baltic Dirty Tanker Index (BDTI) and Baltic Clean Tanker Index (BCTI) in 1998, tanker FFAs again became popular and started trading. The composition of BDTI and BCTI are presented in Tables 2.5 and 2.6.

Table 2.5 Baltic Dirty Tanker Index (BDTI) composition, 2017

Route	Size (MT)	Route Description
TD1	280,000	Middle East Gulf–US Gulf
TD2	270,000	Middle East Gulf–Singapore
TD3	265,000	Middle East Gulf–Japan
TD3C	270,000	Middle East Gulf–China
TD6	135,000	The Black Sea–Mediterranean
TD7	80,000	North Sea–Continent
TD8	80,000	Kuwait–Singapore
TD9	70,000	Caribbean–US Gulf
TD12	55,000	Amsterdam–Rotterdam–Antwerp to US Gulf
TD14	80,000	South East Asia to East Coast Australia
TD15	260,000	West Africa to China
TD17	100,000	Baltic to UK–Continent
TD18	30,000	Baltic to UK–Continent

TD19	80,000	Cross Mediterranean
TD20	130,000	West Africa to UK–Continent
TD21	50,000	Caribbean to US Gulf
VLCC-TCE	300,000	VLCC TCE (Uses: TD1 & TD3)
Suezmax-TCE	160,000	Suezmax TCE (Uses: TD6 & TD20)
Aframax-TCE	105,000	Aframax TCE (Uses: TD7, TD8, TD9, TD14, TD17 & TD19)

Source: Baltic Exchange.

Route	Size (MT)	Route Description
TC1	75,000	Middle East Gulf to Japan
TC2_37	37,000	Continent to US Atlantic coast
TC5	55,000	Middle East Gulf to Japan
TC6	30,000	Algeria to European Mediterranean
TC8	65,000	Middle East Gulf to UK–Continent
TC9	30,000	Baltic to UK–Continent
TC14	38,000	US Gulf to Continent
TC15	80,000	Med / Far East
TC16	60,000	Amsterdam to offshore Lomé
MR Atlantic Basket		MR Atlantic triangulation (Uses: TC2 TCE & TC14 TCE)

Table 2.6 Baltic Clean Tanker Index (BCTI) composition, 2017

Source: Baltic Exchange.

With the development of individual route-specific tanker indexes, the tanker FFA contracts with route indexes as their underlying assets became popular amongst market practitioners and has also been the center for research within academics (Dinwoodie and Morris (2003) and Alizadeh et al. (2015a), amongst others). In 2016, about 250,000 tanker FFA contracts were traded. Details of the hedging performances of tanker FFAs are presented in a later part of the chapter.

Following the abolition of the liner conferences in 2008, the rather oligopolistic container shipping market moved towards a perfect competition environment, exposing liner companies and shippers to the volatility of container freight rates from demand and supply interactions. This developed a demand to hedge container freight rate fluctuations using financial instruments. The Shanghai Shipping Exchange introduced the Shanghai Container Freight Index (SCFI) to provide indexes for container freight rates on various routes (Table 2.7).

Table 2.7 Shanghai Container Freight Index (SCFI) composition, 2017

Routes	Units	Weights (%)
Shanghai to Europe (Base port)	USD/TEU	20.0
Shanghai to Mediterranean (Base port)	USD/TEU	10.0
Shanghai to USWC (Base port)	USD/FEU	20.0
Shanghai to USEC (Base port)	USD/FEU	7.5
Shanghai to Persian Gulf and Red Sea (Dubai)	USD/TEU	7.5
Shanghai to Australia/New Zealand (Melbourne)	USD/TEU	5.0
Shanghai to East/West Africa (Lagos)	USD/TEU	2.5
Shanghai to South Africa (Durban)	USD/TEU	2.5
Shanghai to South America (Santos)	USD/TEU	5.0
Shanghai to West Japan (Base port)	USD/TEU	5.0
Shanghai to East Japan (Base port)	USD/TEU	5.0
Shanghai to Southeast Asia (Singapore)	USD/TEU	7.5
Shanghai to Korea (Pusan)	USD/TEU	2.5

Source: Shanghai Shipping Exchange.

The container FFA contracts, also known as Container Freight Swap Agreement (CFSA) contracts, started trading in OTC markets in 2010, through freight derivatives brokers and were settled against the freight routes of the SCFI. The counterparty (credit) risk was eliminated by clearing these contracts at SGX AsiaClear in Singapore or LCH.Clearnet in London.

2.3. Literature on Shipping Finance and Freight Derivatives

Despite having a very capital-intensive and rich heritage, the academic interest in shipping finance only developed a few decades ago. So there is less literature here as compared to the general finance literature, but there exist many unexplored areas related to the shipping industry that could make a significant contribution to both industry and literature. Koopmans (1939), Zannetos (1966), Devanney (1973), Hawdon (1978), Norman and Wergelnd (1981), Beenstock and Vergottis (1989) are some of the first studies to investigate the shipping freight rate dynamics, price movements and risks associated with shipping freight markets. More recent studies such as Tvedt (1997) and Kavussanos and Dimitrakopoulos (2007) investigate the risk associated with shipping markets while Kavussanos and Alizadeh-M (2002) and Tvedt (2003) examine the freight rate movements and thereby provide a better understanding of freight rate dynamics. Adland (2003) and Adland and Strandenes (2007) evidence the presence of a stochastic component in the freight rates while Adland and Cullinane (2006) suggest non-linear properties for freight rates. Conversely, Bjerksund and Ekern (1995) and Koekebakker et al. (2006) investigate the mean-reverting properties of freight rates. Evans (1994) discusses the market efficiency of shipping markets and shows that shipowners tend to maximise their profitability in the short run, but in the long run, any excess profit generated in the short term is offset by the losses incurred.

Pascali (2016) investigates the development of globalisation after the industrial revolution in the 1900s, the evolution of international trade around the seaport cities that were major hubs of exports and imports. Another study by Greenwood and Hanson (2014) relates the shipping business cycle to the “boom and bust” macroeconomic cycle. This study also provides an interesting insight into how the shipping companies have failed to understand or anticipate the future demand of the shipping sector, due to the endogeneity between the demand and supply of shipping freights. This failure to understand the shipping business cycle incurred huge losses for investors.

Following this line, Kalouptsidi (2014) presents the lag time of supply to meet the demand of the shipping industry due to the timeline for building a ship, which usually takes about two years. High demand encourages investors to build more ships. During the delivery of the ship, after a couple of years, the shipping market is oversupplied. This continuous lead-lag relationship between demand and supply creates a business cycle within the shipping industry and surges in market volatilities. There is a significant lead-lag relationship between the demand and supply for ships due to the time taken to build new vessels; Kavussanos (1997), Glen (1997), Alizadeh and Nomikos (2003) and Alizadeh and Nomikos (2007) have developed various strategies to trade with second-hand ships, which can provide a high return on investment.

Hedging shipping volatiles has attracted the use of derivatives contracts for hedging both vessel prices and freight rates. Though hedging vessel value fluctuation with the use of derivatives contracts has failed to attract market interest, derivatives contracts to hedge freight rate volatilities have become popular. In the recent past, there has been an extensive literature on freight derivatives, including studies by Chang and Chang (1996), Veenstra and Franses (1997), Berg-Andreassen (1997), Haigh (2000), Kavussanos and Visvikis (2004b) and Batchelor et al. (2007) which studies the integration of freight futures contracts with underlying freight rates to help to understand market price movements. This not only helps in anticipating the market but also provides interesting risk management strategies for shipowners and charterers. Hedging performances of freight futures contracts are investigated by Kavussanos and Nomikos (2000c), Kavussanos and Nomikos (2000b) and Haigh and Holt (2002). Other studies involving freight derivatives analysis include Tvedt (1998) and Dinwoodie and Morris (2003). A detailed literature review of freight derivatives and other related derivative contracts is presented in the following section.

2.4. Relationship between Commodity and Freight Markets

Information transmission between only dry-bulk freight rates and their derivatives contracts are extended to other freight rates including dirty and clean tankers markets and maritime commodity markets including oil, agriculture and metal commodities. Understanding these inter-market spillover effects can help in improving hedging and risk management strategies. Inter-market information spillover effects have been widely investigated in stock markets. Liu and Pan (1997) and Ng (2000) have shown a strong lead-lag relationship between the US and Far East stock markets. There have also been studies demonstrating a strong cointegration between crude oil and stock prices (Miller and Ratti, 2009, Arouri et al., 2012) and. We should note that freight rates are derived demand – that is, the rates are driven by commodity prices (Friedlaender and Spady, 1980, Oum, 1979) – and understanding the relationship between the freight and commodity markets can improve the performance of the charterers and shipowners who are directly exposed to these markets. Kneafsey (1975) and Haigh and Holt (1999) investigate the presence of a strong linkage between freight rates and commodity prices.

Within the commodity markets, significant spillover from the crude oil market to other commodity markets such as natural gas and agricultural ones, can also be observed (Du et al., 2011, Ewing et al., 2002, Nazlioglu et al., 2013, Uri, 1996, Du and Mcphail, 2012, Trujillo-Barrera et al., 2012). Similarly, Hamilton (1996) and Worrell et al. (1997) have investigated the relationships between crude oil and iron ore prices. Both iron ore and crude oil are two important macroeconomic parameters in the development of any country. Understanding the price movements of these two commodities is thus essential not only for the policy markets but also charterers, shipowners and other investors who deal with the trade and transportation of these commodities. Further, the derivative products of crude oil, like heating oil and Brent oil prices, move very closely with crude oil prices, as investigated by Shafiee and Topal (2009). Despite oil and gas is one of the major sectors of investment and subject to high volatility, there has been only limited research in this area. Borenstein et al. (1997), Balke et al. (1998) and Chen et al. (2005) are some of the studies to investigate the spillover relationship between the crude oil and gasoline markets. The results suggest that the gasoline market is driven by the crude oil market.

The freight rates for various sectors of shipping, such as dry-bulk and tankers, are also strongly interlinked. Drobetz et al. (2012) and Tsouknidis (2016) suggest a strong information transmission between the dry-bulk and tanker markets. There also exist strong information spillover between the Capesize and Panamax markets, which are the two major sub-sectors within the dry-bulk market (Chen et al., 2010). There has been no research so far investigating the lead-lag relationships within various sub-sectors of the tanker and dry-bulk shipping taken together – that is, dirty and clean tanker freight rates along with Capesize, Panamax, Supramax and Handysize freight rates in a single framework, as is provided in this study. This study includes the information spillover between commodity and freight markets including their futures contracts to provide a broader analysis of price movements for commodity and freight markets.

2.5. Lead-Lag Relationship between Freight Rates and Freight Derivatives

Financial derivatives such as futures and options contracts have a wide range of uses. One of the major uses of derivatives contracts is that they encounter less market friction, such as lower administrative and brokering costs, they are easier to trade without investing huge liquid cash reserves and offer high leverage, which enables futures and options to re-adjust to new market information faster than underlying spot prices. Further, as futures contracts can easily be re-positioned, new market information generates a high volume of trade not only to adjust to the new market prices, causing a surge in market volatility. Chan (1992), Bollerslev (1987), Shyy et al. (1996) and Min and Najand (1999), amongst others, have carefully investigated the spillover of returns and volatilities from stock futures to underlying stock prices and indexes. Kang et al. (2013), Li et al. (2014), Antonakakis et al. (2015) and Fan et al. (2017), are some recent studies of lead-lag relationships between stocks and corresponding futures markets. The results indicate that futures prices are good leading indicators of both prices and volatilities for the underlying stock indexes that are due to the presence of lower market friction in futures markets.

Similar to the studies on general finance derivatives markets, there exist extensive investigations of commodity and freight prices and their corresponding futures contracts. Trujillo-Barrera et al. (2012), Du et al. (2011), Kang et al. (2013), Gardebroek and Hernandez (2013), Wu et al. (2011), Teterin et al. (2016) are some of the recent investigations into the spillover effect between agriculture (such as corn and wheat) and energy (such crude oil and ethanol) prices and their corresponding futures contracts. Similar studies are also well evidenced in freight markets. Frino et al. (2000), Kavussanos and Visvikis (2004b), Kavussanos et al. (2004), Batchelor et al. (2007) and Li et al. (2014) and are some of the studies investigating the lead-lag relationships between freight rates and their corresponding freight futures markets.[3]

The derivative markets seem able in general to absorb new market information faster and spill over the information to the underlying physical market due to their lower market friction. This, however, is not extensive and there are exceptions. Manaster and Rendleman

[3] Freight futures contracts are commonly known as freight forward contracts or freight forward agreements (FFAs) as most of the contracts are traded in OTC markets and are cleared at various clearing houses such as LCH.Clearnet. For ease of exposition, FFA contracts are called freight futures contracts in the thesis.

(1982), Bhattacharya (1987), Anthony (1988) suggest that options prices lead and help to anticipate stock prices, whereas Stephan and Whaley (1990), Chiang and Fong (2001), amongst others, have observed that derivatives contracts lag the underlying stock prices. This can be attributed to the higher market friction in derivatives markets due to market illiquidity.

Studies are investigating the lead-lag relationship between freight futures and underlying freight rates, but to the best of our knowledge, there have been no studies investigating the information transmission between freight options and physical freight rates. This study fills this gap in the freight market, investigating the information transmission between freight futures and freight options markets along with the underlying physical freight markets in a tri-variant framework.

2.6. Hedging Freight Rate Volatilities

Hedging volatilities using various traditional and financial models have been widely investigated in the literature. The traditional hedging of various exposures utilises diversification of assets. The first theoretical model to hedge stock fluctuations by diversifying assets is presented in Markowitz (1952), utilizing the variances, covariances, and correlations between the assets. This had provided a benchmark model for asset allocation and risk management techniques. Later, Johnson (1960) and Stein (1961) employed Markowitz (1952) model on two risk assets (one being the physical spot price and the other the futures prices of the underlying asset) to reduce the variance of the underlying asset returns. Ederington (1979) utilised the same framework to understand the hedging performance of US T-bill futures for reducing the variances in the T-bill returns. Subsequently, Franckle (1980), Figlewski (1984), Figlewski (1985) and Lindahl (1992), amongst others, investigated the hedging performance of futures' contracts by estimating the optimal weights of such contracts needed against the unit weight of the underlying asset to minimise the variance of the underlying asset returns. The weight of futures contracts at which the unit weight of the underlying asset generates minimum variance is termed a minimum variance hedge ratio (MVHR). Later, with the development of the time-varying generalised autoregressive condition heteroskedasticity (GARCH) models, the time-varying optimal hedge ratio has been calculated instead of the constant hedge ratio. Baillie and Myers (1991), Myers (1991), Park and Switzer (1995a) and Yeh and Gannon (2000), amongst others, have investigated the hedging performance of futures contracts in reducing the variance of spot price returns using a bi-variant GARCH model.

Both constant and time-varying hedge ratios are prominent in the shipping literature for hedging freight rate fluctuations using freight futures contracts. Thuong and Visscher (1990), Haigh and Bryant (2000), Haigh and Holt (2000), Kavussanos and Nomikos (2000a), Kavussanos and Nomikos (2000b), Kavussanos and Nomikos (2000c), Haigh and Holt (2002), Kavussanos and Visvikis (2010) and Prokopczuk (2011), Kavussanos and Visvikis (2010) amongst others, are some of the extensive list of studies conducted to estimate the hedging performance of the futures contracts in the dry-bulk and tanker markets. Xian-Ling (2012), Alnes and Marheim (2013) and Alizadeh et al. (2015a) are some of the more recent studies which have investigated the hedging performances of both dry-bulk and tanker freight futures contracts. The results indicate that the hedging performances of freight futures contracts have been constantly low, which is mainly attributed to low market liquidity and the fact that the futures contracts fail to reflect underlying freight rates efficiently. No studies have so far been conducted to investigate the hedging performance of the newly developed container futures contracts.

This study aims to provide a holistic risk management strategy to minimise freight rate fluctuations. It utilises both traditional hedging strategy through diversification of freight rates and financial hedging strategies through the use of freight derivative contracts. The portfolio of freight rates constructed utilises the Markowitz (1952) mean-variance efficient frontier framework. Though similar attempts were made in the literature (Koseoglu and Karagülle, 2013, Andriosopoulos et al., 2013), none of the studies includes container freight rates in the construction of the portfolio. As the container market is one of the most important shipping sectors other than the dry-bulk and tanker markets, the inclusion of container freight rates in the construction of the portfolio adds value to the diversification. The study also utilises a portfolio of futures contracts in addition to well-diversified physical freight rates in order to further minimise freight rate volatilities and thereby improve the hedging performance of the freight futures' contracts. This study provides interesting insights not only for traditional shipowners who rely on traditional diversification and well-informed shipowners (about the freight derivatives markets) who utilize financial derivatives contracts to hedge their exposures but makes a strong contribution to the literature by providing a benchmark beyond which researchers can attempt to improve the hedging performance of low-performing freight futures contracts.

2.7. Concluding Remarks

Information spillover has gained in academic interest as understanding the price movements of related markets can help anticipate the price dynamics of the investing market. Freight futures and options contracts are used to forecast the returns and volatilities of dry bulk shipping freight rates. Further, as the transportation sector is not orthogonal to the commodity markets, the study has been extended to investigate the lead-lag relationship between commodity and freight markets. This study includes both the dry- and wet-bulk commodities and their corresponding freight rates. To provide holistic information about the price dynamics of commodity and freight markets, their respective futures contracts are also included in the analysis, as futures markets can anticipate the underlying physical market. The study concludes by providing a complete risk management solution for shipowners and charterers by hedging: (a) with the traditional mode by diversifying the portfolio of freight rates and (b) with the use of a group of derivatives contracts to improve the variance reduction.

This literature review aims to provide a general background to the academic studies in the areas of ocean freight and freight derivatives markets along with commodity markets to help the readers' understanding. It also highlights the current research gaps which are of interest for risk managers, shipowners, charterers and academics, amongst others. This extensive review highlights the major studies in the area and demonstrates some of the research gaps. An exhaustive detail of the literature review specific to each area of research is presented in each of the empirical Chapters 3–5.

3. Tracing Lead-lag Relationships between Commodities and Freight: A Multi-factor Model Approach

3.1. Introduction

Globalization and integration between markets have developed attention when examining information transmission in different markets, to understand the price movement of the slower-moving market by observing the reactive one (Prasad et al., 2005). It has been shown (Hummels, 2007) that globalisation facilitates international trade and reduces transportation costs, but also provides instant information about global market commodity prices (Bina and Vo, 2007). The spillover effect between commodity prices and cost of international trade has received considerable attention (Kavussanos et al., 2014), since the latter, in the form of maritime of freight rates, is derived (Friedlaender and Spady, 1980) by the former, establishing also a strong linkage between the corresponding markets (i.e. commodity and freight).

Unlike financial products, real commodities are physically distributed to the customers; hence transportation costs are induced. The latter is integrated within commodity prices[4], and since we will be focusing on commodities transported by ships over large distances, it can be safely assumed that freight rates are a major component of transportation costs. Furthermore, the surge and decline of the demand of commodities not only increases and decreases commodity prices, but also imbalances their transportation demand-supply equilibrium: Adam Smith stated that its geographical location and international trade drive the growth of any nation, particularly it closeness towards the sea-coast (or navigable rivers) as ocean freight rates are significantly lower compared to land transportation cost, which facilitates trading activities. Along with this line, Radelet and Sachs (1998) observed that countries with higher transportation costs encounter higher commodity prices for importing nations and lower profit margin for exporting nations. Traditionally, freight rates are considered to be a

[4] Other main factors affecting commodity prices include (i) production cost: this cost constitute of capital cost for land and equipment which are used for production, operational costs including labour cost (and for agricultural commodities seeds, fertilizers pesticides, etc.); (ii) Storage cost: this mainly includes two types of costs – physical storage cost which is the cost of the warehouse and other equipment necessary to preserve the commodities in good condition and secondly the financial storage cost which is the opportunity lost by the investors for investing and storing the particular commodity including the forward computing prices; (iii) seasonality risks: this includes weather and climatic risks operational risks and other political factors (iv) economic factor – supply and demand is one of the major factor affecting the price of the commodities. As the demand of the commodity drops relative to the supply, the commodity price decreases and vice-versa.

derived demand function (Friedlaender and Spady, 1980, Zlatoper and Austrian, 1989), where freight prices are derived from the commodity prices. Notwithstanding, the relationship between freight rates and commodity price has been assessed as exogenous, creating a bi-directional information flow between the two markets (Yu et al. (2007), Kavussanos et al. (2014). Therefore, investigation of the spillover effect between commodity and freight markets can provide valuable insight to anticipate the price movement of the corresponding markets.

Information transmission within financial markets has been extensively investigated. Eun and Shim (1989), Cheung and Mak (1992), Hanson et al. (1993) and Laughlin et al. (2014), amongst others, have investigated information spillovers between the major stock markets around the world. There are relatively fewer studies investing the lead-lag relationships within commodity markets. Du et al. (2011), Du and Mcphail (2012), Ji and Fan (2012) and Nazlioglu et al. (2013) are some recent studies investigating the information transmissions between oil and agricultural commodities. Similar to the spillover between oil prices and agriculture commodity prices, there is not a single piece of research investigating the interaction between oil and metal (such as iron ore) prices. As oil prices constitute some 70% of the transportation costs driving the price movement of all commodities (Litman, 2009), investigating the interaction between metal and oil prices is crucial. Further, both oil and iron ore prices drive the economy of countries (Hamilton, 1996, Worrell et al., 1997), so understanding the interaction of metal prices with oil prices can help not only commodity houses, charterers and construction companies, but also government policy-makers to regulate the commodity prices that facilitate the economic growth of a country. Crude oil and its derivative products such as heating oil and Brent oil and other fossil fuels, including natural gas, are the sources of world energy supply (Shafiee and Topal, 2009). Despite the importance of crude and its products (comprising Brent and heating oil), there have been very few studies investigating the price movement between crude oil and the other products. Borenstein et al. (1997), Balke et al. (1998) and Chen et al. (2005) are some of the studies which have examined the lead-lag relationship between crude oil and its derivative products, and results indicate that crude oil prices affect its derived product prices.

As transportation is the derived demand for the commodities, freight rates are strongly driven by commodity prices. As commodity prices increase (decrease), the demand for commodities decreases (increases), resulting in the decrease (increase) in demand for transportation. As the demand for the transportation decreases (increases), the transportation costs decrease (increase). So, freight rates are lagged and inversely related to commodity prices. Although the integration of commodity and freight rates are presented economically, there exist limited empirical investigations establishing their spillover relationships. Zheng and Lan (2016) suggest that the price changes in the crude oil markets have an impact on the freight rates of Very Large Crude Carriers (VLCCs), Suezmax and Aframax tankers amongst others. Poulakidas and Joutz (2009), Shi et al. (2013), (Sun et al. (2014) and Yang et al. (2015) are other studies which have investigated the significant impact of the crude oil market on tanker freight rates. It has also been observed that there exist bidirectional information flows between agriculture prices and dry-bulk freight rates, but a stronger impact of agricultural prices on freight rates, as investigated by Haigh and Bryant (2000) and Tsioumas and Papadimitriou (2016). Roehner (1996), Chen et al. (2005) and Yu et al. (2007) provide a study of the integration between dry-bulk freight rates and dry-bulk commodity prices. Kavussanos et al. (2010) and Kavussanos et al. (2014) present information on transmission between the dry-bulk commodity futures and dry-bulk freight rate futures, finding a stronger information flow from the former to the latter market. As the oil markets drive global GDP (Cooper, 2003), the forward-looking nature of the futures' contracts of crude oil and other oil products can act as a better leading indicator for tanker freight rates and tanker freight futures contracts. There has been no research investigating the spillovers between oil futures (which include crude oil and product oil futures) and their corresponding tanker freight futures. This study will act as a benchmark to help understand the price dynamics of oil markets and tanker freight rates, along with their corresponding futures contracts.

Transportation costs are an integral part of commodity prices. As the economic growth of countries drives the export and import of commodities, the transportation costs of various commodities are highly cointegrated. Drobetz et al. (2012) and Tsouknidis (2016) have investigated the relationship between the tanker and dry-bulk freight rates. Chen et al. (2010) have studied the interaction of freight rates within the dry-bulk sector – that is, information transmission between Capesize and Panamax Freight rates. To the best of our knowledge, there has been no research investigating spillover effects within the sub-sector of tramp shipping – that is, the information transmission between dirty and clear tanker freight rates, and Capesize, Panamax, Supramax and Handysize freight rates have not been covered in the earlier literature which is examined in this study.

This study contributes to the existing literature in four ways: firstly, it investigates the spillover effect between (a) crude oil and other products, (b) metal and (c) agricultural commodities in a single framework which has not previously been attempted; secondly, to the best of our knowledge, it is the first paper to investigate the information transmission between three major sectors of shipping (a) dry-bulk and (b) tanker freight rates and their respective sub-sector; thirdly, it presents an extensive spillover between commodity prices (including various dry-bulk and liquid-bulk commodities) and their corresponding freight rates, which have so far not been investigated in literature; fourthly, the spillover effects of futures' contracts associated with commodity prices and freight rates are documented, which can act as a leading indicator in aiding decision-making for charterers, commodity houses and shipowners.

The remainder of this chapter is organised in the following way: Section 4.2 presents the data and methodology along with some theoretical considerations used in the analysis. The empirical results of the lead-lag relationships between commodity prices and freight rates, along with their corresponding futures prices, are presented in section 4.3. Section 4.4 discusses the implications of the findings, and the chapter is concluded in Section 4.5.

3.2. Dataset and Methodology

3.2.1. Dataset

The analysis is conducted to test the presence of lead-lag relationships between commodity and transportation (freight) costs. The commodity prices depend on various macroeconomic factors such as GDP and industrial production (Deaton, 1999). For example, if the construction and manufacturing sectors are growing in a nation, the demand for raw materials such as iron ore and steel will increase, along with the demand for fuel such as crude oil, Brent oil, etc. Similarly, if a nation's economy is becoming stable, the government starts to invest more in agricultural imports and consumption for its citizen (Fan et al., 2000). As the macroeconomic factors can affect any types of commodities such as energy, metal and ore and agricultural products, in this study we have used a wide range of commodities for analysis along, with their corresponding freight rates. Crude oil, Brent oil, heating oil, natural gas and coal prices are used, which represent energy commodities; wheat, soya beans, corn, sugar, rice barley, rice, canola, urea, diammonium phosphate (DAP) and ammonia represent agricultural commodities; iron ore, scrap VLCC, scrap Panamax/Capesize and copper represent metal commodities. Their corresponding near-month and second near-month futures' contracts are also used in the analysis. The commodity prices and their futures contracts are obtained through Bloomberg and Thomson Reuter's DataStream. The Baltic Capesize Index Time Charter Equivalent (BCI–TCE), Baltic Panamax Index Time Charter Equivalent (BPI–TCE), Baltic Supramax Index Time Charter Equivalent (BSI–TCE), Baltic Handysize Index (BHSI) and Baltic Dry Index (BDI) are used to represent dry-bulk freight rates, and the Baltic Dirty Tanker Index (BDTI) and Middle East to Far East VLCC freight rates (using by TD3–WorldScale unit and TD3$–US$/mt) represent freight markets for carrying crude oil and the Baltic Clean Tanker Index (BCTI) and Europe to US East Coast MR tankers of 37,000 MT (using TC2_37–WorldScale unit and TC2$–US$/mt) represent freight rates for the derivatives products of crude oil. The near-month and second near-month futures contracts of the corresponding freight rates are also used in the analysis. The freight rates and their futures' contracts are obtained from the Baltic Exchange.[5] These form a total of 65 variables used in the analysis. The analysis is conducted over daily, weekly and monthly frequencies ranging from October 2010 until February 2017 with a total of 1579,

[5] The futures contracts for freight rates are called forward contracts, the trades are conducted in over-the-counter (OTC) markets and are documented in the Baltic Exchange for regulatory purposes. We use the term "freight futures" instead of "freight forward" for simplicity for readers without a shipping background.

327 and 77 observations, respectively.[6] The period from 2010 to 2017 is used because of the availability of the data for most of the variables during this period. As the prices of most of the commodity and freight rates are not available before 2010 and to avoid exclusion of the important variables, we have not used only a sample size between 2010 to 2017.

3.2.2. Methodology

A dynamic multi-factor model is used for the analysis. A multi-factor model is a financial model that engages multiple factors to explain market phenomena and equilibrium asset prices. The reference variable is used as an indicator that is developed from the various macroeconomic *common components* using factor models. This measure utilises the panel regression approach to derive the relationship between the list of variables in the panel series, with the reference variable acting as a microeconomic indicator with distinct information content. Similar macroeconomic indicators have been developed by Forni et al. (2000), Altissimo et al. (2001), Nguiffo-Boyom (2008), Al-Hassan (2009) and Angelopoulos (2017), amongst others.

The use of factor models for exploring the lead-lag relationships between variables can be traced back to Sargent and Sims (1977) and Quah and Sargent (1993). Subsequently, Stock and Watson (2002) developed the *approximate dynamic* factor model, and Forni et al. (2000) developed the *generalised dynamic* factor model, which extends the *static* factor model and its application to macroeconomic variables. The model has been enhanced and developed by Forni et al. (2005), Kapetanios and Marcellino (2009) and Doz et al. (2011), using one-sided filtering, state–space models and Kalman filtering processes, respectively. Stock and Watson (2011) present an extensive analysis of various dynamic factor models. Den Reijer (2005), Banerjee and Marcellino (2006), Nieuwenhuyze (2006), Carriero and Marcellino (2007) and Nguiffo-Boyom (2008), amongst others, have explored the impact of dynamic factor models on the GDP of various countries. Tracing the macroeconomic data and forecasting the variables have been well evidenced (Darracq Pariès and Maurin, 2008, Guichard and Rusticelli, 2011, Perevalov and Maier, 2010)).

In this study, we have used the one-sided generalised dynamic factor model (GDFM) of Forni et al. (2005). An individual variable can easily be segregated into leading, concurrent and

[6] VLCC scrap and Panamax/Capesize Scrap data is only available at a monthly frequency. Urea, DAP and ammonia data are available for only monthly and weekly frequencies. So, the weekly and daily observations constitute 63 and 60 variables, respectively.

lagging variables concerning the reference variable using GDFM. GDFM generates two mutually orthogonal components of the variables (a) The *common component* – this is a linear component of all the factors shared by the variables in the series with different degrees of commonality; (b) the *idiosyncratic component* – this constitutes the variable specific factors, measurement errors and disturbances. Tracing a lead-lag relationship using GDFM is conducted in two steps: firstly, the common and idiosyncratic components are calculated using a spectral density matrix and autocovariance; secondly, the maximisation of the contemporaneous covariances is included in the common factors through linear combination as follows:

A panel series of N variable and number of observations t (where $t = 1, 2, \ldots T$) is defined as X_{Nt}. The sum of the common component (χ_t) and the idiosyncratic component (ξ_t) is denoted by X_t. Alternatively, $X_t = \chi(F_t) + \xi_t$, where F_t is the lag operator for q >> N common factors and. The forecasting ability of X_t decreases from t to T as $\chi(F_t)$ is the two-sided filter of X_t. This is avoided by applying the spectral density matrix of the frequency domain, dynamic principal component analysis (PCA) and inverse Fourier transform of the time domain, as developed by Forni et al. (2005). The covariance matrices for the idiosyncratic and the common components are used to calculate the lead–lag relationships between the variables by observing the spectral density matrices and are smoothed over *M* frequencies through generalized principal components. Lastly, the static factors presented orthogonally state the common components. The static factors represent the contemporaneous linear combinations of X_t with the lowest ratio of idiosyncratic and common variance. This presents the degree of heterogeneity with respect to the impulse response on each common factor. The variance of the common component explains the extent of the variance through using GDFM.

The equation is presented as follows:

$$\Gamma_{Nt}^{T} = E[X_{Nt}(X_{Nt-k})^{T}] \quad (1)$$

where the number of lags is represented by *k*, and the transpose by $(.)^T$; Γ_{Nt}^{χ} denotes the variance of the common factor (χ_t), and Γ_{Nt}^{ξ} denotes the variance of the idiosyncratic component (ξ_t) of X_{Nt}; The total variance of the panel is represented by Γ_{Nt}^{T}.

The autocovariance matrices of order k (-k, …., 0, …., k) are presented as follows:

$$\Gamma_{Nk}^{T} = (T-k)^{-1} \sum_{t=k+1}^{T} X_{Nt} (X_{Nt})^{T} \quad (2)$$

The Fourier transform used to estimate the spectral density matrix over Bartell-lag windows $\left(w_k = \frac{|k|}{M+1}\right)$ is estimated as follows:

$$\sum_{N}^{T}(\theta_s) = \sum_{k=-M}^{M} w_k \Gamma_{Nk}^{T} e^{-i\theta_s k} \quad (3)$$

where $\theta_s = \frac{2s\pi}{2M+1}$, s = -M, -M+1, …., 0, 1, …., M and M=M(T).

Dynamic PCA is applied to decompose $\sum_{N}^{T}(\theta_s)$ into $\sum_{N}^{\chi T}(\theta_s)$ and $\sum_{N}^{\xi T}(\theta_s)$ by estimating the value of matrices $\Sigma_{N}^{\chi T}$ utilizing the first q dynamic factors as follows:

$$\Sigma_{N}^{\chi T} = \lambda_{N1}^{T}(\theta) p_{N1}^{T} + \cdots + \lambda_{Nq}^{T}(\theta) \left(p_{Nq}^{T}\right)^{*} p_{Nq}^{T} \quad (4)$$

where $\lambda_{Nq}^{T}(\theta)$ and p_{Nq}^{T} represents the largest eigenvalue and the largest eigenvector of $\Sigma_{N}^{\chi T}$ respectively; $(.)^{*}$ denotes the conjugate transpose.

The calculation of an optimal number of q and M is presented in the latter part of the text. The inverse Fourier transformation is estimated as follows:

$$\Gamma_{Nh}^{\chi T} = (2M+1)^{-1} \sum_{h=-M}^{M} \sum_{N}^{\chi T}(\theta_s) e^{i\theta_s k} \quad (5)$$

If the variance of χ_t at $M = 0$ ($\Gamma_{j0}^{\xi T} = \Gamma_{j0}^{T} - \Gamma_{j0}^{\chi T}$, where $j\epsilon[1,2,\ldots,r]$), the variance of the idiosyncratic factors is the residual variance for each static factor r similar to Forni et al. (2005), which used a range of 6 to 15 static factors. Lastly, the generalized principle components (K_{N}^{Th}) are calculated as the product of $\Gamma_{Nh}^{\chi T}$ and $Z_{N}^{T}((Z_{N}^{T})^{T}\Gamma_{j0}^{T}Z_{N}^{T})^{-1}(Z_{N}^{T})^{T}$, where Z_{Nj}^{T} is denoted as the generalized eigenvectors matrix of $\Gamma_{j0}^{\chi T}$ and $\Gamma_{j0}^{\xi T}$. K_{N}^{Th} is used to estimate the common factors as follows:

$$\chi_{i,T+hT}^{NT} = \sum_{j=1}^{N} K_{N,ij}^{Th} x_{jT} \quad (6)$$

where the number forecasting period is denoted as h.

3.3. Empirical Results

Using a multi-factor model and by understanding the economic relationships between the 65 variables of various commodities, freight rates and their corresponding futures prices, we can create various categories of variables which have not only economic significances but also generate strong lead-lag relationships. Though the lead-lag relationships of commodity prices (energy and agricultural) and freight rates (transportation costs of the commodities), and their corresponding futures, have been investigated in the earlier literature, many of the interactions between commodity prices and freight rates have not investigated. The spectral coherence between the variables for monthly, weekly and daily frequencies are presented in Table 0.1, Table 0.2 and Table 0.3, respectively, in the Appendix. The lead-lag relationships of the variables are estimated with reference to the following variables: (a) Baltic Dry Index (BDI), (b) Middle East to far East dirty tanker route (TD3 route), (c) North West Europe to US East Coast clean tanker route (TC2 route), (d) Second near-month Panamax Futures, (e) Crude oil and (f) Corn prices. Their economic significance decides the reference variables – that is, variables that can economically affect a wide range of variables and hence can be used as a reference. The results are presented in Table 0.4 to Table 0.9 in the Appendix. The lead-lag relationship presented in Table 0.4 to Table 0.9 is rearranged to form groups to find the lead-lag relationship within groups with economic importance. Each rearranged table is presented with the results. The commonalities of the variables are presented in Table 0.10 in the Appendix.

The variables are categorised based on economic significances as follows: (a) commodities, (b) freight rates, (c) commodities vs freight rates. The categories are sub-categorised in dry-bulk and tanker (liquid-bulk) sectors to gain a better understanding of the information spillover between the variables. The lead-lag relationships between the variables in each category are presented as follows:

Spillover effects within commodities: To gain a better understanding of lead-lag relationships of commodity markets, the results are rearranged and presented in Table 3.1.

Table 3.1 Commodity Lead-lag Relationships – Reference with Crude Oil

	Monthly Dataset		Weekly Dataset		Daily Dataset	
	No. of Factors – 4	**Cycl.**	**No. of Factors – 4**	**Cycl.**	**No. of Factors – 4**	**Cycl.**
Crude	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Brent	**-0.7**	**0.0**	**0.2**	**0.0**	**-0.1**	**0.0**
Heating oil	**-0.8**	**0.0**	**-5.8**	**0.0**	**2.2**	**0.0**
Natural gas	**16.1**	**0.0**	**-4.7**	**0.0**	**5.4**	**0.0**
Coal	**-4.5**	**0.0**	**2.5**	**0.0**	**-0.5**	**0.0**
Wheat	**11.7**	**3.1**	**-5.2**	**3.1**	**-4.3**	**3.1**
Soybeans	**-14.3**	**0.0**	**-2.8**	**0.0**	**2.2**	**0.0**
Corn	**-12.9**	**0.0**	**-3.0**	**3.1**	**-3.2**	**3.1**
Iron ore	**-6.9**	**0.0**	**2.2**	**0.0**	**2.1**	**0.0**
Copper	**0.3**	**0.0**	**-1.5**	**0.0**	**0.2**	**0.0**
Sugar	**4.7**	**0.0**	**-1.8**	**0.0**	**1.2**	**0.0**
Rice	**-15.9**	**0.0**	**2.7**	**0.0**	**2.1**	**0.0**
Barley	**-14.6**	**0.0**	**-5.7**	**0.0**	**-0.9**	**3.1**
Canola	**11.8**	**3.1**	**10.6**	**3.1**	**-4.2**	**3.1**
Urea	**0.3**	**0.0**	**15.9**	**3.1**		
DAP	**12.5**	**3.1**	**10.9**	**3.1**		
Ammonia	**-5.8**	**0.0**	**16.7**	**3.1**		
Scrap VLCC	**-2.4**	**0.0**				
Scrap Cape/Pana	**-1.7**	**0.0**				

Note: Under No. of Factors – 4 columns, the numbers specified lead-lag relationships w.r.t. the reference variable. As crude oil is considered as the reference variable in this table, Crude oil variable is not leading/lagging from itself, and hence is represented as zero. The variable with positive (negative) parameters leads (lags) the reference variable. In the Cycl. column, the parameters representing 0.0 are in phase with the reference variable (i.e. crude oil prices in this case), whereas 3.1 corresponds to counter-cyclic variables, which means that, with an increase in the reference variable, the counter-cyclic variables decreases, and vice-versa.

As observed in Table 3.1, agriculture commodities and metal (including ores) lag energy commodity prices. With reference to the crude oil market, agriculture commodities have a maximum lag up to 15.9 periods for rice and metal commodities have a maximum lag of up to 6.9 periods for iron ore markets in monthly analysis. Overall, the results of the analysis for all three frequencies (daily, weekly and monthly) indicate that crude oil prices lead commodity markets, followed by other energy derivative products (such as Brent oil, heating oil and natural gas), metals and ores (such as iron ore, VLCC scrap and Panamax Scrap) and lastly by the agriculture commodities (which include sugar, corn, soybeans, barley, rice, wheat and canola oil along with the chemicals used for fertilizer, such as urea and ammonia).

The lead-lag relationships amongst commodity futures markets are rearranged in Table 3.2 w.r.t. crude oil prices as a reference variable. Similar to the spot market, it can also be observed that energy markets absorb the new information, followed by metal prices (iron ore and scrap iron) and agriculture markets.[7] Unlike the commodity spot market, the results for commodity futures markets are consistent for weekly frequency analysis, where the agricultural commodities generate a maximum lag of up to 9.5 (for near-month canola futures) and up to 3.0 for second near-month iron ore futures.

Table 3.2 Commodity Futures Lead-lag Relationships: Reference with Crude Oil

	Monthly Dataset		Weekly Dataset		Daily Dataset	
	No. of Factors – 4	**Cycl.**	**No. of Factors – 4**	**Cycl.**	**No. of Factors – 4**	**Cycl.**
CME_Crude_F1	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
ICE_Brent_F1	**-0.5**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**
CME_Heating_F1	**-0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
CME_Natural_gas_F1	**16.8**	**0.0**	**-1.7**	**0.0**	**1.1**	**0.0**
ICE_Natural_Gas_F2	**-7.9**	**0.0**	**2.8**	**0.0**	**-0.1**	**0.0**
ICE_Coal_F1	**-4.5**	**0.0**	**3.7**	**0.0**	**-0.6**	**0.0**
ICE_Coal_F2	**-4.9**	**0.0**	**3.8**	**0.0**	**-0.7**	**0.0**
CME_Wheat_F1	**12.9**	**3.1**	**-6.3**	**3.1**	**-3.7**	**3.1**
CME_Wheat_F2	**12.8**	**3.1**	**-6.0**	**3.1**	**3.6**	**0.0**
CME_Soybeans_F1	**-14.7**	**0.0**	**-3.5**	**0.0**	**2.1**	**0.0**
CME_Soybeans_F2	**-14.8**	**0.0**	**-2.2**	**0.0**	**2.1**	**0.0**
CME_Corn_F1	**-13.4**	**0.0**	**4.4**	**0.0**	**3.1**	**0.0**
CME_Corn_F2	**-13.0**	**0.0**	**-4.1**	**3.1**	**3.2**	**0.0**
CME_Iron_F1	**2.4**	**0.0**	**-2.9**	**0.0**	**-1.2**	**0.0**
CME_Iron_F2	**2.8**	**0.0**	**-3.0**	**0.0**	**-2.5**	**0.0**
Copper_F3	**0.2**	**0.0**	**-1.4**	**0.0**	**0.2**	**0.0**
Sugar_F1	**5.2**	**0.0**	**-1.6**	**0.0**	**1.2**	**0.0**
Sugar_F2	**4.8**	**0.0**	**-1.9**	**0.0**	**1.2**	**0.0**
Rice_F1	**-16.4**	**0.0**	**-3.1**	**3.1**	**2.1**	**0.0**
Rice_F2	**-16.1**	**0.0**	**-3.6**	**3.1**	**2.1**	**0.0**
Barley_F1	**4.5**	**0.0**	**-8.3**	**0.0**	**3.8**	**0.0**
Barley_F2	**3.1**	**0.0**	**-6.6**	**0.0**	**1.5**	**0.0**
Canola_F1	**13.1**	**3.1**	**-9.5**	**0.0**	**3.8**	**0.0**
Canola_F2	**12.3**	**3.1**	**-6.3**	**0.0**	**3.4**	**0.0**

Note: The details of the parameters are denoted in **Table 3.1**

The economic growth of countries has a strong impact on oil prices (Lardic and Mignon, 2006, Jiménez-Rodríguez* and Sánchez, 2005, Lardic and Mignon, 2008). As a country's GDP grows, there is a huge demand for energy for transportation and construction, which increases oil prices. This is followed by a high demand for raw materials such as iron, steel

[7] Futures' prices for chemical (urea and ammonia) and scrap iron (VLCC and Panamax) are not available. Hence the spillover of only spot prices for chemicals (fertilizers) and scrap iron is investigated

and iron ore for construction, which leads to the increase in iron and iron ore prices observed in this analysis. Metal prices such as iron ore and steel prices increase with an increase in crude oil and its derivative product prices, also observed in our analysis. Further, oil prices form the major component of cost of transportation (70% of maritime transportation comprises fuel costs) and production of agro-based commodities and other utility products such as agriculture fertilisers increases, reflected in their corresponding prices (Hanson et al., 1993). The increase in crude oil prices is thus followed by an increase in fertiliser prices and agricultural commodity prices, as observed by Du and Mcphail (2012) and Nazlioglu et al. (2013).

Overall, it can be observed that crude oil and other oil product prices lead general commodity prices, followed by iron (along with ore) prices, chemicals (fertilisers) and lastly agriculture-based commodities. Similarly, a lead-lag relationship can be observed for their corresponding futures prices – that is, crude oil and their derivative products such as Brent and heating oil futures prices lead iron ore futures, followed by sugar, corn, soybeans, barley, rice, wheat, and canola (edible oil) futures.

Lead-lag relationships within the oil and natural gas markets: Energy (oil and natural gas) commodities are one of the major driving forces in the price fluctuation which has been observed above. Within energy commodities (from Table 3.1), it can be observed that crude oil derivative products such as Brent and heating oil prices follow crude oil prices, as observed by Borenstein et al. (1997). One of the potential reasons is that with an increase (or decrease) in crude oil prices, the cost of producing heating oil, gasoline and Brent oil also increases (or decreases), with is reflected in their corresponding prices. It can also be observed that natural gas prices affect crude oil prices, unlike other refined oil products. Its prices are mainly affected by demand and supply. As natural gas is mainly used in the US for heating and extraction of electricity, weather conditions play a vital role in driving natural gas prices. Since natural gas is derived during the extraction of crude oil from the oil fields, its prices are not directly related to crude oil prices.[8] Overall, natural gas prices lead crude oil prices, followed by Brent oil prices and heating oil prices. The similar observation can also be made for their corresponding futures prices.

[8] Crude oil prices affect natural gas partially only because for shipping natural gases through ships, the crude oil derivative product (bunker oil) is still primarily used as fuel oil. A surge in crude oil prices increases bunker oil prices and hence the transportation of natural gas becomes expensive, increasing the price of natural gas for the end user.

Table 3.3 Freight Rates Lead-lag Relationship: Dry-bulk vs Tanker Markets

Reference variable: Baltic Dry Index (BDI)						
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors – 4	**Cycl.**	**No. of Factors – 4**	**Cycl.**	**No. of Factors – 4**	**Cycl.**
BCI_TCE	**0.8**	**0.0**	**0.5**	**0.0**	**0.6**	**0.0**
BPI_TCE	**0.0**	**0.0**	**0.8**	**0.0**	**-1.5**	**0.0**
BSI_TCE	**-1.0**	**0.0**	**-1.8**	**0.0**	**-11.1**	**0.0**
TC2$	**-8.0**	**3.1**	**-15.4**	**3.1**	**-4.5**	**3.1**
TD3$	**-16.0**	**3.1**	**-4.4**	**3.1**	**-3.6**	**0.0**
BHSI	**-5.2**	**3.1**	**-12.8**	**3.1**	**-4.7**	**3.1**
BDTI	**-13.5**	**3.1**	**3.6**	**0.0**	**0.2**	**0.0**
BCTI	**-2.3**	**0.0**	**-2.2**	**0.0**	**-14.2**	**0.0**
BDI	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BLPG1	**-16.2**	**3.1**	**-11.7**	**3.1**	**-0.9**	**3.1**
TD3	**-16.0**	**3.1**	**-4.1**	**3.1**	**-2.9**	**0.0**
TC2_37	**-7.9**	**3.1**	**-14.7**	**3.1**	**-4.5**	**3.1**

	Reference variable: VLCC freight rates – Middle East to Far East (TD3 route)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors – 4	**Cycl.**	**No. of Factors – 4**	**Cycl.**	**No. of Factors – 4**	**Cycl.**
BCI_TCE	**-14.8**	**3.1**	**-3.4**	**3.1**	**4.5**	**0.0**
BPI_TCE	**14.6**	**3.1**	**3.4**	**3.1**	**1.8**	**0.0**
BSI_TCE	**15.4**	**3.1**	**3.6**	**3.1**	**-5.6**	**0.0**
TC2$	**-8.5**	**0.0**	**-2.0**	**0.0**	**11.2**	**0.0**
TD3$	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BHSI	**-9.6**	**0.0**	**-2.2**	**0.0**	**11.0**	**0.0**
BDTI	**-3.7**	**0.0**	**-0.9**	**0.0**	**2.4**	**0.0**
BCTI	**16.7**	**3.1**	**3.9**	**3.1**	**-10.0**	**0.0**
BDI	**15.3**	**3.1**	**3.5**	**3.1**	**3.6**	**0.0**
BLPG1	**-3.1**	**0.0**	**-0.7**	**0.0**	**-6.6**	**3.1**
TD3	**-0.3**	**0.0**	**-0.1**	**0.0**	**0.2**	**0.0**
TC2_37	**-9.0**	**0.0**	**-2.1**	**0.0**	**11.1**	**0.0**

	Reference variable: Europe to US Atlantic Coast freight rates (TC2 route)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors – 4	**Cycl.**	**No. of Factors – 4**	**Cycl.**	**No. of Factors – 4**	**Cycl.**
BCI_TCE	**-17.9**	**0.0**	**-4.2**	**3.1**	**3.6**	**3.1**
BPI_TCE	**5.1**	**3.1**	**1.2**	**3.1**	**8.0**	**3.1**
BSI_TCE	**6.0**	**3.1**	**1.4**	**3.1**	**14.8**	**3.1**
TC2$	**0.2**	**0.0**	**0.1**	**0.0**	**-0.1**	**0.0**
TD3$	**9.0**	**0.0**	**2.1**	**0.0**	**-11.1**	**0.0**
BHSI	**-0.2**	**0.0**	**-0.1**	**0.0**	**0.2**	**0.0**
BDTI	**4.8**	**0.0**	**1.1**	**0.0**	**-4.5**	**0.0**
BCTI	**6.9**	**3.1**	**1.6**	**3.1**	**-17.3**	**3.1**
BDI	**5.9**	**3.1**	**1.4**	**3.1**	**4.5**	**3.1**
BLPG1	**2.6**	**0.0**	**0.6**	**0.0**	**-4.3**	**0.0**
TD3	**8.6**	**0.0**	**2.0**	**0.0**	**-10.2**	**0.0**
TC2_37	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note: The details of the parameters are denoted in **Table 3.1**

Information spillover within freight markets: Shipping markets are highly interlinked. As observed by Tsouknidis (2016), there exist strong spillover effects between dry-bulk and tanker freight rates. Table 3.3 rearranges the lead-lag relationships of freight rates calculated with reference to the Baltic Dry Index (BDI), freight rates of VLCC tankers from the Middle East to Far East route (TD3) and product tanker freight rates from Europe to the US East Coast (TC2). It is interesting to observe that, in all the analysis, tanker freight rates and dry-bulk freight rates are counter-cyclical – that is, an increase in dry-bulk freight rates corresponds with a decrease in tanker freight rates. This finding is in line with Stopford (2009), indicating that dry-bulk and tanker freight rates are inversely correlated. While using BDI as a reference variable, it is observed that tanker market creates a maximum lag of 16 periods for the TD3 variable (as observed at a monthly frequency) and the dry-bulk market generates a maximum lag of 5.5 periods for the Baltic Exchange Handysize Index (BHSI). Similarly, using the TD3 and TC2 routes, Capesize, Panamax and Supramax time-charter (T/C) rates lead the reference variable as compared to dirty and clean tanker freight rates.[9] Overall, it can be concluded that dry-bulk markets lead tanker markets. This may be due to the fact that the dry-bulk market is more sensitive to new market information as compared to tanker freight rates, due to the presence of a large number of shipowners as compared to the tanker market.

A better understanding of information transmission within the dry-bulk and tanker sectors, along with their corresponding futures contracts can be had from Table 3.4 and Table 3.5, that are constructed with reference variables from the Baltic Dry Index (BDI), freight rates of VLCC tankers from the Middle East to the Far East route (TD3), product tanker freight rates from Europe to the US East Coast (TC2) and second near-month Panamax T/C futures for dry-bulk and tanker markets, respectively; the findings are presented as follows:

Dry bulk – freight rates vs futures: It can be observed that the Capesize freight rates are highly sensitive to new market information, followed by Panamax, Supramax and Handysize freight, similar to Kavussanos (1996) and Jing et al. (2008). When BDI is used as a reference, Capesize freight rates lead BDI by 0.8 periods, Panamax T/C rates are equivalent to the BDI, Supramax T/C rates and BHSI lag BDI by 1.0 and 5.2 periods, respectively, in monthly

[9] The only exception is observed for Capesize freight rates in monthly and weekly frequency analysis, which lags the TD3 and TC2 reference variables whereas the daily frequency leads the reference variable.

analysis. [10] For Capesize markets, the futures contracts lead the BDI (reference variable) by 2.8 and 3.2 periods for near-month and second near-month contracts, respectively, while Capesize freight rates lead BDI by only 0.5 periods in the weekly analysis. For Panamax markets, the futures' contracts lead the BDI (reference variable) by 4.6 and 5.2 periods for near-month and second near-month contracts, respectively while Panamax freight rates lead BDI by only 0.8 periods in the weekly analysis. While weekly analysis for Supramax markets indicates that futures contracts lead BDI by 5.8 and 5.5 for near-month and second near-month futures contracts, respectively, the underlying Supramax freight rates only lag by 1.8 periods. Overall, the futures contracts lead the underlying freight rates, which is in line with existing research (Kavussanos and Nomikos, 2003, Kavussanos and Visvikis, 2004b, Alexandridis et al., 2017).

Tanker – freight rates vs futures: It can be deduced that in case of transportation costs of crude oil and its derivative oil products, new information is first absorbed in the crude oil freight rates (TD3 route – cost of carrying crude oil from the Middle East to the Far East), which is then reflected in the freight rates of product carriers (TC2 route – Europe to the US Atlantic Coast). The findings are relevant in both monthly and weekly frequency analysis. As oil products are derived from crude oil, similar to the spillover effect observed within the energy commodities where crude oil prices lead other oil product prices, VLCC freight rates (TD3 route) lead product tanker freight rates (TC2 route). Unlike dry-bulk freight futures, in both monthly and weekly frequency analysis, it can be observed that tanker freight futures contracts lag the underlying freight rates while using TD3 and TC2 as reference variables. These abnormal findings are observed due to the illiquid tanker freight futures' markets during the period of observation (Garcia et al. (1986)argues that illiquidity can increase market friction, leading to a slower reaction to new market information, which lags the futures market over and above the underlying spot market).

[10] BHSI is used as a proxy for Handysize spot freight rates.

Table 3.4 Lead-lag Relationship for Dry-bulk Freight Markets: Freight Rates vs Futures

	Reference variable: Baltic Dry Index (BDI)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors – 4	**Cycl.**	**No. of Factors – 4**	**Cycl.**	**No. of Factors – 4**	**Cycl.**
BCI_TCE	**0.8**	**0.0**	**0.5**	**0.0**	**0.6**	**0.0**
BPI_TCE	**0.0**	**0.0**	**0.8**	**0.0**	**-1.5**	**0.0**
BSI_TCE	**-1.0**	**0.0**	**-1.8**	**0.0**	**-11.1**	**0.0**
BHSI	**-5.2**	**3.1**	**-12.8**	**3.1**	**-4.7**	**3.1**
4TC_C+1MON	**0.6**	**0.0**	**2.8**	**0.0**	**7.9**	**0.0**
4TC_C+2MON	**0.8**	**0.0**	**3.2**	**0.0**	**9.6**	**0.0**
4TC_P+1MON	**1.2**	**0.0**	**4.6**	**0.0**	**9.4**	**0.0**
4TC_P+2MON	**1.5**	**0.0**	**5.2**	**0.0**	**9.4**	**0.0**
5TC_S+1MON	**0.9**	**0.0**	**5.8**	**0.0**	**11.1**	**0.0**
5TC_S+2MON	**1.6**	**0.0**	**5.5**	**0.0**	**10.4**	**0.0**
BDI	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

	Reference variable: VLCC freight rates – Middle East to Far East (TD3 route)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
BCI_TCE	**-14.8**	**3.1**	**-3.4**	**3.1**	**4.5**	**0.0**
BPI_TCE	**14.6**	**3.1**	**3.4**	**3.1**	**1.8**	**0.0**
BSI_TCE	**15.4**	**3.1**	**3.6**	**3.1**	**-5.6**	**0.0**
BHSI	**-9.6**	**0.0**	**-2.2**	**0.0**	**11.0**	**0.0**
4TC_C+1MON	**-17.2**	**3.1**	**-4.0**	**3.1**	**-6.9**	**0.0**
4TC_C+2MON	**17.0**	**3.1**	**4.0**	**3.1**	**-10.5**	**0.0**
4TC_P+1MON	**11.3**	**3.1**	**2.6**	**3.1**	**-10.6**	**0.0**
4TC_P+2MON	**7.3**	**3.1**	**1.7**	**3.1**	**-10.8**	**0.0**
5TC_S+1MON	**11.1**	**3.1**	**2.6**	**3.1**	**-11.6**	**0.0**
5TC_S+2MON	**8.6**	**3.1**	**2.0**	**3.1**	**-12.5**	**0.0**
BDI	**15.3**	**3.1**	**3.5**	**3.1**	**3.6**	**0.0**

	Reference variable: Europe to US Atlantic Coast freight rates (TC2 route)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
BCI_TCE	**-17.9**	**0.0**	**-4.2**	**3.1**	**3.6**	**3.1**
BPI_TCE	**5.1**	**3.1**	**1.2**	**3.1**	**8.0**	**3.1**
BSI_TCE	**6.0**	**3.1**	**1.4**	**3.1**	**14.8**	**3.1**
BHSI	**-0.2**	**0.0**	**-0.1**	**0.0**	**0.2**	**0.0**
4TC_C+1MON	**14.5**	**3.1**	**3.4**	**3.1**	**-8.6**	**3.1**
4TC_C+2MON	**11.6**	**3.1**	**2.7**	**3.1**	**-10.2**	**3.1**
4TC_P+1MON	**0.8**	**3.1**	**0.2**	**3.1**	**-10.9**	**3.1**
4TC_P+2MON	**-4.9**	**3.1**	**-1.1**	**3.1**	**-11.0**	**3.1**
5TC_S+1MON	**3.0**	**3.1**	**0.7**	**3.1**	**-11.3**	**3.1**
5TC_S+2MON	**-0.3**	**3.1**	**-0.1**	**3.1**	**-10.5**	**3.1**
BDI	**5.9**	**3.1**	**1.4**	**3.1**	**4.5**	**3.1**

	Reference variable: Second Near Month Panamax T/C futures					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
BCI_TCE	**0.7**	**0.0**	**-4.5**	**0.0**	**-9.0**	**0.0**
BPI_TCE	**-2.0**	**0.0**	**-4.8**	**0.0**	**-11.3**	**0.0**
BSI_TCE	**-4.7**	**0.0**	**-7.8**	**0.0**	**13.3**	**0.0**
BHSI	**2.4**	**3.1**	**-0.3**	**3.1**	**9.9**	**3.1**
4TC_C+1MON	**0.4**	**0.0**	**-1.3**	**0.0**	**-0.2**	**0.0**
4TC_C+2MON	**0.2**	**0.0**	**-0.7**	**0.0**	**0.0**	**0.0**
4TC_P+1MON	**-0.1**	**0.0**	**-0.4**	**0.0**	**-0.1**	**0.0**
4TC_P+2MON	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
5TC_S+1MON	**-0.7**	**0.0**	**0.5**	**0.0**	**0.6**	**0.0**
5TC_S+2MON	**-0.6**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**
BDI	**-1.5**	**0.0**	**-5.2**	**0.0**	**-9.4**	**0.0**

Note: The details of the parameters are denoted in **Table 3.1**

Table 3.5 Lead-lag Relationship for Tanker Freight Markets: Freight Rates vs Futures

	Reference variable: Baltic Dry Index (BDI)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
TC2$	**-8.0**	**3.1**	**-15.4**	**3.1**	**-4.5**	**3.1**
TD3$	**-16.0**	**3.1**	**-4.4**	**3.1**	**-3.6**	**0.0**
BDTI	**-13.5**	**3.1**	**3.6**	**0.0**	**0.2**	**0.0**
BCTI	**-2.3**	**0.0**	**-2.2**	**0.0**	**-14.2**	**0.0**
TC2$+1_M	**-10.0**	**3.1**	**-12.7**	**3.1**	**-2.0**	**3.1**
TC2$+2_M	**-11.9**	**3.1**	**-12.1**	**3.1**	**-2.4**	**3.1**
TD3$+1_M	**-16.0**	**3.1**	**-6.2**	**3.1**	**-3.7**	**0.0**
TD3$+2_M	**-16.0**	**3.1**	**-5.3**	**3.1**	**-3.4**	**0.0**
TD3	**-16.0**	**3.1**	**-4.1**	**3.1**	**-2.9**	**0.0**
TC2_37	**-7.9**	**3.1**	**-14.7**	**3.1**	**-4.5**	**3.1**

	Reference variable: VLCC freight rates – Middle East to Far East (TD3 route)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
TC2$	**-8.5**	**0.0**	**-2.0**	**0.0**	**11.2**	**0.0**
TD3$	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
BDTI	**-3.7**	**0.0**	**-0.9**	**0.0**	**2.4**	**0.0**
BCTI	**16.7**	**3.1**	**3.9**	**3.1**	**-10.0**	**0.0**
TC2$+1_M	**-6.4**	**0.0**	**-1.5**	**0.0**	**7.6**	**0.0**
TC2$+2_M	**-4.2**	**0.0**	**-1.0**	**0.0**	**7.7**	**0.0**
TD3$+1_M	**-0.6**	**0.0**	**-0.1**	**0.0**	**-1.0**	**0.0**
TD3$+2_M	**-0.7**	**0.0**	**-0.2**	**0.0**	**-1.1**	**0.0**
TD3	**-0.3**	**0.0**	**-0.1**	**0.0**	**0.2**	**0.0**
TC2_37	**-9.0**	**0.0**	**-2.1**	**0.0**	**11.1**	**0.0**

	Reference variable: Europe to US Atlantic Coast freight rates (TC2 route)					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
TC2$	**0.2**	**0.0**	**0.1**	**0.0**	**-0.1**	**0.0**
TD3$	**9.0**	**0.0**	**2.1**	**0.0**	**-11.1**	**0.0**
BDTI	**4.8**	**0.0**	**1.1**	**0.0**	**-4.5**	**0.0**
BCTI	**6.9**	**3.1**	**1.6**	**3.1**	**-17.3**	**3.1**
TC2$+1_M	**1.8**	**0.0**	**0.4**	**0.0**	**-2.2**	**0.0**
TC2$+2_M	**3.3**	**0.0**	**0.8**	**0.0**	**-2.3**	**0.0**
TD3$+1_M	**8.0**	**0.0**	**1.9**	**0.0**	**-13.0**	**0.0**
TD3$+2_M	**8.2**	**0.0**	**1.9**	**0.0**	**-13.2**	**0.0**
TD3	**8.6**	**0.0**	**2.0**	**0.0**	**-10.2**	**0.0**
TC2_37	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

	Reference variable: Second Near-Month Panamax T/C futures					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
TC2$	**6.2**	**3.1**	**-2.3**	**3.1**	**11.7**	**3.1**
TD3$	**-6.1**	**3.1**	**9.8**	**3.1**	**10.8**	**0.0**
BDTI	**5.7**	**0.0**	**-5.0**	**0.0**	**13.3**	**3.1**
BCTI	**-7.8**	**0.0**	**-9.6**	**0.0**	**12.4**	**0.0**
TC2$+1_M	**-4.0**	**3.1**	**-4.7**	**3.1**	**-17.8**	**3.1**
TC2$+2_M	**-7.6**	**3.1**	**-4.2**	**3.1**	**-15.6**	**3.1**
TD3$+1_M	**-11.9**	**3.1**	**1.6**	**3.1**	**5.9**	**0.0**
TD3$+2_M	**-12.1**	**3.1**	**2.2**	**3.1**	**5.4**	**0.0**
TD3	**-7.5**	**3.1**	**8.9**	**3.1**	**10.9**	**0.0**
TC2_37	**8.1**	**3.1**	**-1.4**	**3.1**	**11.0**	**3.1**

Note: The details of the parameters are denoted in **Table 3.1**

Spillover effects – commodities vs freight rates: The shipping market has derived demand of commodities, as it is a service provided for facilitating the efficient and cost-effective transportation of goods/cargoes (Friedlaender and Spady, 1980). Demand for commodities creates a demand for the transportation of those commodities. Hence, freight rates trail commodity prices. The lead-lag relationship for both dry and liquid commodities, their corresponding freight rates (transportation costs) and futures' contracts are presented as follows:

Dry commodities vs dry-bulk freight rates – spot and futures: A wide range of dry-bulk commodities including iron ore, coal, wheat, rice, barley, sugar, corn, soybeans and copper can be used to investigate the lead–lag relationships with dry-bulk freight rates, which include the Baltic Capesize Index Time Charter Equivalent (BDI–TCE), Baltic Panamax Index Time Charter Equivalent (BPI–TCE), Baltic Supramax Index Time Charter Equivalent (BSI–TCE) and Baltic Handysize Index (BHSI), along with the futures contracts used for the analysis. Table 3.6 presents the lead-lag relationship for dry commodities prices and dry-bulk freight rates, with BDI as the reference variable and dry-commodities futures and dry-bulk futures prices with second near-month Panamax time charter futures' prices.

The findings suggest that all the dry-bulk commodities informationally lead dry-bulk freight rates, except sugar prices, which lag freight rate prices. The results are consistent with monthly and weekly frequency analysis. Similar findings are observed in Yu et al. (2007), where there are strong spillover effects between agricultural prices and freight rates whereas freight rates have less impact on commodity prices. Copper creates the maximum lead amongst commodities of up to 14.7 periods while Capesize freight rates generate the maximum lead of only 0.8 periods in the monthly analysis, using BDI as a reference variable. Similar to the physical spot market, copper futures exhibit the maximum lead amongst the dry-bulk commodity futures of 11 periods, whereas near-month Capesize futures contracts lead amongst dry-bulk futures' contracts. In general, commodity futures lead freight futures as freight markets are derived demand to commodity markets, and the findings are in line with the previous studies by Kavussanos et al. (2010) and Kavussanos et al. (2014).

Table 3.6 Lead-lag Relationship for Dry-bulk Commodity and Freight: Spot vs Futures

	Reference variable: BDI					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
BCI_TCE	**0.8**	**0.0**	**0.5**	**0.0**	**0.6**	**0.0**
BPI_TCE	**0.0**	**0.0**	**0.8**	**0.0**	**-1.5**	**0.0**
BSI_TCE	**-1.0**	**0.0**	**-1.8**	**0.0**	**-11.1**	**0.0**
BHSI	**-5.2**	**3.1**	**-12.8**	**3.1**	**-4.7**	**3.1**
Coal	**9.9**	**0.0**	**2.4**	**0.0**	**-6.9**	**0.0**
Wheat	**-0.7**	**3.1**	**-11.8**	**3.1**	**-3.7**	**3.1**
Soybeans	**-4.0**	**0.0**	**11.7**	**3.1**	**-2.9**	**3.1**
Corn	**3.7**	**3.1**	**17.9**	**3.1**	**-4.7**	**3.1**
Iron	**2.1**	**0.0**	**9.8**	**0.0**	**-2.1**	**0.0**
Copper	**14.7**	**0.0**	**-4.6**	**0.0**	**-14.0**	**0.0**
Sugar	**-15.7**	**0.0**	**-3.8**	**0.0**	**-17.2**	**0.0**
Rice	**6.1**	**3.1**	**-3.7**	**3.1**	**5.3**	**0.0**
Barley	**4.9**	**3.1**	**12.5**	**3.1**	**11.6**	**3.1**
BDI	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

	Reference variable: Second Near Month Panamax T/C futures					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
4TC_C+1MON	**0.4**	**0.0**	**-1.3**	**0.0**	**-0.2**	**0.0**
4TC_C+2MON	**0.2**	**0.0**	**-0.7**	**0.0**	**0.0**	**0.0**
4TC_P+1MON	**-0.1**	**0.0**	**-0.4**	**0.0**	**-0.1**	**0.0**
4TC_P+2MON	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
5TC_S+1MON	**-0.7**	**0.0**	**0.5**	**0.0**	**0.6**	**0.0**
5TC_S+2MON	**-0.6**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**
ICE_Coal_F1	**9.6**	**0.0**	**6.3**	**0.0**	**9.2**	**0.0**
ICE_Coal_F2	**5.2**	**0.0**	**5.7**	**0.0**	**8.6**	**0.0**
CME_Wheat_F1	**0.1**	**3.1**	**-6.1**	**3.1**	**-6.4**	**3.1**
CME_Wheat_F2	**-0.1**	**3.1**	**-6.5**	**3.1**	**-6.7**	**3.1**
CME_Soybeans_F1	**3.5**	**3.1**	**-13.5**	**3.1**	**-6.5**	**3.1**
CME_Soybeans_F2	**3.6**	**3.1**	**-12.9**	**3.1**	**-6.8**	**3.1**
CME_Corn_F1	**3.8**	**3.1**	**-10.7**	**3.1**	**-6.3**	**3.1**
CME_Corn_F2	**2.6**	**3.1**	**-10.5**	**3.1**	**-6.4**	**3.1**
CME_Iron_F1	**7.6**	**0.0**	**2.2**	**0.0**	**5.4**	**0.0**
CME_Iron_F2	**8.3**	**0.0**	**0.8**	**0.0**	**3.1**	**0.0**
Copper_F3	**11.0**	**0.0**	**-9.5**	**0.0**	**6.5**	**0.0**
Sugar_F1	**6.5**	**0.0**	**-9.1**	**0.0**	**3.6**	**0.0**
Sugar_F2	**5.8**	**0.0**	**-8.7**	**0.0**	**3.6**	**0.0**
Rice_F1	**-7.8**	**0.0**	**-0.7**	**3.1**	**6.6**	**0.0**
Rice_F2	**-6.9**	**0.0**	**-0.8**	**3.1**	**6.5**	**0.0**
Barley_F1	**4.8**	**0.0**	**7.8**	**0.0**	**7.7**	**0.0**
Barley_F2	**5.8**	**0.0**	**-17.4**	**0.0**	**8.5**	**0.0**

Note: The details of the parameters are denoted in **Table 3.1**

Oil commodities vs tanker freight rates – spot and futures: Crude oil, Brent oil, heating oil and natural gas prices are used to observe the lead-lag relationships with transportation costs of such liquid commodities using tanker freight rates such as TC2 and TD3 route freight rates (US$/mt) along with tanker freight indexes such as the Baltic Clean Tanker Index (BCTI) and the Baltic Dirty Tanker Index (BDTI), representing product and crude oil freight rates, respectively. Table 3.7 presents the lead-lag relationships between oil commodities and tanker freight rates extracted from various reference crude oil markets. The findings suggest that the crude oil and its derivative products prices lead their freight rates. At a weekly frequency, it can be observed that TD3 and TC2 lag crude oil prices by 10.3 and 6 periods, respectively, while heating oil lags by only 5.4 periods and Brent oil is almost contemporaneous with crude oil. The results are consistent for analysis in a weekly frequency. It can further be observed that oil prices and freight rates are counter-cyclical, indicating that an increase (decrease) in oil prices will be followed by a decrease (increase) in freight rates. This happens because as oil prices increase, the demand for the transportation of oil decreases, since the consumption of oil from storage increases. Conversely, as oil prices decrease, the demand for oil transportation increases, as oil traders want to store them for sale at a higher price when the oil market revives.[11] Similar to the spot market, the oil futures markets lead the tanker freight futures markets. Crude oil, Brent oil and heating oil futures contracts are contemporaneous with the crude oil spot market while the TC2 and TD3 routes lag crude oil prices by 1.5 and 1.0 periods, respectively, in analysis at a weekly frequency.

Overall, between the commodity and freight market, it can be observed that commodity prices lead transportation cost (freight rates) and futures markets lead the underlying spot market. Commodity markets lead the freight market as freight markets, being derived demand of the commodity markets, are driven by the commodity prices. As the futures contracts offer higher leverage and flexibility (regarding trading and brokering costs causing cheaper readjustment of contracts), futures markets reflect new market information faster than the underlying spot market. These findings could provide important insights for various market practitioners to facilitate their business activities and trade, as is explained in detail in the next section.

[11] Oil is a not perishable commodity that can be easily stored.

Table 3.7 Lead-lag Relationship for Commodities and Freights: Oil and Gas vs Tankers

	Reference variable: Crude					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
TC2$	**8.1**	**3.1**	**-10.3**	**0.0**	**-15.2**	**3.1**
TD3$	**0.4**	**3.1**	**-6.0**	**3.1**	**-4.1**	**3.1**
BDTI	**-2.3**	**0.0**	**-3.8**	**3.1**	**-9.5**	**3.1**
BCTI	**17.5**	**0.0**	**-0.1**	**0.0**	**9.8**	**0.0**
Crude	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Brent	**-0.7**	**0.0**	**0.2**	**0.0**	**-0.1**	**0.0**
Heating_oil	**-0.8**	**0.0**	**-5.8**	**0.0**	**2.2**	**0.0**
Natural_Gas	**16.1**	**0.0**	**-4.7**	**0.0**	**5.4**	**0.0**
BLPG1	**5.9**	**3.1**	**-7.7**	**3.1**	**2.8**	**3.1**
TD3	**0.3**	**3.1**	**-6.0**	**3.1**	**-5.1**	**3.1**
TC2_37	**8.2**	**3.1**	**10.2**	**3.1**	**-15.2**	**3.1**

	Reference variable: Crude Oil					
	Monthly Dataset		**Weekly Dataset**		**Daily Dataset**	
	No. of Factors - 4	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
TC2$+1_M	**-6.4**	**0.0**	**-1.5**	**0.0**	**7.6**	**0.0**
TC2$+2_M	**-4.2**	**0.0**	**-1.0**	**0.0**	**7.7**	**0.0**
TD3$+1_M	**-0.6**	**0.0**	**-0.1**	**0.0**	**-1.0**	**0.0**
TD3$+2_M	**-0.7**	**0.0**	**-0.2**	**0.0**	**-1.1**	**0.0**
CME_Crude_F1	**0.1**	**3.1**	**0.0**	**3.1**	**4.2**	**3.1**
ICE_Brent_F1	**-0.1**	**3.1**	**0.0**	**3.1**	**3.9**	**3.1**
CME_Heating_F1	**0.1**	**3.1**	**0.0**	**3.1**	**3.7**	**3.1**
CME_Natural_gas_F1	**-17.8**	**3.1**	**-4.1**	**3.1**	**1.8**	**3.1**
ICE_Natural_Gas_F2	**6.7**	**3.1**	**1.6**	**3.1**	**0.6**	**3.1**

Note: The details of the parameters are denoted in **Table 3.1**

3.4. Discussion

As noted in the previous section, commodity markets receive new market information and transmit it to freight markets. Within each commodity segment, it can be observed that crude oil price informationally leads other markets, followed by Brent and heating oil markets, and then metal and other agricultural commodities. This is attributable to the fact that crude oil is the major energy commodity, and hence has a strong impact on macroeconomic factors including international trade, export and import, and even the GDP of countries (Cooper, 2003). As the demand for iron ore and scrap iron are directly proportional to the growth of any nation (Tcha and Wright, 1999), crude oil prices affect metal and ore prices. Similarly, as the GDP of the nation increases, the government increases its expenditure on rural development, and thereby increase in demand for agricultural commodities increases the price of agro-based commodities (Fan et al., 2000). So crude oil prices are followed by the agricultural commodity prices. Unlike commodities, it can be observed that dry-bulk freight markets are more reactive to new market information as compared to the tanker freight markets. This is because of the presence of a high number of shipowners in the dry-bulk segment as compared to the tanker sectors, creating a perfectly competitive market for dry-bulk shipping.[12] Futures contracts also lead the underlying spot markets for both commodity and freight markets. The lead-lag relationships between commodity and freight futures are similar to that of the underlying spot markets, and for similar reasons.

Research and research findings have made extensive contributions, with importance for both industry and academics. In terms of the industry impact, this research is of interest to the commodity houses/traders and charterers who are directly exposed to commodity and freight rate fluctuations. This research also adds value to shipowners who are affected by freight rates volatilities. The work is indeed vital for investors such as hedge funds, investment banks and export-import banks, who invest in the commodities and shipping sector, along with government policy-makers whose main interest lies in understanding the trading (export and import) activities associated with the country. The trading strategies on freight contracts by observing the commodity price movement for the industry practitioners can be explained as follows:

(a) *Long–short freight positions*: As freight markets trail commodity markets, it is useful to understand the price movement of commodity markets that hold positions in freight markets. The two main categories of commodities' markets have a very different impact on the corresponding transportation costs. The increase in dry-bulk commodity prices is followed by an increase in dry-bulk freight rates whereas the decrease in crude oil, Brent oil and heating oil prices is followed by an increase in corresponding tanker freight rates. This contrary result can be observed due to the fact that oil is not a perishable cargo, unlike agricultural commodities (such as wheat, rice, corn, etc.), and hence does not require specialized storage techniques, as well as a reduced risk of being destroyed, which encourages charterers and commodity houses to ship oil commodities when there is a fall in their prices, store it at various oil storage locations, and waiting for the oil market to revive to gain profit from selling the oil at a higher price. The increase in shipment causes a surge in tanker freight rates, as experienced in the 2014 oil crisis. On the other side, as agro-based commodities must be used within a stipulated timespan, if there is a drop in commodity price (which is

[12] The top 7 tanker companies comprise 20% of the tanker segments while the top 7 bulk carrier companies consist of only 15% of the dry-bulk shipping.

mainly due to a drop in demand for the commodity), commodity houses are not interested in shipping dry commodities, which results in a fall in dry-bulk freight rates. So, if there are increase (decrease) in dry-bulk (wet; which includes crude oil and its derivative products) prices, the charterers and commodity houses should hold long-term freight contracts, as the freight rates are expected to rise in the future, whereas shipowners should hold short-term freight contracts to take advantages of the rising freight markets. On the other side, if there are decrease (increase) in dry-bulk (oil and its products) prices, the shipowners should hold long-term freight contracts and lock the freight prices at higher rates as the freight rates are expected to fall in future, while the charterers should get into only short-term freight contracts since the fall in freight rates will be beneficial for the charterers. Similar strategies are applicable for freight futures contracts as freight and commodity futures follow the same pattern as that of the underlying spot prices.

(b) *Policy implications*: Government policies can play a crucial role in the export and import activities of any nation. As the GDP of any nation grows, the trading activities of those nations increase. This creates a need to facilitate a trade to meet the growing demand for the commodities. Otherwise the economic growth of the nation will slow down due to a lack of materials, such as crude oil or iron ore, which are vital for construction works. At the same time, it is an opportunity to strengthen the nation's international trade and build up relationships with various nations and companies to bring an overall development. Government policy-makers should make their regulation dynamic to meet the market requirement to facilitate trade. For example, import and export dues should be flexible or at times even relaxed to increase trading activities. Free trade should be encouraged, which not only increases trading activities but also brings economic benefit to the nation by providing other value-added services as is the case in the model applied in Singapore. Policy-makers should always understand the price movement of commodity and freight markets, which can help develop the economy of any maritime nation.

This research has not only strong industry implications, but also extensive academic contributions. The study provides a strong linkage between the commodity and freight rates for a wide range of oil, metal and agricultural commodities which have not been investigated in the past. This study, therefore, acts as fundamental research to provide a base for other academic studies to flourish. Further, the lead-lag relationships between commodity prices and freight rates are robust for both the dry and wet sector – that is, commodity markets lead freight rates, dry-bulk freight rates are cyclical with dry-bulk commodities whereas tanker freight rates are counter-cyclical to oil prices. Though these results make economic sense, they call for further investigation using other models such as a vector autoregressive (VAR) along with a generalised autoregressive condition heteroskedasticity (GARCH) model to investigate the lead-lag relationship between commodities and freight markets for both level and variances. Above all, it brings the not very popular multi-factor model into the spotlight and provides ways to use this model to investigate macroeconomics factors, including commodity and freight markets.

3.5. Conclusion

The commodity markets have experienced pronounced price spikes and crash in the last decade, while shipping markets have experienced low volatilities. Commodities and freight are also considered a diversifiable asset along with stock prices, which encourages investors to hold commodities and stocks in their portfolio. These developments demand to study both commodity and freight price co-movements to effectively allocate the resources to take advantages of such price dynamics. This study combines commodity and freight rates along with their futures contracts in a factor model approach to investigate the linkage amongst the asset returns and provide a new perspective on research activities. Daily, weekly and monthly datasets are used in the analysis of 65 variables ranging from October 2010 until February 2017. The results suggest that commodity markets strongly contribute to freight price co-movements. The most influential variables prove to be the crude oil and other oil products' markets. It can also be observed that there is strong information transmission between not only between the commodity and freight markets but also within the commodity markets and freight markets themselves – that is, the crude oil market transmits information to the metal and agricultural market sectors, and tanker freight rates have an effect on dry-bulk freight markets. This result is also consistent with behaviour in the futures markets. These findings have significant implications for the diversification of investments (weekly linked commodities and freight positions should be held rather than strongly linked contracts) and the financial stability of portfolio returns and, above all, the lead-lag relationships between the commodity and freight markets can act as a risk-transfer function for shipowners, charterers and commodity traders, amongst others.

4. Economic Information Transmissions between Shipping Markets: A Case Study from the Dry-bulk Sector

4.1. Introduction

In a frictionless world, derivatives and underlying asset (physical) prices respond simultaneously to new market information and are thus perfectly correlated. In practice, however, there exist market frictions that can induce a lead-lag relationship between the two economic price series, allowing market participants to project the movements of the trailing market, based on new information transmitted by the leading market. Typically, derivatives contracts are more flexible and involve lower transaction costs than underlying physical contracts, facilitating a swifter adjustment of derivative prices to new market information relative to underlying physical prices. The lack of a significant number of market participants in illiquid derivatives markets makes them less responsive to new information as it increases the cost of repositioning the contracts (Capozza et al., 2004, Löffler, 2005). This property is well documented in the general finance literature (Fama and French, 1987, Sloan, 1996) and has been extensively utilised by market practitioners.

The scope of investigating lead-lag relationships between different markets is a multi-faceted one. First, it can provide insights into the inter-relationships between these markets, comparing their market efficiency levels, where the more efficient market absorbs new market information faster and transmits it to the least efficient market. Second, return spillovers from one market to another can be used as a price discovery vehicle, enabling practitioners to draw inferences for the price of the trailing market by observing price movements in the leading market. Gaining insight into future market prices is important since it can act as an effective anticipatory mechanism for market participants in the decision-making process. Third, it can help draw inferences on volatility structures to hedge risk exposures. Market volatility projections can generally be based on (i) the interaction of volatilities between the two markets; that is, if volatility transmissions exist between markets, a surge in the market volatility of the informationally leading market indicates a possible increase in the volatility of the trailing market (Ng, 2000, Baele, 2005); and (ii) a leverage effect; that is, a negative shock leads to greater volatility in the market relative to a positive shock of the same magnitude (Engle and Ng, 1993). This study focuses on investigating the economic spillover effects between physical and several derivatives freight markets in the shipping industry.

The international shipping industry is characterised by global trade, large-scale capital investments, but also sizable operational and commercial risks, due to the significant volatilities in rates and prices. Shipping is the channel of world trade, connecting nations together, and is widely regarded as the most efficient and inexpensive mode of transportation for all types of merchandise. According to the International Chamber of Shipping (ICS), around 90% of world trade is transported by more than 50,000 seagoing vessels. The commercial fleet is registered in over 150 nations and operated by over 1.5 million seafarers of every nationality. According to a recent study for the European Community Shipowners' Associations (ECSA), the "*overall contribution of the European shipping industry to the EU's Gross Domestic Products (GDP) in 2013 is estimated to have been €147 billion*" (Economics, 2015). The international freight rate market is characterised by some unique features, which differentiate it from other "*soft*" commodity markets. These are the high volatility, the seasonality effects associated with commodities transported by the ocean-going vessels, the cyclical behaviour of rates and prices following business cycles and the non-storable nature of freight rates, amongst other things (Kavussanos and Visvikis, 2006a, Kavussanos and Visvikis, 2011). The non-storable commodity nature of the underlying service in question is a distinct feature of freight derivatives and means that, in this case, the traditional cost-of-carry no-arbitrage arguments for fair pricing do not apply (Kavussanos and Visvikis, 2004b, Alizadeh, 2013, Kavussanos et al., 2014).

This study extends previous research on price discovery in sea-going transportation markets in several ways. First, considering the importance of the shipping industry and the inherent relationships between the derivatives and the physical markets in shipping, to the best of our knowledge this is the first study that empirically assesses the information spillover of returns and volatilities between time-charter rates and corresponding freight futures and options prices, and provides direct evidence of price discovery in the freight options market. Freight futures/forwards are agreements between a buyer (typically charterers, hedging against freight rate increases) and a seller (typically shipowners, hedging against freight rate decreases) of freight services for a specific time in future but at a pre-agreed freight rate. These contracts are cash-settled at the maturity date of the contract against a settlement price. For all the dry-bulk time-charter futures contracts investigated in this study, the settlement price is the average of all time-charter rates during the maturity month, as published by the Baltic Exchange.

Freight call or put options contracts are also cash-settled against a settlement price, and follow the same settlement average process as above (that is, they are Asian options), which can only be exercised on the last trading (settlement) day of the contracts (that is, they have a European style exercise).[13] A distinct feature of freight options is that they can be seen as arithmetic price Asian options on the underlying freight rate market or, equivalently, as European options on futures/forward contracts. For Asian options, the payoff is dependent on the average price of the underlying asset over some period before the settlement of the contract. Therefore, the first difference of Asian options with other options types is that they have lower volatility and, thus, are cheaper than European or American options. Typically, Asian options are written on underlying assets that have low trading volumes, and therefore, an average value of the underlying asset over a period of time is used as the settlement price, to avoid any possibility of price influence. Furthermore, for Asian options, there are no analytical pricing formulas, as the assumption of lognormal price distribution does not hold. As a result, the following four options pricing models are typically used to price Asian options: (i) Kemna and Vorst (1990) propose a closed-form pricing model to geometric averaging price options; (ii) Turnbull and Wakeman (1991) suggest an analytical arithmetic form approximation with a lognormal distribution; (iii) Levy (1992) extends the Turnbull–Wakeman analytical approximation and argues that Asian options should be estimated on a discrete time basis; and (iv) Cheung and Mak (1992) develop an approximation for arithmetic Asian options based on a geometric conditioning framework (Kavussanos and Visvikis, 2006b).

Freight derivatives contracts are traded over-the-counter (OTC) through various freight brokers and cleared in various clearing-houses (LCH.Clearnet, NOS Clearing, SGX Asia Clear and CME Clearing Europe), but also traded in organized derivatives' markets (NASDAQ OMX, ICE Futures Europe and CME Group) and electronic trading screens (Cleartrade Exchange in Singapore and Baltex in London). More specifically our investigation focuses on three major categories of dry-bulk vessels; namely Capesize (around 160,000 deadweight – dwt), Panamax (around 75,000 dwt) and Supramax (around 54,000 dwt) vessels. Although freight forward/futures' prices have been found to informationally

[13] For a detailed analysis of the freight derivatives market see Kavussanos and Visvikis (2006a and 2011).

lead the underlying freight rates (Kavussanos et al., 2004, Von Spreckelsen et al., 2014, Zhang et al., 2014) and lag the commodity futures prices (Kavussanos et al., 2014), there exists no evidence on the interaction with freight options.[14]

Employing a research design that utilises both futures and options derivatives allows us to highlight differences in price discovery between these two inter-related but yet distinct markets. Wang and Chen (2007) argue that the major characteristics of options markets differ from futures and spot markets, such as the "*diverse strategies involving call/put trading in options markets*". They also argue that it is expected that informed traders would prefer to trade in options markets due to the opportunity to employ a greater degree of leverage and the inherent downside protection (maximum potential loss). Thus, in theory, one would expect that futures markets would fulfil their price discovery function, by attracting participants with both hedging and speculation trading motives, whereas participants in options markets would tend to concentrate on strategic risk hedging.

Second, this study examines for the first time whether the level of price discovery of freight futures and options markets has changed over time and whether the degree/extent of information transmission between freight derivatives markets is related to concurrent market conditions, such as trading volume and open interest. Trading activities in derivatives markets play a critical role in price movements and information spillovers (Karpoff, 1987, Admati and Pfleiderer, 1988, Bessembinder, 1992, Bessembinder and Seguin, 1993, Lee and Swaminathan, 2000). Bessembinder et al. (1996) argue that trading volume is related to the exogenous liquidity needs of the traders, all available information flows, cross-sectional differences in the opinions of traders, and the strategic interactions between traders with different information levels. Bessembinder and Seguin (1993) and Watanabe (2001), amongst others, report a significant positive relationship between price volatility and trading volume, and a significant negative relationship between price volatility and open interest. They conclude that these relationships may vary with changes in regulation. Chakravarty et al. (2004) argue that the price discovery of options markets is more pronounced when the trading volume of options is higher than that of the underlying asset.

[14] In the literature, only studies on freight options pricing have been conducted Koekebakker, S., Adland, R. & Sødal, S. 2007. Pricing freight rate options. *Transportation Research Part E: Logistics and Transportation Review,* 43**,** 535-548, Nomikos, N. K., Kyriakou, I., Papapostolou, N. C. & Pouliasis, P. K. 2013. Freight options: Price modelling and empirical analysis. Ibid.51**,** 82-94..

Following these lines, this study also examines the effect of freight futures trading volume on time-charter rates, freight futures prices and freight options prices to offer a more in-depth understanding of the lead-lag relationships between these related markets and to assess the influence of trading activity on price fluctuations. Also, market liquidity is important for the absorption of new market information, since lower market liquidity can generate a higher illiquidity risk premium and, in turn, lead to more pronounced market frictions and slower incorporation of information. In the freight derivatives market, the study of Alizadeh et al. (2015b) is the only one to examine the liquidity of freight futures contracts, using the Amihud illiquidity measure (Amihud, 2002). Although the freight options market is considered less liquid compared to the freight futures market based on trading volumes, there exists no study measuring the relative liquidity of freight options.[15] To more effectively compare the relative liquidity of freight futures and options and gain a more in-depth understanding of the lead-lag relationship between these markets, this study adopts the Amivest liquidity measure for both freight futures and options markets at different maturities. A link is established for the first time between the freight options market and its liquidity, as by attracting more investors in this market this could potentially reduce price volatility. Such a link corroborates earlier results by Kavussanos et al. (2004) demonstrating that the introduction of freight derivatives trading decreased price volatility had an impact on its asymmetry, and improved the speed of information flow in freight markets.

Third, this study uses a tri-variate GARCH model to capture the three-way price dynamics of futures, options and spot markets, as well as the strength of information spillovers. Accordingly, we do not provide evidence only on price discovery channels, but also on the cross-market volatility spillover mechanisms, given their importance for hedging, value at risk and options pricing (Wang and Chen, 2007). Unlike the existing literature investigating futures and spot markets that pay little attention to the information spillovers associated with the options market, our approach allows for more comprehensive modelling of all potential transmission channels. Gaining an understanding of options dynamics within such a tri-variate framework has practical implications for market-makers when managing adverse selection risk and price discovery signals (Ehrmann et al., 2011).

[15] During the period of investigation, the total Capesize, Panamax and Supramax futures traded cumulatively to around 2.1 million, 1.5 million and 390,000 lots, respectively, while Capesize, Panamax and Supramax options came to about 710,000, 87,000 and 6,000 lots, respectively, as reported by the Baltic Exchange.

Fourth, studying a more recently established and emerging derivatives market serves the purpose of gaining insight into whether it is less efficient in assimilating new market information into prices compared to other more mature markets. Chiang and Fong (2001), Bae et al. (2004) and Chakravarty et al. (2004), amongst others, argue that in emerging markets traders may be less informed and significant market frictions and restrictions tend to exist, potentially leading to less efficient price discovery. The information spillover mechanisms within the emerging freight derivatives market is thus an important empirical question that deserves further investigation.

Our results support the existence of significant information transmissions (both in returns and volatilities) between time-charter rates, freight futures and freight options markets for all three vessel types examined, indicating that new information is first absorbed into freight futures markets and subsequently spilled over to time-charter markets, before it is transmitted to freight options markets. Although freight futures contracts can be used as a price discovery vehicle for time-charter rates, freight options contracts cannot be relied upon to serve a price discovery function. These results can be at least partially attributed to the lower trading liquidity of the freight options market compared to freight futures market. It is also found that the spillover results uncovered here can generate on average economically profitable trading strategies.

This study has important practical implications for the shipping industry. First, practitioners (shipowners, charterers, and investors, amongst others) can gain a better understanding of the interactions between three (non-storable) related markets, which can be used as a price discovery vehicle when taking positions in either physical or derivatives freight markets. The spillover results can be utilised in hedging, and investment strategies since by observing the informationally leading market (e.g. freight futures) shipowners and charterers can draw inferences on the future (short-run) direction of both the freight options and the physical freight markets. Second, the volatility interactions between the three related markets can provide an effective risk (volatility) prediction mechanism, which can enhance investors' decision-making. Accordingly, the volatility spillovers of the freight derivatives markets can serve as a volatility discovery mechanism for shipowners and charterers to position themselves in the physical freight market and, thus, minimise their freight rate exposure more efficiently. Third, the study provides an analysis of liquidity risk for freight futures and options markets, over a wide range of maturities, which by attracting more market participants can lead to an increase in market liquidity in the freight derivatives market. Further, the finding that the liquidity risk of freight derivatives contracts can adequately explain the documented spillover relationships between the three related markets can be utilised by practitioners, for hedging purposes, when taking positions in the physical as well as in the freight derivatives markets, improving their risk-return profile. Finally, the results of this study can act as a benchmark for researchers and regulators to gain a better understanding of the freight derivatives markets, and especially the freight options market, with the scope for developing better and more transparent pricing models, which could in turn potentially improve market liquidity and efficiency.[16]

The remainder of this study is organised as follows: Section 3.2 describes the properties of the data and methodology used, along with the theoretical background. Section 3.3 presents the empirical results. Section 3.4 provides a discussion of the main findings and the economic significance of the results. Finally, section 3.5 concludes the study.

4.2. Data and Methodology

4.2.1. Data

This study utilises daily six-month Time-Charter Equivalent (TCE) rates,[17] freight futures for different maturities and corresponding at-the-money (ATM) freight options prices and implied volatilities for three types of dry-bulk (Capesize, Panamax and Supramax) vessels, from April 2013 to August 2016, as reported by the Baltic Exchange.[18] The Capesize four time-charter route basket, the Panamax four time-charter basket and the Supramax six time-charter basket are used for underlying time-charter rates and derivatives (futures and options) prices.[19] Corresponding trading volumes and open interest for freight futures and freight

[16] For more information on the practical implications of information spillovers in the freight derivatives market, in terms of design of investment portfolios, asset pricing and risk management see Kavussanos et al. (2014).

[17] TCE rates are calculated by taking voyage revenues, subtracting voyage expenses and then dividing the total by the round-trip voyage duration in days.

[18] Near-month, second near-month, near-quarter, second near-quarter, third near-quarter, near-calendar year and second near-calendar year contracts are used. Near-month/quarter/year contracts signify contracts starting in near-month/quarter/year and settle in the next month/quarter/year, respectively. Second near-month/quarter/year contracts signify contracts starting in the second following month/quarter/year and settle in the second next month/quarter/year, respectively, and so on. A perpetual contract rollover technique is used at the last trading day of the month/quarter/year, to avoid price jumps at the expiration period of the derivatives contracts.

[19] Though the Capesize 2014 five time-charter route basket attracts more trading interest at the time of writing, this study uses the Capesize four time-charter route basket as the investigated sample is from April 2013, while the Capesize 2014 basket is available only from February 2014. The Capesize time-charter basket comprises of the following equally weighted average routes: C8_03 (Gibraltar/Hamburg transatlantic round voyage), C9_03 (Continent/Mediterranean trip China–Japan), C10_03 (China–Japan transpacific round voyage) and C11_03 (China–Japan, redelivery ARA or passing Passero) routes.

option's contacts are gathered from LCH.Clearnet. Although the Baltic Exchange initiated coverage of Baltic Freight Assessments (BFA, henceforth referred as freight futures) in January 2003 and Baltic Options Assessments (BOA) in January 2008 for all dry-bulk vessel types, comprehensive trading volume data (daily trading activities with respect to various maturities) for freight futures and options are available from LCH.Clearnet only after April 2013. BFAs are mid bid-ask FFA prices for several contract maturities ahead, while BOA is the daily average assessments of implied volatility for ATM freight options, as provided by the respective panels of freight derivatives brokers (panelists) appointed by the Baltic Exchange. The option's implied volatility is the theoretical volatility based on the option's quoted price.[20] For the days in the sample period where the Baltic Exchange does not produce a TCE rate, the corresponding freight futures and options prices are also excluded. Also, all models are estimated with the full sample (January 2008–August 2016), without the sample restriction of the trading volume variable, to capture a complete shipping business cycle and include the effects of the global financial crisis. The results are qualitatively the same as the ones reported here. In order to further investigate if the information spillover results are time-varying over different time periods, we split our sample into three different periods: (a) full sample (January 2008–August 2016), (b) Pre-sample (January 2008–April 2013) and (c) Post-sample (April 2013– August 2016). Again, the results are qualitatively the same as the results in the ensuing analysis.

Since freight options have freight futures as their underlying asset, they are calculated using Black (1976) pricing model, using ATM implied volatility with a Turnbull and Wakeman (1991) approximation (Nomikos et al., 2013).[21] ATM options prices are used in this study to avoid any underpricing and overpricing from out-of-the-money (OTM) and in–the-money (ITM) options, respectively, which can lead to biased results when investigating information

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The Panamax time-charter basket comprises of the following equally weighted average routes: of P1A_03 (Skaw–Gibraltar transatlantic round voyage), P2A_03 (Skaw–Gibraltar trip to Taiwan–Japan), P3A_03 (Japan–South Korea transpacific round voyage) and P4_03 (Japan–South Korea trip to Skaw Passero) routes. The Supramax time-charter basket comprises the following routes: S1A (Antwerp–Skaw trip to Singapore–Japan) 12.5%, S1B (Canakkale trip to Singapore–Japan) 12.5%, S4A US (Gulf trip to Skaw–Passero) 12.5% and S4B (Skaw–Passero trip to US Gulf) 12.5% routes each and S2 (South Korea–Japan, one Australian or Pacific round voyage) 25% and S3 (South Korea–Japan trip to Skaw–Gibraltar) 25% routes.

[20] The brokers providing data for BFA and BOA prices are: BRS Brokers, Clarkson Securities Ltd., Freight Investor Services Ltd., GFI Brokers, Pasternak Baum & Company Inc. and Simpson Spence & Young Ltd.

[21] The Turnbull, S. M. & Wakeman, L. M. 1991. A quick algorithm for pricing European average options. *Journal of financial and quantitative analysis,* 26**,** 377-389. approximation assumes a lognormal distribution under arithmetic averaging, while the first and second moments of the averaging process are used to evaluate the options contracts.

transmissions (Wiggins, 1987). The main price drivers of options are the following: (i) the Delta of an option measures how much its price is expected to change per $1 change in the price of the underlying asset. For ATM options (like the ones in this study) the Delta should be very close to 0.50, as the trading value is about the same for both calls and puts; (ii) the Theta of an option measures the rate of change in an option's price given a unit change in the time to expiration. ATM options have a higher time value and a higher decay rate than OTM or ITM options; (iii) the Vega of an option measures the amount of the option's price changes with an increase in volatility. Since ATM options have the greatest amount of time value, they also have higher Vegas than OTM and ITM options; and (iv) the Rho of an option measures the amount by which the price of options changes with a unit increase in the risk-free interest rate. Overall, all above price drivers have been taken into consideration in the estimation of options prices in this study.

The OTC nature of freight derivatives markets makes it difficult to obtain trading volume and open interest data for all maturities. The Baltic Exchange collects weekly trading volume and open interest data from different clearing-houses, although the data are not segregated based on maturities but are cumulated for each vessel type, which could potentially lead to biased results (for example, the number of Capesize freight futures contracts traded in a week is presented as an aggregate of all different contract maturities).[22] Thus, the trading volume and open interest from LCH.Clearnet is used instead since: (i) they are based on vessel types, and contract maturities, and (ii) this specific clearing-house captures more than half of the cleared freight derivatives' market.[23]

4.2.2. Stationarity and cointegration

The order of integration (stationarity) of each price series is determined by the ADF (Dickey and Fuller, 1981), PP (Phillips and Perron, 1988) and KPSS (Kwiatkowski et al., 1992) unit root tests. More recent studies argue that a variable could exhibit a stationary behaviour preceding and following a structural breakpoint while being non-stationary for the whole sample period (Perron and Vogelsang, 1992). In this study, a unit root test with one structural break is also employed for price series that are endogenous variables in the system, following

[22] From LCH.Clearnet, Inter Continental Exchange (ICE), NOS Clearing, and SGX Asia Clear clearing-houses.

[23] The weekly average trading volume of Capesize time-charter futures contracts, as reported by the Baltic Exchange and LCH.Clearnet, is 11,837 lots and 7,102 lots, respectively, during the post-sample period. The weekly average open interest of Capesize time-charter contracts, as reported by the Baltic Exchange and LCH.Clearnet, is 143,667 lots and 97,667 lots, respectively, during the sample period.

the work of Banerjee et al. (1992), Perron and Vogelsang (1992) and Vogelsang and Perron (1998).

Johansen (1988) standard cointegration tests are also conducted to assess whether there exist long-run (cointegrating) relationships between the endogenous variables. When there exists evidence of long-run (cointegrating) relationships the following Vector Error Correction Model (VECM) is estimated:

$$\Delta X_t = \prod X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + \varepsilon_t \ ; \quad \varepsilon_t \mid \Omega_{t-1} \sim distr.(0, H_t) \tag{1}$$

where X_t is a 3×1 vector (S_t, F_t, O_t)' of logarithmic time-charter rates, freight futures and freight options prices, respectively; Δ denotes the first-order difference operator; and ε_t is a 3×1 vector of error-terms $(\varepsilon_{S,t}, \varepsilon_{F,t}, \varepsilon_{O,t})$' that follows a conditional distribution of zero mean and time-varying covariance matrix (H_t). $\prod X_{t-1}$ denotes the error-correction term (linear combination of non-stationary S_t, F_t and O_t prices exhibiting a stationary property), where X_{t-1} represents lagged S_t, F_t and O_t prices, and $\prod$ represents the coefficient of X_{t-1}. If the rank of $\prod$ is 2 there exist 2 cointegrating vectors, and if the rank of $\prod$ is 1 there exists 1 cointegrating vector. This also determines the presence of long-run relationships between the variables, and the expression $\prod X_{t-1}$ represents the error-correcting vector(s).

Perron (1989) argues that although variables can be stationary, a shock can change their behaviour. Similarly, Johansen et al. (2000) state that if no cointegrating vector exists between two or more non-stationary variables, this does not explicitly imply the non-existence of long-run relationships between them, but rather points to the non-existence of long-run relationships in the absence of a structural break. Therefore, if the standard Johansen (1988) test fails to determine any cointegrating relationships between the variables, then the Johansen *et al*. (2000) approach is adopted to test for cointegration with one structural break among the S_t, F_t and O_t variables.[24]

[24] Though Johansen et al. (2000) allows for cointegration with two structural breaks, this study tests only for a cointegration with one structural break due to insufficient sample length. Moreover, the Johansen et al. (2000) test can account for multiple cointegrating terms, and as such is suitable for evaluating cointegration relationships between three variables (i.e. time-charter, futures and options), where the rank of the variables could be greater than one. Other cointegration tests, such as the one by Gregory, A. W. & Hansen, B. E. 1996. Residual-based tests for cointegration in models with regime shifts. *Journal of econometrics,* 70**,** 99-126., are restricted to only test for a single cointegrating term between two variables and, as such, are not suitable here.

4.2.3. Return and volatility spillovers

Spillover effects on returns between Capesize, Panamax and Supramax time-charter rates and their corresponding freight futures and freight options prices are investigated using the following VECM model:

$$\Delta S_t = q_s ect_{t-1} + \sum_{i=1}^{p} C_{s\_s}^{i} \Delta S_{t-i} + \sum_{i=1}^{p} C_{f\_s}^{i} \Delta F_{t-i} + \sum_{i=1}^{p} C_{o\_s}^{i} \Delta O_{t-i} + a_s R_{t-1} + \varepsilon_t^s \quad (2a)$$

$$\Delta F_t = q_f ect_{t-1} + \sum_{i=1}^{p} C_{s\_f}^{i} \Delta S_{t-i} + \sum_{i=1}^{p} C_{f\_f}^{i} \Delta F_{t-i} + \sum_{i=1}^{p} C_{o\_f}^{i} \Delta O_{t-i} + a_f R_{t-1} + \varepsilon_t^f \quad (2b)$$

$$\Delta O_t = q_o ect_{t-1} + \sum_{i=1}^{p} C_{s\_o}^{i} \Delta S_{t-i} + \sum_{i=1}^{p} C_{f\_o}^{i} \Delta F_{t-i} + \sum_{i=1}^{p} C_{o\_o}^{i} \Delta O_{t-i} + a_o R_{t-1} + \varepsilon_t^o \quad (2c)$$

$$e_t^j \mid \Omega_{t-1} \sim distr.(0, H_t)$$

where ΔS_t, ΔF_t and ΔO_t are logarithmic first-difference time-charter rates, freight futures, and freight options prices, respectively; ect_{t-1} is the lagged error-correction term, which represents the long-run relationship between the time-charter rates and their derivatives prices; e_t^j are stochastic error-terms with zero mean and time-varying covariance matrix H_t; and $C_{m\_n}^{i}$ (where, m = s, f, o and n = s, f, o with $m \neq n$) indicate short-run spillover relationships, R_{t-1} represents the one-period lagged ratio of trading volume over open interest of futures contracts, capturing the effect of freight futures' trading activities on time-charter rates, futures prices, and options prices if a_s, a_f and a_o, respectively, are statistically significant.[25]

If the coefficient $C_{m\_n}^{i}$ is non-zero and statistically significant, a unidirectional causal relationship exists from market *m* to market *n*, indicating that market *m* Granger causes market *n*. A bi-directional (feedback) effect in returns exists if two (or more) $C_{m\_n}^{i}$ terms in the system (with $m \neq n$) are statistically significant. Causality relationships are tested applying a standard Wald test on the joint significance of the lagged estimated coefficients of $C_{m\_n}^{i}$. A standard VECM model is estimated if cointegration is found using the Johansen (1988) test. If cointegration is not found using the Johansen (1998) test, then we test for the existence of a long-run relationship with one structural break using the Johansen *et al.* (2000)

[25] s, f and o represent time-charter rates, freight futures and freight options, respectively.

test and also estimate a VECM augmented with exogenous terms in order to capture the change in properties due to the structural break.[26]

If no cointegration is found, a Vector Autoregression (VAR) model is estimated, excluding the ect_{t-1} term from Equations (2a), (2b) and (2c). The order of the variables in the VAR models is based on the decreasing exogeneity of the variables. Since derivatives prices are derived from the underlying assets, the physical time-charter rates are considered first in the ordering of the VAR models. Then, given that freight options are priced with futures as the underlying assets, futures prices are economically more exogenous than options prices. Therefore, the used order here of the VAR models considers time-charter rates first, followed by freight futures prices, and then by freight options prices. However, robustness tests are conducted with five different VAR orders for the 3 endogenous variables and for 7 different maturities, totalling to 35 different VAR models for the Capesize vessels. The parameter results including coefficients, standard deviations and Wald tests, remain inline to the VAR models with the aforementioned order, and as such, different orders seem not to affect the ensuing results.

Furthermore, impulse response functions are estimated to provide a detailed insight into the spillover relationships in returns of the investigated variables, by measuring the reaction of one market (say, time-charter) to one standard deviation shock generated at any of the other two markets (say, freight futures and freight options). The VAR and -models are estimated as Seemingly Unrelated Regressions (SUR), where a Generalized Impulse Response (GIR) is applied to overcome the issues induced by the orthogonalisation of the shocks through Cholesky decomposition of the covariance matrix of Equation (1) (Kavussanos and Visvikis, 2004b).[27]

The conditional second moments (variance) of time-charter, freight futures and freight options prices are estimated using the following Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, as in Engle and Kroner (1995), generally known as Baba Engle Kraft and Kroner (BEKK) GARCH, to ensure a positive definite covariance matrix and to significantly decrease the number of parameters to be estimated:

[26] The change at the structural breakpoint arises because of a change in the trend or shift in regime, or both. This is captured by adding a dummy variable (0s before the structural break and 1s after the structural break) and some trend as exogenous variables.
[27] A SUR system is used to impose restrictions (i.e. providing 1 standard deviation shock) to 1 variable and understand how the other variables react to that shock in the different equations in the system.

$$H_t = A'A + C'\varepsilon_{t-1}\varepsilon'_{t-1}C + D'(\varepsilon_{t-1} < 0)(\varepsilon'_{t-1} < 0)D + B'H_{t-1}B \quad (3)$$

where *A*, *C*, *D* and *B* are (3x3) diagonal coefficient matrices, representing the constant, the lagged coefficient of the error-term, the lagged coefficient of the asymmetric error-term (only negative errors) and the lagged conditional volatility coefficient, respectively. A restricted BEKK-GARCH is the following:

$$h_{jj,t} = a_j + (c_{jj}\varepsilon^j_{t-1})^2 + (d_{jj}\varepsilon^j_{t-1}(\forall\ \varepsilon^j_{t-1} < 0))^2 + (b_{jj})^2 h_{jj,t-1}$$

(3a)

where $j = s, f, o$, with a conditional covariance equation:

$$h_{ij,t} = c_{ii}c_{jj}\varepsilon^i_{t-1}\varepsilon^j_{t-1} + d_{ii}d_{jj}\varepsilon^i_{t-1}(\forall\ \varepsilon^i_{t-1} < 0)\varepsilon^j_{t-1}(\forall\ \varepsilon^j_{t-1} < 0) + b_{ii}b_{jj}h_{ij,t-1} \quad (3b)$$

where $j = s, f, o$ and $i = s, f, o$ with $i \neq j$.

In the above model, as the number of estimated parameters increases the number of iterations in the process also increase, which can lead to non-convergence of the estimation process, and hence, failure in the parameter estimation. To overcome this issue, we estimate a restricted BEKK-GARCH model using a Quasi-Maximum Likelihood (QML) approximation. Moreover, other GARCH specifications could also be applicable, like the Dynamic Conditional Correlation (DCC)-GARCH, although they require a large sample of observations for the QML estimation to be maximised and for all parameters to be estimated.

In the finance literature, the choice between BEKK-GARCH and DCC-GARCH models is relevant when producing forecasts of volatility spillovers, where the former models are mainly used for forecasting conditional covariances, while the latter models are preferred when forecasting conditional correlations. Since this research does not involve the forecasting of spillovers, the choice of GARCH models is rather immaterial. However, as a robustness test, we have also estimated the models using DCC-GARCH with a sample of 2,164 usable observations (January 2008–August 2016), yielding similar results with the ones reported in the ensuing analysis using a sample of 849 usable observations (April 2013–August 2016). Such results are in line with Caporin and Mcaleer (2008), which state that BEKK-GARCH and DCC-GARCH models perform similarly for parameter estimations. For the latter sample, the DCC-GARCH model fails to converge in some of the investigated maturities, as the number of parameters to estimate is higher and usually requires larger samples with a higher number of iterations (Silvennoinen and Teräsvirta, 2009). Billio and

Caporin (2009) argue that a BEKK-GARCH structure is more capable of dealing with a high number of parameter estimations than a DCC-GARCH one. Caporin and Mcaleer (2012) argue that BEKK-GARCH models hold their asymptotic properties under untestable moment conditions, whereas the asymptotic properties of DCC-GARCH models may fail under a set of untestable regularity conditions (like seasonality). As such, BEKK-GARCH models are used in the ensuing analysis.

In Equation (3a), if c_{jj} coefficient is statistically significant, any shock (either positive or negative) to market j will increase the volatility of that market. A statistically significant d_{jj} coefficient indicates that the related market is more reactive to a negative shock than to a positive shock of the same magnitude, resulting in increasing volatility. In contrast, a statistically significant b_{jj} coefficient indicates the presence of volatility clustering; that is, a high volatile market is followed by a high volatile market in the future, and a low volatile market is followed by a low volatile market.

Equation (3b) tests for volatility spillovers between the markets. If the $b_{ii}b_{jj}$ coefficient is statistically significant (b_{ii} and b_{jj} are individually significant) there exists a volatility spillover between either of the markets (Zhang et al., 2009, Xiao and Dhesi, 2010). For example, if the $b_{ss}b_{ff}$ coefficient is significant, then there exist significant spillover effects between the time-charter and freight futures' markets. Similarly, if the $c_{ii}c_{jj}$ coefficient is statistically significant (c_{ii} and c_{jj} are individually significant) it indicates that any shock (positive or negative) generated in one market is transmitted to the other market. For example, if the $c_{ss}c_{ff}$ coefficient is statistically significant, a shock generated in the time-charter market leads to an increase in the volatility of the futures market, and vice versa. Finally, if the $d_{ii}d_{jj}$ coefficient is statistically significant (d_{ii} and d_{jj} are individually significant) it indicates that negative shocks generated within either market affect the volatility of the other market. Similar to the previous example, if the $d_{ss}d_{ff}$ coefficient is significant there exist volatility leverage effects between the time-charter market and the futures market.

4.2.4. Price liquidity interaction and liquidity

This study also investigates the impact of futures trading volume activities on time-charter, freight futures and freight options markets. Referring to Equations (2a), (2b) and (2c) R_{t-1}

denotes the lagged ratio of trading volume over open interest, representing the trading activity of the futures market. The lagged value of this ratio is used since trading activities and prices exhibit strong endogenous relationships, and hence, cannot be determined contemporaneously (Lamoureux and Lastrapes, 1994). An increase in the ratio denotes an increase in trading activities at a given amount of open interest, and thus an increase in market liquidity. If the lagged a_s, a_f or a_o coefficient of R_{t-1} is statistically significant and positive (negative) then the corresponding time-charter, freight futures or freight options prices, respectively, will increase (decrease).

To understand the interaction of time-charter, freight futures and options prices, it is important to investigate the liquidity of the derivatives contracts, since a liquid market is sensitive to new market information, adjusting prices faster than an illiquid market (Silber, 1991, Hasbrouck and Seppi, 2001). Alizadeh et al. (2015b) use the Amihud (2002) liquidity measure in the freight derivatives market to assess the existence of liquidity risk and report that liquidity risk is priced and, thus, liquidity has a significant role to play in FFA returns. However, the Amihud (2002) liquidity measure is found to be biased when the sample period includes days where trading volume is thin, while it cannot be defined on the days when the trading volume is zero (Chelley-Steeley et al., 2015). According to Chelley-Steeley et al. (2015), this occurs because the ratio takes the average of absolute returns over the trading volume. Thus, division by zero is not possible, trading days with zero trades are treated as missing values, distorting (inflating) the liquidity ratio. In our sample, there are some days with zero trading activity and, thus, the conventional Amihud (2002) liquidity measure cannot be used (as the denominator cannot be zero). Instead, we employ the Amivest liquidity measure to compare the liquidity of freight futures and options contracts. The Amivest measure was first employed by Cooper et al. (1985), following Amivest Corporation's monthly Liquidity Report published since 1972 (Foucault et al., 2013). The Amivest ratio reflects the liquidity index of an asset; that is, as the ratio increases the asset is more liquid.

The monthly Amivest measure $\text{Liq}_k^{i,j}$ for derivatives contract *i* (*i* takes the value f or *o* representing freight futures or freight options, respectively) for vessel type *j* (*j* takes the value *c*, *p* and *s* representing Capesize, Panamax or Supramax vessels, respectively) maturing in *k* periods ahead (*k* takes the value +1M, +2M, +1Q, +2Q, +3Q, +1C and +2C representing the respective maturity period of the derivatives contracts):

$$\mathrm{Liq}_k^{i,j} = \frac{1}{\eta \mathrm{D}_t}\sum_{\mathrm{d}=1}^{\mathrm{D}_t}\frac{\mathrm{Vol}_{k,d}^{i,j}}{|\mathrm{R}_{k,d}^{i,j}|} \quad (4)$$

where D_t is the number of trading days in the month *t*, η is the number of contract months for *k* periods maturities (more specifically, if *k* takes the value of +1M or +2M, η will be one; if *k* takes the value of +1Q or +2Q or +3Q, η will be three; if *k* takes the value of +1C or +2C, η will be twelve), $\mathrm{R}_{k,d}^{i,j}$ and $\mathrm{Vol}_{k,d}^{i,j}$ represent the daily returns and trading volume, respectively, for derivatives contract *i*, for vessel type *j*, maturing in period *k*, on day *d* (within month *t*). The average $\mathrm{Liq}_k^{i,j}$ is estimated for Capesize, Panamax and Supramax vessels at different contract maturities to assess the liquidity level of the freight futures and options contracts under investigation; that is, derivatives contracts with higher average value of $\mathrm{Liq}_k^{i,j}$ have higher market liquidity.

4.3. Empirical Research Results

4.3.1. Descriptive statistics, stationarity and cointegration

Table 4.1 presents preliminary descriptive statistics for Capesize logarithmic returns of six-month time-charter rates, as well as corresponding freight futures and freight options prices for different contract maturities.[28] Untabulated descriptive data statistics show that Capesize time-charter rates are more volatile than those for Panamax vessels, followed by Supramax vessels. This is consistent with the view that the larger the vessel, the less flexible it is regarding carrying a wider range of cargoes, trading in more routes and being able to approach more ports and terminals. Hence, when an oversupply of vessels and lack of sufficient cargos in the market lead to low freight rates, Capesize vessels are affected the most due to their low flexibility, inducing significant volatility in rates (Kavussanos, 1996). Moreover, Capesize futures and options prices are more volatile than for Panamax vessels, followed by Supramax vessels. In Table 4.1 it can be seen that the standard deviation of near-month maturity freight futures and options contracts is the highest before it starts to decrease as the distance to maturities increases, which is in line with the literature (Miller, 1979, Milonas, 1986).

[28] Panamax and Supramax vessels also exhibit similar results.

Table 4.2 reports unit root tests for Capesize time-charter rates, corresponding freight futures, and options, as well as the trading volume-to-open interest ratio for different freight futures maturities and vessel types. Conventional ADF (1981) and PP (1988) tests applied to log-levels, and log-first differences prices reveal that all prices are stationary in log-first difference and have unit root in log-levels. The only exception is for near-maturity freight options for all three vessel-types and the trading ratio since they are all stationary in log-levels (results for Panamax and Supramax vessels are similar). The KPSS (1992) test results are also in line with the above ADP and PP unit root results. Furthermore, unit root tests with one structural break (Perron and Vogelsang, 1992) offer similar results to those without a structural break. One-month forward freight options (as well as the liquidity trading ratio variables) are found stationary in levels with and without a structural break, except for Supramax options.

Johansen (1988) cointegration tests, reported in Table 4.3, show that freight futures and options contracts exhibit cointegration with time-charter rates for the Capesize vessels near-calendar year and second-calendar year. In unreported results for Panamax and Supramax vessels, second near-month and near-quarter freight futures and options contracts exhibit long-run relationships with their corresponding time-charter rates. The Schwartz Bayesian Information Criterion (SBIC), used to determine the lag length of the VAR models, indicates different lag length specifications for different maturities. The Johansen et al. (2000) test reveals that in the presence of one structural break, several more cointegrating relationships between time-charter rates, freight futures, and freight options exist; In particular, time-charter rates with: (i) second near-month maturity Capesize futures and options (for example, see the price series T/C – F_C2 – O_C2 in Table 4.3); (ii) second near-month, near-quarter, second near-quarter, third near-quarter, near calendar year and second near-calendar year maturity Panamax futures and options (not tabulated); and (iii) for all seven maturity Supramax futures and options (not tabulated). For Capesize and Panamax vessels, the structural breakpoint is located between September 2014 and February 2015, during which the associated sizes of orderbooks (the number of newbuilding vessels ordered at shipyards under construction and delivery) increased significantly, pushing the futures prices lower than the time-charter rates.[29] The breakpoint for Supramax vessels is observed during January 2015, which coincide with a significant drop in crude oil prices, resulting in increased tanker

[29] Typically, during a low market, such the one since 2009, market participants anticipate that the market will recover and, hence, futures prices are usually higher than the underlying time-charter rates (contango market), except during mid-2014 to beginning of 2015 for Capesize and Panamax vessels.

freight rates and, as a result, to a significant number of conversions of dry-bulk vessels under construction to tankers.

Table 4.1 Descriptive Statistics of Capesize Six-month Time-charter (T/C), Futures (F) and Options (O) Log-prices

	T	Mean	Std	Skew	Kurt	J-B	Q(12)	Q2(12)	ARCH(5)
T/C	849	0.000031	0.00828	1.177	11.760	73.030	580.988	317.530	192.418
						[0.001]	[0.000]	[0.000]	[0.000]
F_M1	849	0.000022	0.00954	0.375	10.164	26.555	25.609	21.848	11.861
						[0.001]	[0.0122]	[0.039]	[0.037]
O_M1	849	0.000087	0.02161	3.390	18.604	66.512	15.093	5.733	2.372
						[0.001]	[0.236]	[0.929]	[0.796]
F_M2	849	0.000024	0.00716	-0.116	13.240	19.724	20.498	2.339	1.585
						[0.001]	[0.058]	[0.999]	[0.903]
O_M2	849	0.000086	0.01102	2.051	12.779	38.382	9.506	6.595	4.763
						[0.001]	[0.659]	[0.883]	[0.445]
F_Q1	849	0.000000	0.00733	-1.010	59.944	16.778	9.857	0.294	0.145
						[0.002]	[0.629]	[0.100]	[1.000]
O_Q1	849	0.000027	0.01099	5.310	52.960	39.382	8.659	0.514	0.352
						[0.001]	[0.732]	[1.000]	[1.000]
F_Q2	849	-0.000165	0.00585	-5.949	97.043	4.879	4.308	0.363	0.144
						[0.081]	[0.977]	[1.000]	[1.000]
O_Q2	849	-0.000179	0.00766	-4.590	77.674	5.536	6.512	2.406	2.110
						[0.059]	[0.888]	[1.000]	[0.834]
F_Q3	849	-0.000062	0.00584	-2.870	81.256	3.844	11.564	0.405	0.222
						[0.134]	[0.481]	[1.000]	[1.000]
O_Q3	849	-0.000066	0.00821	-3.296	67.435	8.094	8.481	0.873	0.550
						[0.021]	[0.747]	[1.000]	[0.990]
F_C1	849	-0.000076	0.00239	1.601	22.310	48.480	33.746	2.471	1.856
						[0.001]	[0.001]	[0.998]	[0.869]
O_C1	849	-0.000104	0.00697	1.041	54.603	51.557	111.391	213.733	282.188
						[0.001]	[0.000]	[0.000]	[0.000]
F_C2	849	-0.000069	0.00170	2.323	35.343	55.012	28.541	2.392	1.959
						[0.001]	[0.005]	[0.999]	[0.855]
O_C2	849	-0.000145	0.00809	-0.047	69.256	124.127	141.883	209.641	330.775
						[0.001]	[0.000]	[0.000]	[0.000]

Notes: Data series are daily prices measured in logarithmic first-difference. *T* is the number of observations. Squared brackets [.] are significance levels. T/C is BFA time-charter average basket; F_M1 is near-month freight futures; O_M1 is near-month ATM freight options; F_M2 is second near-month freight futures; O_M2 is second near-month ATM freight options; F_Q1 is near-quarter freight futures; O_Q1 is near-quarter at-the-money freight options; F_Q2 is second near-quarter freight futures; O_Q2 is second near-quarter ATM freight options; F_Q3 is third near-quarter freight futures; O_Q3 is third near-quarter ATM freight options; F_C1 is near-calendar freight futures; O_C1 is near-calendar ATM freight options; F_C2 is second near-calendar freight futures; O_C2 is second near-calendar ATM freight options. Mean is the sample mean of the series. Std is the estimated standard deviation of the series. Skew and Kurt are the estimated centralised third (skewness) and fourth (kurtosis) moments of the data, respectively. J-B is the Jarque and Bera (1980) test for normality. Q(12) and Q2(12) is the Ljung and Box (1978) Q-statistic on the first 12-lags of the sample autocorrelation function of the raw price series and of the squared price series, respectively; the statistic is distributed as $\chi^2(12)$. ARCH(5) is the Engle (1982) test for ARCH effects; the statistic is distributed as $\chi^2(5)$.

Table 4.2 Unit Root Tests of Capesize Time-charter, Futures and Options Log-prices at Different Maturities

	ADF		PP		KPSS		Break	
	Level	**1st Diff**	**Level**	**1st Diff**	**Level**	**1st Diff**	**Level**	**1st Diff**
T/C	-2.912	-9.578	-2.597	-13.455	1.478	0.056	-4.319	-10.111
	(4)	(3)	(17)	(6)	(23)	(17)	(4)	(1)
							[20/11/2014]	
F_M1	-2.235	-25.194	-2.079	-24.965	1.559	0.078	-3.560	-26.156
	(1)	(0)	(1)	(7)	(23)	(4)	(1)	(0)
							[06/11/2014]	
O_M1	-3.726	0.000	-3.316	0.000	0.903	0.000	-4.546	0.000
	(0)	()	(13)	()	(23)	()	(0)	()
							[31/10/2014]	
F_M2	-1.874	-25.795	-1.795	-25.673	1.543	0.119	-3.292	-27.149
	(1)	(0)	(2)	(4)	(23)	(0)	(1)	(0)
							[28/10/2014]	
O_M2	-2.384	-27.689	-2.364	-27.653	0.876	0.084	-3.250	-28.276
	(0)	(0)	(6)	(10)	(23)	(9)	(0)	(0)
							[28/10/2014]	
F_Q1	-1.779	-27.051	-1.872	-27.004	1.683	0.087	-3.274	-29.738
	(0)	(0)	(2)	(6)	(23)	(4)	(0)	(0)
							[09/09/2014]	
O_Q1	-2.433	-28.872	-2.408	-28.881	0.964	0.063	-3.261	-31.776
	(0)	(0)	(7)	(10)	(23)	(10)	(0)	(0)
							[05/09/2014]	
F_Q2	-0.906	-28.368	-0.938	-28.360	2.363	0.115	-2.739	-32.468
	(0)	(0)	(2)	(4)	(23)	(4)	(0)	(0)
							[23/06/2014]	
O_Q2	-1.403	-29.184	-1.353	-29.205	1.944	0.098	-3.039	-33.359
	(0)	(0)	(2)	(5)	(23)	(5)	(0)	(0)
							[23/06/2015]	
F_Q3	-1.344	-27.547	-1.356	-27.550	2.153	0.112	-3.041	-3.049
	(0)	(0)	(3)	(1)	(23)	(1)	(0)	(0)
							[02/03/2015]	
O_Q3	-1.793	-28.836	-1.738	-28.835	2.037	0.076	-3.376	-31.725
	(0)	(0)	(4)	(2)	(23)	(2)	(0)	(0)
							[20/03/2015]	
F_C1	-0.328	-21.427	-0.378	-24.993	2.655	0.315	-2.847	-22.783
	(2)	(1)	(1)	(5)	(23)	(0)	(2)	(1)
							[09/09/2014]	
O_C1	-0.845	-21.606	-0.948	-40.053	2.595	0.128	-2.819	-27.200
	(2)	(2)	(5)	(0)	(23)	(10)	(2)	(1)
							[18/09/2015]	
F_C2	-0.462	-24.866	-0.337	-24.722	2.839	0.219	-2.819	-25.429
	(1)	(0)	(3)	(3)	(23)	(3)	(2)	(0)
							[09/09/2014]	
O_C2	-0.221	-20.701	-0.740	-42.320	2.693	0.154	-3.370	-22.552
	(4)	(3)	(6)	(2)	(23)	(11)	(4)	(3)
							[24/09/2015]	
R1_f1	-7.454		-19.540				-7.926	
	(6)		(19)				(6)	
R1_f2	-6.400		-6.400				-7.467	
	(4)		(4)				(4)	
R1_f3	-5.994		-20.235				-7.155	
	(4)		(20)				(4)	
R1_f4	-2.998		-22.258				-7.339	
	(14)		(18)				(5)	
R1_f5	-6.896		-25.305				-11.829	
	(5)		(18)				(3)	
R1_f7	-6.785		-24.352				-10.195	
	(5)		(18)				(3)	
R1_f8	-8.480		-24.544				-23.857	
	(4)		(14)				(0)	

Notes: See Table 4.1 for the notation of the variables. Parentheses (.) are the number of lags, while squared brackets [.] are the breakpoint dates. R_M1 is the ratio of daily trading volume over open interest for near-month futures contracts; R_M2 is the ratio for second near-month futures contracts; R_Q1 is the ratio for near-quarter futures contracts; R_Q2 is the ratio for second near-quarter futures contracts; R_Q3 is the ratio for third near-quarter futures contracts; R_C1 is the ratio for near-calendar futures contracts; and R_C2 is the ratio for second near-calendar futures contracts.

Table 4.3 Cointegration Tests for Capesize Vessels

	Lags	Johansen				Johansen with structural break			
		max		trance		max		trance	
		H_o	H_1	H_o	H_1	H_o	H_1	H_o	H_1
		r = 0	r = 1	r = 0	r = 1	r = 0	r = 1	r = 0	r = 1
		r <= 1	r = 2	r <= 1	r = 2	r <= 1	r = 2	r <= 1	r = 2
		r <=2	r = 3	r <=2	r = 3	r <=2	r = 3	r <=2	r = 3
						Break-point			
T/C — F_M1 - O_M1		–	–	–	–				
T/C —F_M2 — O_M2	2	21.782	21.131	39.818	29.797				
		14.515	14.264	18.036	15.494				
		3.521	3.841	3.521	3.841				
T/C — F_Q1 — O_Q1	2	16.816	21.131	33.771	29.797				
		13.29	14.264	16.954	15.494				
		3.663	3.841	3.663	3.8414				
T/C — F_Q2 — O_Q2	2	11.182	21.131	20.099	29.797				
		8.250	14.264	8.917	15.497				
		0.667	3.841	0.667	3.841				
T/C — F_Q3 — O_Q3	2	15.214	21.131	26.535	29.797				
		11.099	14.264	11.320	15.494				
		0.221	3.841	0.221	3.841				
T/C — F_C1 — O_C1	2	27.652	21.131	36.484	29.797				
		8.801	14.264	8.832	15.494				
		0.031	3.841	0.031	3.8414				
T/C — F_C2 — O_C2	2	15.394	21.131	27.358	29.79&	56.688	43.460	69.178	59.090
		11.868	14.264	11.964	15.494	11.414	26.440	12.490	37.420
		0.096	3.841	0.096	3.841	1.076	12.850	1.076	18.900

Notes: Lags is the lag length of the Vector Autoregressive (VAR) models used for the cointegration test without a structural break (Johansen, 1988), and for the cointegration test with a structural break on the constant and slope (Johansen et al., 2000). The lag length is determined by minimising the SBIC (1978). *r* represents the number of cointegrating vectors. λ_i, is the λmax and λtrace cointegration tests of the estimated eigenvalues of the Π matrix in Equation (1). Critical values for the λmax and λtrace statistics for cointegration without a structural break and cointegration with a structural break are calculated and provided under alternate hypothesis.

Overall, distant-maturity contracts, for all three types of vessels exhibit cointegrating relationships with their corresponding time-charter rates. The coefficient of the error-correction terms is significant and negative, indicating that the documented cointegrating relationship among the investigated markets acts as a buffer to any external shocks keeping them together in a long-run equilibrium relationship.[30] This may be the result of the supply of newbuilding vessels matching cargo requirements, as shipyards typically take some time to deliver a vessel.[31] As the size of the orderbook helps in anticipating freight rates, the time period between the order and delivery of newbuilding vessels is matched by the distant-maturity derivatives contracts. Furthermore, near-maturity derivatives contracts also appear to exhibit long-run relationships with time-charter rates for all three types of vessels, with the error-correction terms being significant and negative, similar to the case of distant-maturity contracts.[32] This may be due to the liquidity of the freight futures contracts, as it is significantly higher for near-maturity contracts (explained in the later part of the study), resulting in a strong adjustment of near-maturity derivatives prices to the time-charter prices.

4.3.2. Spillover effect on returns and volatilities

Tables 4.4 and 4.5 present the spillover effects results of returns and volatilities between time-charter rates and corresponding freight futures and options prices, for the three-major dry-bulk vessels under different contract maturities. VECM models are used when cointegration is detected and VAR models when it is not. Panel A presents the interaction between the returns of the underlying time-charter market and the two derivatives markets, along with the trading activity of futures markets. In the system of equations, some variables are found to be weakly statistically significant jointly, although individually fail to explain the dependent variable. Wald tests are conducted to understand whether individual markets (say, the freight options market) are sufficient to explain the dependent market (say, the physical time-charter market) or just have an explanatory power only in the presence of stronger markets (say, the freight futures markets). Panel B shows the interactions of volatilities between the time-charter rates, freight futures and options prices. The empirical findings are as follows.

4.3.2.1. Spillover effects under cointegrating relationships

Table 4.4 presents sixteen models where cointegrating relationships are found between time-charter rates, freight futures and freight options prices for different vessels. These are: (i)

[30] Near-calendar and second near-calendar contracts for Capesize (C_C1 and C_C2), Panamax (P_C1 and P_C2) and Supramax (S_C1 and S_C2) vessels.
[31] Delivery time and availability of slots vary from one shipyard to another. If there is relatively no waiting time delivery typically takes from 12 to 24 months.
[32] Second near-month and near-quarter contracts for Panamax (P_M2 and P_Q1), from near-month to near-quarter contracts for Supramax (S_M1, S_M2 and S_Q1) and second near-month contracts for Capesize (C_M2), except near-quarter contracts for Capesize (C_Q1).

nearby maturity contracts (near-month Supramax (S_M1), second near-month Capesize (C_M2), Panamax (P_M2) and Supramax (S_M2)); (ii) *medium maturity contracts* (near-quarter and second near-quarter Panamax (P_Q1 and P_Q2) and Supramax (S_Q1 and S_Q2) and third near-quarter Supramax (S_Q3); and (iii) *distant maturity contracts* (near-calendar and second near-calendar Capesize (C_C1 and C_C2) and Panamax (P_C1 and P_C2) and Supramax (S_C1 and S_C2)). In Panel A, the lagged error-correction terms ect1 and ect2 (ect2 is presented only in the case where two cointegrating vectors are established) are significant in all cases with at least one cointegrating vector in the regression model being significant. Most of the ect coefficients (speed of adjustment) are negative, indicating that variables that divert from the cointegrating relationship increase in value to restore the long-run equilibrium relationship.

Firstly, according to the short-run dynamics of the models, lagged time-charter rates significantly explain most of the futures prices (apart from the second near-quarter (S_Q2) Supramax regression), while all lagged futures prices significantly explain time-charter rates, apart from one regression (near-quarter (S_Q1) Supramax). This indicates that there is a bi-directional spillover effect in returns between the time-charter market and the futures market, but according to a Wald (joint significance) test, this effect runs stronger from the futures (derivatives) market towards the time-charter (underlying) freight market.

Secondly, in terms of the interaction between freight futures and freight options returns, lagged options prices significantly explain futures prices only in eight out of sixteen models (second near-month (P_M2) and second near-quarter (P_Q2) Panamax, and near-month (S_M1), second near-month (S_M2), second near-quarter (S_Q2), third near-quarter (S_Q3), near-calendar (S_C1) and second near-calendar (S_C2) Supramax), while lagged futures prices significantly explain freight options prices in all sixteen models. Also, the joint impact (according to a Wald test) of freight futures returns on freight options returns is stronger than the reverse, indicating that the freight futures market is informationally leading the freight options market.

Thirdly, results on the interaction between lagged time-charter rates and lagged freight options prices indicate that time-charter returns significantly explain freight options returns for all models apart from four regressions (second near-month (P_M2) Panamax, and near-month (S_M1) near-quarter (S_Q1) and second near-calendar (S_C2) Supramax). In contrast, lagged freight options returns can explain time-charter rates only in seven (out of sixteen) models (near-calendar (C_C1) Capesize, near-quarter (P_Q1), second near-quarter (P_Q2), third near-quarter (P_Q3), near-calendar (P_C1) and second near-calendar (P_C2) Panamax and near-quarter (S_Q1) Supramax). This rather unexpected result indicates that the time-charter (underlying) market is informationally leading the freight options (derivatives) market, which is inconsistent with conventional wisdom and expectations. Overall, results from Wald joint tests suggest that information in returns is transmitted first from the freight futures market to the time-charter market, and then is spilt over to the freight options market.

Panel B of Table 4.4 presents the parameter estimates of the conditional variance models. The b_{jj} coefficient is significant in all regressions indicating a strong volatility spillover between time-charter rates and the corresponding freight futures and freight options prices for all three vessel types. Also, the c_{jj} coefficient is significant in all models (except for near-month (S_M1) Supramax), indicating that a shock (either positive or negative) can be transmitted, say, from the futures market to the time-charter or options market, leading to an increase in the latter market's volatility. Furthermore, the leverage effect d_{jj} coefficient for time-charter rates is statistically significant in eleven (out of sixteen) models (apart from near-calendar (C_C1) Capesize, second near-quarter (P_Q2) Panamax, second near-month (S_M2), near-quarter (S_Q1) and second near-calendar (S_C2) Supramax), indicating that a negative shock generated in the time-charter market does not necessarily result in increasing volatilities in other markets, as compared to a positive shock of the same magnitude. In contrast, the leverage volatility effect is more prevalent in the derivatives markets, as it is observed in all sixteen models. This could be a result of the increased flexibility of derivatives contracts over physical trades, as discussed earlier. Accordingly, open positions in freight derivatives markets can be closed almost immediately upon the arrival of bad news, resulting in an increase in market volatility.

4.3.2.2. Spillover effects under non-cointegrating relationships

Table 4.5 presents five models where cointegrating relationships (with or without structural breaks) are not found between time-charter rates, freight futures and options prices for different vessel types. These are: (i) *nearby maturity contracts* (near-month Capesize (C_M1) and Panamax (P_M1)); and (ii) *medium maturity contracts* (near-quarter (C_Q1), second near-quarter C_Q2) and third near-quarter (C_Q3) Capesize).

In Panel A, the coefficients of the lagged returns indicate the presence of significant short-run relationships between time-charter rates, freight futures and options prices. Firstly, lagged freight futures prices significantly explain time-charter rates in four (out of five) models (C_M1, C_Q1, C_Q3 and P_M1), and also in four models (C_Q1, C_Q2, C_Q3 and P_M1) the lagged time-charter rates can significantly explain futures prices. These results indicate a bi-directional spillover effect between the freight futures and the time-charter markets, but with stronger information flow from the futures (derivatives) market to the time-charter (underlying) market using a Wald test, which is in accordance with both theory and expectations.

Secondly, results on the interactions between freight futures and freight options prices indicate that freight futures returns significantly explain options returns in four (out of five) models (C_M1, C_Q1, C_Q3, and P_M1), while freight options returns can explain futures returns in four models (C_M1, C_Q1, C_Q3, and P_M1). Also, based on the magnitude of the joint significance of the lagged variables (Wald test), the results point to stronger spillover effects from the freight futures market to the freight options market. Thirdly, it can be seen that time-charter rates can significantly explain freight returns can explain time-charter rates in only three cases (C_M1, C_Q3 and P_M1). These results confirm the presence of a bi-directional flow of information between time-charter returns and freight options returns. Wald joint tests indicate that new market information is first reflected in the futures market before it is spilt into the time-charter market, and finally appears in the options market.

Panel B of Table 4.5 presents the parameter estimates of the conditional variance models. It is observed that the b_{jj} coefficient is significant in all models, indicating an existence of volatility spillovers between time-charter, freight futures and options markets. The c_{jj} coefficient is statistically significant in all models (except in C_Q2 and C_Q3), indicating that a shock (either positive or negative) can be transmitted between the three markets, similarly to the results in the previous section for cointegrating models. Finally, the leverage volatility effect, according to the d_{jj} coefficient, is observed in four models for the derivatives markets (C_M1, C_Q1, C_Q2 and P_M1), but only in three models for the time-charter market (C_M1, C_Q1 and P_M1).

Table 4.4 Maximum-likelihood Estimates of Restricted BEKK VECM-GARCH Models

	C_M2	C_C1	C_C2	P_M2	P_Q1	P_Q2	P_Q3	P_C1
	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)
	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)
	(Options)	(Options)	(Options)	(Options)	(Options)	(Options)	(Options)	(Options)
Panel A: Conditional mean parameters								
ect1	-0.022[a]	-0.005[b]	-0.004[a]	-0.0003	-0.001[b]	-0.004[a]	-0.003[a]	-0.003[a]
	-0.017[a]	0.004 [a]	0.000	0.000	-0.002	-0.006[a]	0.008[a]	0.001
	-0.019[a]	0.010[a]	0.001[a]	-0.020[a]	-0.012[a]	-0.019[a]	0.002	0.000
ect2	0.031[a]	—	—	—	—	—	—	-0.002
	0.036[a]	—	—	—	—	—	—	-0.038[a]
	0.078[a]	—	—	—	—	—	—	0.032[a]
T/C (lag 1)	0.555[a]	0.551[a]	0.602[a]	0.871[a]	0.872[a]	1.012[a]	1.104[a]	1.008[a]
	-0.095[a]	-0.121[a]	-0.044[a]	0.081[a]	0.070[c]	0.269[a]	0.173[a]	0.103[b]
	-0.098[a]	-0.180[a]	-0.035[a]	0.039	-0.101[a]	0.278[a]	0.192[a]	0.136[c]
Futures (lag 1)	0.311[a]	0.808[a]	1.164[a]	0.074[a]	0.037[a]	-0.004	-0.008	0.129[a]
	0.205[b]	0.278[a]	0.393[a]	0.386[a]	0.215[a]	-0.227[a]	0.207[a]	0.303[a]
	0.290[a]	0.451[a]	0.650[a]	0.522[a]	0.091[b]	-0.281[a]	0.302[a]	0.379[a]
Options (lag 1)	-0.036	0.104[a]	0.040	-0.0001	0.018[a]	0.036[a]	0.052[a]	0.018[b]
	-0.072	-0.021	0.004	-0.094[a]	-0.031	0.055[a]	0.014	-0.019
	-0.135[c]	-0.078	-0.120[a]	-0.172[a]	0.057[c]	0.011	0.093[a]	-0.049
T/C (lag 2)	—	—	—	—	—	-0.167[a]	-0.239[a]	-0.175[a]
	—	—	—	—	—	-0.519[a]	-0.234[a]	-0.193[a]
	—	—	—	—	—	-0.574[a]	-0.193[a]	-0.229[a]
Futures (lag 2)	—	—	—	—	—	0.020	0.012	0.012
	—	—	—	—	—	-0.192[a]	0.069[b]	-0.132[a]
	—	—	—	—	—	-0.135[a]	0.096[a]	-0.382[a]
Options (lag 2)	—	—	—	—	—	0.006	0.013	0.005
	—	—	—	—	—	0.002	-0.025	-0.008
	—	—	—	—	—	-0.091[c]	-0.015	0.241[a]
Ratio (lag 1)	0.004[a]	0.001	0.0007	0.0002	0.0002	0.000	-0.0001	0.0004
	0.003[a]	-0.0001	0.0005[c]	-0.0006	0.001[c]	0.000	-0.001[a]	0.0001
	0.006[a]	0.0004	0.0009[a]	0.000	0.001[a]	0.003[a]	-0.0003	0.0002
Wald Test								
Futures → T/C	34.95[a]	95.61[a]	85.02[a]	49.39[a]	31.66[a]	0.90	0.64	29.80[a]
Options → T/C	0.76	3.97[b]	2.11	0.04	15.94[a]	9.29[b]	16.72[a]	10.82[a]
Joint → T/C	101.53[a]	120.37[a]	98.41[a]	101.06[a]	100.14[a]	30.49[a]	51.23[a]	59.94[a]
T/C → Futures	9.33[a]	24.67[a]	12.71[a]	0.64	0.23	14.11[a]	10.37[a]	10.59[a]
Options → Futures	1.59	0.25	0.2	0.94	0.37	0.65	0.33	2.68
Joint → Futures	10.57[a]	24.84[a]	12.93[a]	1.43	0.61	15.04[a]	10.5[b]	13.14[b]
T/C → Options	8.64[a]	11.79[a]	3.76[b]	3.15[c]	0.37	7.31[a]	3.69	0.02
Futures → Options	10.84[a]	112.07[a]	28.27[a]	9.86[a]	18.74[a]	20.03[a]	43.54[a]	101.73[a]
Joint → Options	16.65[a]	113.78[a]	28.99[a]	11[a]	18.74[a]	31.83[a]	54.76[a]	116.48[a]
Panel B: Conditional variance parameters								
a_{jj}	6.33e-05[a]	0.000277[a]	0.000208[a]	1.8e-05[a]	3.2e-05[a]	4.44e-05[a]	2.24e-05[a]	4.81e-05[a]
	2.33e-05[a]	3.02E-07	8.17e-06[a]	2.2e-05[a]	0.000208[a]	9.95e-06[a]	0.000196[a]	3.77e-06[a]
	-2.88e-05[a]	-7.34e-06[a]	3.54E-07	-2.23E-05	0.000466[a]	1.91e-05[a]	0.000282[a]	7.97e-06[a]
c_{jj}	0.202[a]	0.455[a]	0.324[a]	0.631[a]	0.549[a]	0.666[a]	0.479[a]	0.681[a]
	0.077[a]	0.270[a]	0.322[a]	0.106[a]	0.666[a]	0.575[a]	1.296[a]	0.479[a]
	0.050[b]	0.293[a]	0.378[a]	0.056[c]	1.497[a]	0.539[a]	1.372[a]	0.573[a]
d_{jj}	0.156[a]	-0.063	0.231[a]	0.151[c]	-0.261[a]	0.119	0.191[b]	-0.455[a]
	0.198[a]	-0.111[a]	0.616[a]	0.380[a]	0.850[a]	-0.414[a]	-1.221[a]	0.304[a]
	0.194[a]	0.342[a]	0.693[a]	0.897[a]	2.051[a]	-0.781[a]	-1.590[a]	0.610[a]
b_{jj}	0.960[a]	0.837[a]	0.897[a]	0.695[a]	0.648[a]	0.436[a]	0.760[a]	-0.271[a]
	0.985[a]	0.964[a]	0.899[a]	0.954[a]	0.651[a]	0.857[a]	0.148[a]	0.899[a]
	0.994[a]	0.957[a]	0.904[a]	0.904[a]	0.224[a]	0.839[a]	0.0821[b]	0.861[a]

Notes: [a] Significance at the 1% significance level.
[b] Significance at the 5% significance level.
[c] Significance at the 10% significance level.

Table 4.4 Maximum-likelihood Estimates of Restricted BEKK VECM-GARCH Models (cont.)

	P_C2	S_M1	S_M2	S_Q1	S_Q2	S_Q3	S_C1	S_C2
	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)
	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)
	(Options)	(Options)	(Options)	(Options)	(Options)	(Options)	(Options)	(Options)
Panel A: Conditional mean parameters								
ect1	-0.001[c]	-0.010[a]	-0.016[a]	-0.010[a]	0.0004[b]	0.001	0.001[a]	-0.004[a]
	0.001	-0.0004	-0.012[b]	0.002	0.002[a]	0.009[a]	0.001[b]	-0.0008
	0.003[b]	-0.016[b]	-0.012[a]	0.001	0.008[a]	0.018[a]	0.003[a]	0.000
ect2	—	0.008[c]	0.014[a]	-0.003	—	—	—	—
	—	-0.005	-0.003	-0.010	—	—	—	—
	—	0.164[a]	0.191[a]	0.167[a]	—	—	—	—
T/C (lag 1)	1.070[a]	0.834[a]	0.676[a]	0.860[a]	0.888[a]	0.880[a]	0.857[a]	0.878[a]
	0.122[a]	0.858[a]	0.321[a]	0.311[a]	0.028	0.370[a]	0.104[c]	0.134[b]
	0.302[a]	0.218	0.286[a]	0.003	0.114[c]	0.332[a]	-0.475[a]	0.046
Futures (lag 1)	0.195[a]	0.023[c]	-0.023[b]	-0.008	0.018[b]	0.023	0.098[a]	-0.064[a]
	0.304[a]	0.276[a]	0.421[a]	0.404[a]	0.078[c]	0.086[b]	0.401[a]	0.248[a]
	0.759[a]	0.451[a]	0.439[a]	0.439[a]	0.006	0.360[a]	0.579[a]	0.548[a]
Options (lag 1)	0.015[a]	-0.002	-0.003	-0.008[a]	-0.014[c]	-0.018[c]	-0.007	-0.005
	0.008	-0.017[c]	-0.061[a]	-0.018	0.030[b]	-0.022	0.002	-0.009
	-0.137[a]	-0.025	-0.069[c]	-0.043	0.072[b]	-0.207[a]	-0.073	-0.092[b]
T/C (lag 2)	-0.223[a]	0.0580	0.250[a]	0.152[a]	-0.002	0.0231	-0.004	0.139[a]
	-0.136[a]	-0.561[a]	-0.327[a]	-0.330[a]	0.032	-0.081	-0.158[a]	-0.119[b]
	-0.287[a]	-0.051	-0.363[a]	-0.389[b]	-0.327[a]	-0.162	0.0134	0.0176
Futures (lag 2)	-0.026	-0.007	-0.027[a]	-0.006	-0.021[a]	-0.015	-0.008	-0.102[a]
	-0.115[a]	-0.065	-0.006	0.009	-0.251[a]	-0.049	-0.081[b]	-0.049
	-0.377[a]	-0.118[b]	-0.090	-0.024	-0.081[b]	-0.060	-0.016	-0.306[a]
Options (lag 2)	0.004	-0.001	-0.001	-0.006	-0.014[c]	-0.006	-0.003	-0.007[c]
	-0.0004	-0.009	-0.029	-0.028	-0.030[c]	-0.0478[a]	-0.011[a]	-0.019[a]
	0.104[a]	-0.001	-0.044	-0.048	-0.220[a]	-0.118[c]	0.0125	0.0073
Ratio (lag 1)	0.0001	0.0001	0.0003[a]	-0.0003[b]	-0.0001	-0.0001	-0.0002[b]	0.0001
	0.0002	-0.0004	-0.001	-0.0003	-0.002[a]	0.002[a]	-0.0001	0.000
	0.0005	-0.002[a]	0.001	0.000	-0.0002	0.002[a]	-0.0001	0.001[a]
Wald Test								
Futures → T/C	39.10[a]	1.04	9.15[a]	6.46[b]	1.03	4.68[c]	3.25	2.49
Options → T/C	5.01[c]	0.46	0.18	0.71	0.95	1.76	0.37	2.61
Joint → T/C	52.81[a]	1.30	10.55[b]	8.78[c]	2.25	6.86	3.88	5.84
T/C → Futures	12.85[a]	18.44[a]	10.87[a]	15.35[a]	2.52	5.78[c]	3.28	0.42
Options → Futures	3.45[a]	2.55	1.36	3.12	1.28	0.47	2.62	5.6[c]
Joint → Futures	15.69[a]	21.43[a]	12.48[b]	17.23[a]	3.82	6.25	5.71	6.25
T/C → Options	7.22[a]	0.96	1.03	4.94[c]	0.08	0.63	3.79	1.12
Futures → Options	16.83[a]	0.92	4.72[c]	12.62[a]	12.22[a]	46.68[a]	49.35[a]	26.55[a]
Joint → Options	32.36[a]	2.49	6.14	18.79[a]	12.52[b]	47.65[a]	49.58[a]	26.94[a]
Panel B: Conditional variance parameters								
a_{jj}	4.1e-05[a]	3.52e-05[b]	1.8e-05[a]	4.9e-06[a]	1.3e-06[a]	1.63e-06[a]	1.61e-06[a]	6.53e-06[a]
	2.79e-06[a]	2.78e-05[a]	0.000167[a]	0.000335[a]	8.43e-06[a]	9.05e-06[a]	4.69e-06[a]	9.3e-07[a]
	2.14E-06	0.000294[a]	6.95e-05[a]	9.13e-05[a]	-2.48E-06	-2.51E-06	1.05E-06	-1.15E-06
c_{jj}	0.672[a]	0.1727	1.038[a]	0.769[a]	0.167[a]	-0.426[a]	0.251[a]	0.751[a]
	-0.137[a]	0.0222	0.180[a]	0.172[b]	0.860[a]	0.048	0.390[a]	0.235[a]
	-0.381[a]	0.0114	0.056	0.090[a]	1.121[a]	0.212[a]	0.692[a]	0.514[a]
d_{jj}	0.354[a]	-0.202[b]	0.065	0.0588	-0.708[a]	-0.583[a]	0.678[a]	0.024
	0.257[a]	-0.257[a]	0.791[a]	-0.371[b]	0.127	-0.727[a]	-0.094[c]	-0.248[a]
	0.607[a]	-2.25[a]	1.181[a]	-1.25[a]	0.438[a]	-0.749[a]	-0.543[a]	-0.454[a]
b_{jj}	0.410[a]	0.418	0.094	0.733[a]	0.907[a]	0.882[a]	0.892[a]	0.721[a]
	0.966[a]	0.963[a]	0.728[a]	0.554[a]	0.839[a]	0.897[a]	0.918[a]	0.965[a]
	0.906[a]	0.604[a]	0.804[a]	0.760[a]	0.762[a]	0.902[a]	0.847[a]	0.911[a]

Table 4.5 Maximum-likelihood estimates of Restricted BEKK VAR-GARCH Models

	C_M1	C_Q1	C_Q2	C_Q3	P_M1
	(T/C)	(T/C)	(T/C)	(T/C)	(T/C)
	(Futures)	(Futures)	(Futures)	(Futures)	(Futures)
	(Options)	(Options)	(Options)	(Options)	(Options)
Panel A: Conditional mean parameters					
T/C (lag 1)	0.539[a]	0.574[a]	0.660[a]	0.634[a]	0.867[a]
	-0.007	-0.132[a]	-0.133[a]	-0.049[a]	0.133[a]
	-0.064[a]	-0.178[a]	-0.125[a]	-0.064[a]	0.134[a]
Futures (lag 1)	0.362[a]	0.207[a]	0.051	0.242[a]	0.052[a]
	0.421[a]	0.340[a]	-0.087	0.057[a]	0.211[a]
	0.618[a]	0.443[a]	0.068	0.068[a]	0.675[a]
Options (lag 1)	-0.053[a]	-0.008	0.082	0.145[a]	-0.004[b]
	-0.141[a]	-0.239[a]	0.111	0.038[a]	-0.080[a]
	-0.249[a]	-0.316[a]	-0.033	0.051[a]	-0.351[a]
Ratio (lag 1)	0.001	0.0026[a]	0.0009	0.0014	-0.0001
	-0.002[a]	0.0055[a]	0.0103[a]	0.0036[a]	-0.003[a]
	0.001[c]	0.0063[a]	0.0104[a]	0.0057[a]	-0.003[a]
Wald Test					
Futures → T/C	88.04[a]	18.83[a]	2.11	37.59[a]	65.71[a]
Options → T/C	2.47	1.93	1.18	44.04[a]	1.75
Joint → T/C	144[a]	70.15[a]	33.00[a]	70.3[a]	86.2[a]
T/C → Futures	8.92[a]	3.02[c]	8.79[a]	6.58[a]	0.01
Options → Futures	4.67[a]	0.03	0.13	0.54	4.78[b]
Joint → Futures	12.93[a]	3.04	9.07[b]	6.85[b]	4.92[c]
T/C → Options	4.48[b]	4.35[b]	13.34[a]	10.72[a]	3.57[c]
Futures → Options	15.89[a]	20.41[a]	12.74[a]	5.36[b]	9.16[a]
Joint → Options	16.87[a]	22.31[a]	23.62[a]	16.12[a]	10.42[a]
Panel B: Conditional variance parameters					
a_{jj}	7.68e-05[a]	0.0003[a]	0.001[a]	0.0004[a]	1.33e-05[a]
	1.61E-05	2.27e-05[a]	-1.67e-06[a]	1.98e-07[c]	8.09e-05[a]
	-0.0001[a]	4.14e-05[c]	2.33e-06[a]	2.00E-07	8.23e-05[a]
c_{jj}	0.160[a]	0.303[a]	0.836[a]	0.579[a]	0.573[a]
	0.333[a]	0.718[a]	-0.007	2.40E-05	0.283[a]
	0.157[a]	1.171[a]	-0.006	0.001	0.212[a]
d_{jj}	0.255[a]	0.193[a]	0.006	2.07E-06	0.198[b]
	0.712[a]	1.181[a]	0.037[a]	1.14E-08	0.897[a]
	1.427[a]	0.733[a]	0.066[a]	4.60E-08	3.569[a]
b_{jj}	0.956[a]	0.887[a]	0.360[a]	0.750[a]	0.763[a]
	0.895[a]	0.757[a]	1.001[a]	1.001[a]	0.873[a]
	0.850[a]	0.692[a]	1.000[a]	1.001[a]	0.744[a]

Notes: The significance levels of the coefficient parameters are denoted in **Table 4.4**.

4.3.3. Impulse response analysis

Generalized Impulse Responses (GIR) functions of a SUR-VAR (when a cointegrating relationship is not established) and of a SUR-VECM (when a cointegrating relationship is established) are next estimated to provide insights into the dynamics of the causality effects between the three investigated markets. Impulse responses measure the reaction of one market (e.g. time-charter) by inducing one standard deviation shock to the prices of the other market (e.g. freight futures or options).

Figure 3.1 depicts the impact of a shock on the Capesize market. The upper graphs illustrate the response of time-charter rates (CTC),[33] those in the middle the response of freight futures prices (CTF), while the lower graphs show the response of freight option prices (CTO) triggered due to a one standard deviation shock in each respective market. We observe the market response for a 10 day-ahead horizon. The results indicate that Capesize time-charter rates are strongly affected by the shock generated in freight futures and freight options prices irrespective of maturity, with the shock in freight futures having a greater impact. Results corroborate the same pattern for Panamax rates. Moreover, Capesize and Panamax futures (options) prices are affected by a corresponding shock generated in time-charter rates and options (futures) prices, irrespective of maturity. However, it appears that the impact of the shock diminishes faster in the freight futures market than in the time-charter market, indicating that the freight futures market can adapt to shocks more rapidly than the underlying freight market. Supramax time-charter rates marginally react to a shock generated in futures prices and do not affect options' prices at all. This may be due to the low liquidity of Supramax freight futures contracts and the negligible liquidity of Supramax freight options. Overall, for all three types of vessels examined, the futures market has stronger effects in the other two markets (time-charter and freight options) than the time-charter market, while the freight options market has the least significant impact. These results indicate that market participants should still rely on freight futures prices to gain a view of the underlying freight market but cannot use freight options markets for price discovery purposes. Therefore, practitioners who collect and analyse new market information on a daily

[33] For example, the upper graphs represent the impact of Capesize time-charter rates (CTC) to a one standard-deviation shock on near-month futures (CTF_1M), near-month options (CTO_1M), second near-month futures (CTF_2M), second near-month options (CTO_2M), near-quarter futures (CTF_1Q), near-quarter options (CTO_1Q), second near-quarter futures (CTF_2Q), second near-quarter options (CTO_2Q), third near-quarter futures (CTF_3Q), third near-month options (CTO_3Q), near-calendar futures (CTF_1C), near-calendar options (CTO_1C), second near-calendar futures (CTF_2C) and second near-calendar options (CTO_2C).

basis should investigate freight futures markets first, as any new information is revealed there before it is spilt over to the physical time-charter market, and finally to the freight options market.

Figure 4.1 Impulse Responses for Capesize Markets

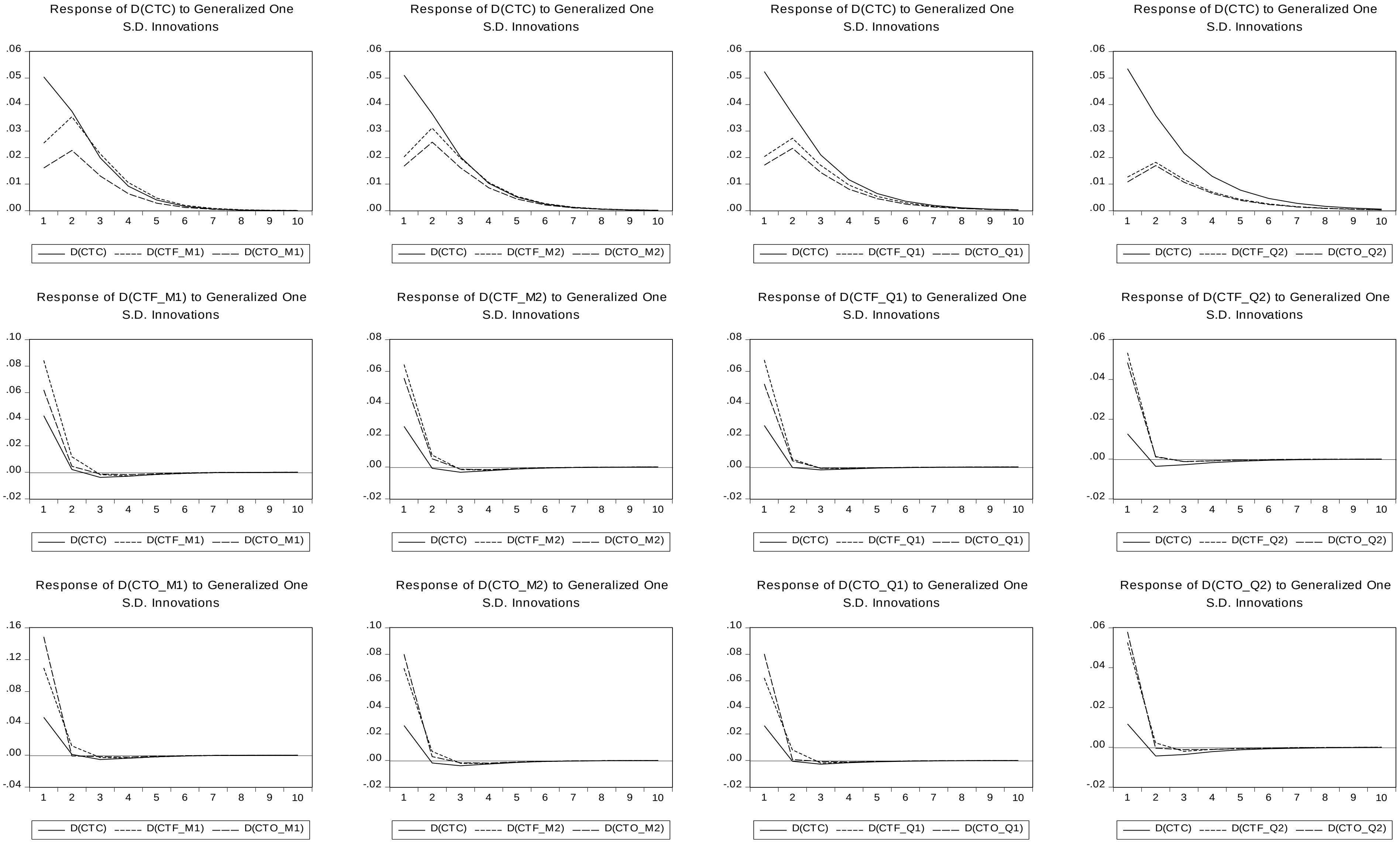
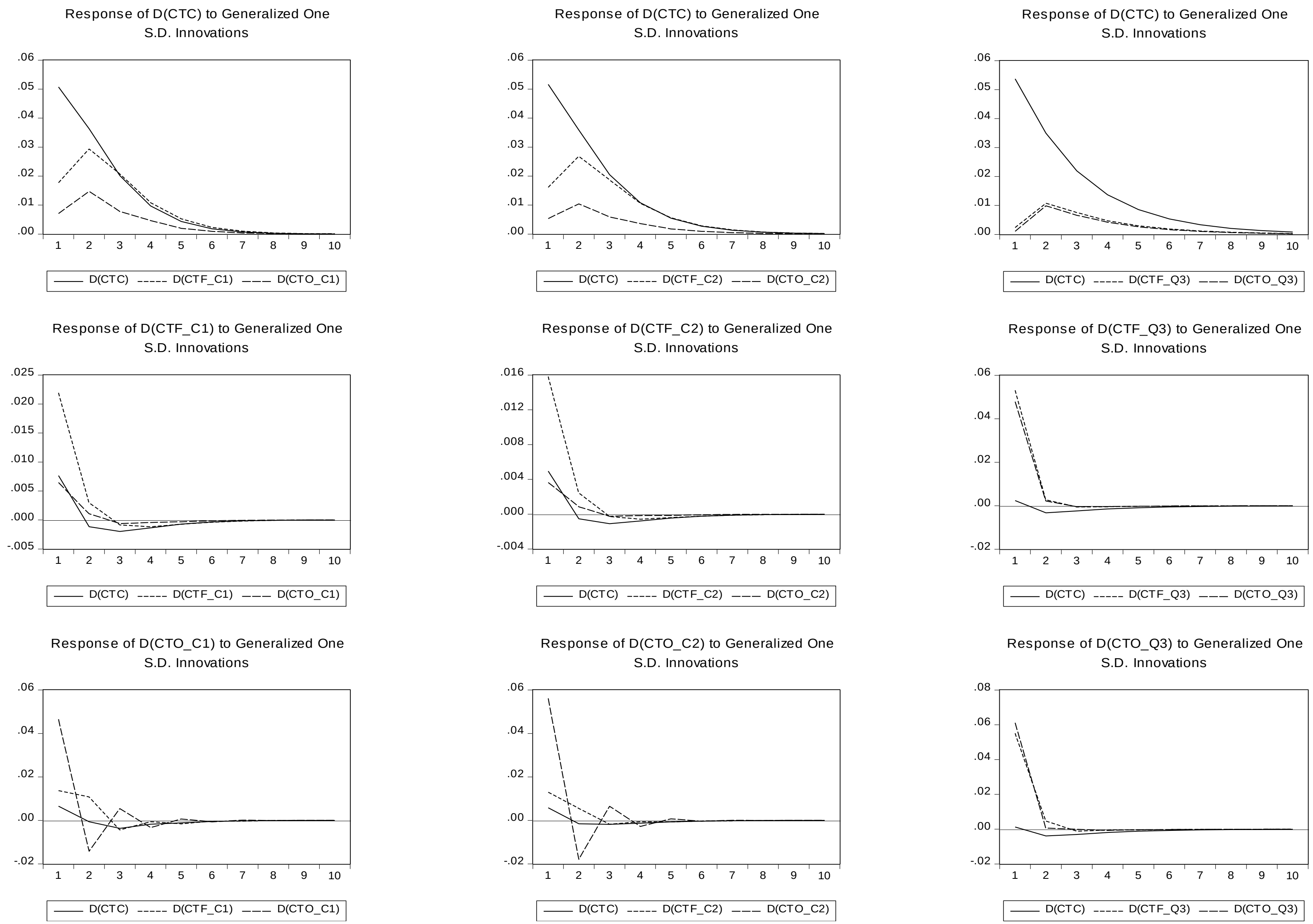


Figure 4.1 Impulse Responses for Capesize Markets (cont.)



4.3.4. Price-trading activities and liquidity measure

In the literature, there is a strong linkage between the trading activities of stock prices with other asset class prices (Bessembinder, 1992, Bessembinder et al., 1996, Bessembinder and Seguin, 1993, Lee and Swaminathan, 2000, Tauchen and Pitts, 1983). Along these lines, in Table 4.4, we observe a strong interaction between freight futures trading activity ($Ratio_{t-1}$) and freight derivatives (futures and options) prices. Specifically, for Capesize vessels, the lagged ratio of futures trading volume over open interest significantly affects futures and options prices for near to medium distance maturity derivatives contracts (near-month (C_M1), second near-month (C_M2) and near-quarter (C_Q1), second near-quarter (C_Q2) and third near-quarter (C_Q3)), but does not affect time-charter rates at all, except second near-month (C_M2) and near-quarter (C_Q1). For Panamax vessels, the futures trading activities affect near-maturity futures and options contracts only (near-month (P_M1) and near-quarter (P_Q1)). In contrast to Capesize time-charter rates, Panamax time-charter rates are not affected by futures trading activities. Similar to Capesize and Panamax time-charter rates, Supramax time-charter rates are not affected by trading activities futures contracts except second near-month (S_M2), near-quarter (S_Q1) and near-calendar (S_C1) contracts. Supramax freight futures and options prices are only influenced by the trading activities of third near-quarter (S_Q3) futures together. It seems that freight futures trading activities cannot sufficiently explain time-charter rates for either vessel type.

In order to also examine if the options trading activities affect time-charter, futures and options prices, we estimate the ratio of options trading volume over options open interest (from LCH.Clearnet) for 21 models' overall different maturities. Only 10 models could be estimated (as the open-interest dropped to zero for all others) with three endogenous variables in each case, adding up to 30 price relationships altogether. Untabulated results indicate that only five (out of 30) price relationships are found to be affected by options trading activities (options prices in C_Q2 and P_M1 maturities, futures' prices in C_Q2 and P_Q1 maturities, and time-charter prices for P_M2 maturity). Consequently, it seems that options trading activities are not significantly affecting time-charter, futures or options prices in most cases, which is in line with the rest of our results.

In an attempt to explain the unexpected results relating to the freight options market, Table 4.6 reports the Amivest liquidity measure results of time-charter, freight futures and options contracts for Capesize, Panamax and Supramax contracts for different maturity periods. Evidently, the liquidity of futures contracts is more than that of options contracts for all vessel types. This may justify the slower reaction of freight options to new market information relative to freight futures, due to the lack of active market practitioners in the freight options' market.

It is also observed that near-month futures contracts (F_M1) are more liquid than second near-maturity futures contracts (F_M2) for Capesize and Supramax vessels, but second near-maturity futures contracts (F_M2) are more liquid than near-month futures contracts (F_M1) for Panamax vessels. Considering quarter-ahead and calendar-ahead contracts, near-quarter futures contracts (F_Q1) are subject to the highest degree of liquidity for all types of vessels. Second near-calendar freight futures (F_C2) contracts are negligible in terms of liquidity for all three types of vessels.

The results indicate that freight futures contracts with higher liquidity produce a strong information transmission compared to freight futures with lower market liquidity. Capesize freight options contracts are the most traded, followed by Panamax options, while Supramax options contracts are the most illiquid. Since Capesize time-charter rates are more volatile than Panamax time-charter rates, shipowners and charterers are more interested in securing long-term freight rates for the Capesize market, leading to higher liquidity for distant-maturity Capesize futures contracts (than Panamax futures contracts), as observed in Table 4.6. Overall, the low liquidity of freight options may be the main factor behind the poor price discovery results documented in the previous section.[34]

Table 4.6 Amivest Liquidity Ratio for Futures and Options at Different Maturity Periods

	F_M1	O_M1	F_M2	O_M2	F_Q1	O_Q1	F_Q2	O_Q2	F_Q3	O_Q3	F_C1	O_C1	F_C2	O_C2
CAPE	1387	162	989	113	1433	201	641	211	544	208	914	150	-	12
PMAX	1290	5	1392	26	1735	35	593	25	582	31	528	13	-	12
SUPRA	417	-	373	-	474	-	272	-	231	-	195	-	-	-

Notes: CAPE, PMAX and SUPRA represent the Capesize, Panamax and Supramax markets, respectively. Futures and options contract maturities are as defined in Table 4.1. The table reports the liquidity ratio of freight futures and options markets for various maturities for the three vessel categories using the Amivest liquidity measure, where a higher liquidity ratio represents higher liquidity in the respective market.

[34] In order to verify that there is no possible measurement bias in the Amivest ratio, similar to the one in the Amihud ratio, we also re-estimated the Amivest ratio based on a weekly sample period and the (untabulated) results are qualitatively the same; that is, options liquidity is significantly lower than futures liquidity for all three vessel types over the different maturities.

4.4. Discussion

In this study, a system with endogenous time-charter rates, freight futures prices, and freight options prices is investigated for the first time. Overall, the results indicate the existence of bi-directional spillovers, in both returns and volatilities, between: (i) freight futures and time-charter markets, (ii) freight futures and freight options markets, and (iii) time-charter and freight options' markets, with a stronger information flow reported from the former market to the latter in each case. The stronger information flow from the futures market to the time-charter market may be attributed to the higher transaction costs associated with the trading of physical time-charter contracts, contributing to slower assimilation of new information into prices. As indicated by the Amivest liquidity measure, the stronger information flow from the futures market to the freight options market is partially driven by the lower liquidity of the latter, resulting in slower incorporation of new market information. Moreover, the freight options market receives stronger information spillovers from the physical time-charter market, possibly due to the higher liquidity costs involved.

The coefficients of the lagged return values for physical time-charter rates, futures and options demonstrate that the futures (options) market positively affects the time-charter and options (futures) markets, though the time-charter market negatively affects the futures and options markets. This suggests that during the sample period, freight derivatives market movements tend to increase returns of time-charter rates but, conversely, movements of the physical freight rate market tend to decrease derivatives returns. A possible explanation for these spillover effects is the shipowners' perception of the freight rates' mean-reverting properties. It has been documented that freight rates revert to their long-run mean levels (see, for example, Greenwood and Hanson, 2014). Freight rate (and freight futures) prices are determined by market agents' expectations, rather than by a strict cost-of-carry (no-arbitrage) relationship since a freight service is a non-storable commodity. This idiosyncratic feature makes shipowners expect an increase in freight futures prices when time-charter rates are low, attesting the mean-reverting property of freight rates.

This can stimulate increased investment in assets (ships) at a lower price to gain high returns in the near future from a market turnaround. In turn, such strategies can lead to over-supply of vessels exerting pressure to time-charter rates that remain at low levels, sending negative signals to the derivatives markets. Accordingly, the positive sentiment for an expected improvement in the freight market results in a contango forward curve, where freight derivatives prices are higher than the underlying freight rates, inflating the orderbook of dry-bulk vessels, and prolonging the downturn in freight rates.

One important implication of our results is that the freight futures market informationally leads the physical time-charter market, and can thus be efficiently used as a price discovery vehicle for dry-bulk freight rates, by attracting participants with both hedging and speculation trading motives. Interestingly, it seems that the freight options market should not be relied upon to serve as a price discovery function, as it lags behind both the freight futures and physical time-charter markets. Instead, the freight options market is probably most relevant as a vehicle to match willing buyers and sellers for strategic risk hedging, of which at least one party has an interest in a vessel and charterparty. In order to empirically investigate the argument that freight futures are mainly used for trading/speculation, whereas freight options are mainly used for strategic hedging purposes, we follow Alizadeh (2013) and regress the trading volume of freight derivatives (futures and options) contracts over one-period lagged freight market volatility. Untabulated results show that for freight futures contracts, in all three vessel types, there is a weak but statistically significant and negative relationship between trading volume and volatility. This negative relationship could be resulted due to information driven trades by a higher number of traders/speculators in the market (Alizadeh, 2013). These results are also consistent with Batchelor et al. (2007), where they argue that an increase in FFA market volatility lowers market liquidity. In contrast, results show that there is no significant relationship between freight options contracts and freight market volatility, indicating that market participants trade freight options contracts irrespective of the volatility of the freight market for strategic hedging purposes. These new findings for the freight options' market, documented here for the first time, can be utilised by shipowners, charterers and investors when making chartering and budgeting decisions, by freight brokers when pricing and quoting freight options prices and premiums, and also by regulators when developing policies for the freight market.

Similar to our main finding that the options market informationally lags behind the spot market, Stephan and Whaley (1990), Chan et al. (1993), Chiang and Fong (2001) and Chan et al. (2002), amongst other studies in the general finance literature, highlight that options prices fall short of fulfilling their price discovery function, which can be partially driven by the illiquidity of the options markets. More specifically, existing literature suggests that although informed practitioners trade in options markets, they have a preference for using "*limit orders*".[35] Essentially, in an illiquid market, informed traders place limit orders at prices which may not reflect the expectations of uninformed traders, making it difficult to attract willing counterparties to trade such options contracts. This restricts informed traders from trading freely and thus disseminating information in an illiquid market, which makes options prices informationally lag behind physical prices. Hence, despite the high degree of inherent financial leverage offered by the options market, options prices may contain less information than physical prices due to lower market liquidity.

Another reason for the low market liquidity of freight options contracts may be that traditional freight option pricing models are less efficient. A strand of literature posits that freight options prices calculated using the conventional Black (1976) model tend to be mispriced compared to using other more contemporary pricing models such as Merton's jump-diffusion model (Nomikos et al., 2013). Due to this mispricing, the freight options market fails to attract investors and hedgers, resulting in lower liquidity that may drive a price discovery function inefficiency. To tackle these problems, there is a need to develop more efficient freight options pricing models.

Chiang and Fong (2001) argue that another reason could be that market-makers focus on prices on the more liquid and mature futures market and revise them frequently, whereas prices are only infrequently updated for the less active and mature options market and, thus, lag behind (stale). Another explanation for our empirical results might lie in the fact that the freight options market is mostly utilised by shipowners and freight buyers for hedging (insurance) purposes, rather than for speculation. In practice, freight options may be held together in conjunction with the underlying assets (i.e. vessels, charterparties or even FFAs) as part of an effective hedging strategy. For example, a shipowner may exit a position in a put freight option when she no longer has an interest in the underlying asset, which would not occur regularly (unless, for example, a vessel is disposed of, and the long-term charter is

[35] A limit order is an order initiated at a specific price. For a buyer (seller) of an option contract, the order cannot be filled at a price higher (lower) than the limit price. If the limit price cannot be realized, then the order remains open until a suitable counterparty is (ever) found. For example, if a charterer (investor) places an order to buy (sell) 20 Capesize time-charter call options at $10,000/day at a limit price of $60/lot then the order will only be filled at $60 or lower (higher).

terminated). This could explain the low liquidity of the freight options market and, more importantly, why speculators have not exploited the apparent information asymmetry.

A policy implication that follows the failure of the price discovery function of freight options relates to the call for further transparency and regulation in derivatives trades. With the growing market risk, followed by the global financial crisis in 200–2008, regulatory bodies started to intervene to control the trade in securities and derivatives. The Dodd-Frank Wall Street Reform and Consumer Protection Act (DFA) adopted since 2010 in the US, the European Markets Infrastructure Regulation (EMIR) adopted in 2012 that follows the standards of the European Securities and Markets Authority (ESMA), and the Markets in Financial Instruments Directive II (MiFID II) adopted in 2014 all aim to reduce systemic risk, improve transparency and reduce counterparty and operation risks. MiFID II has classified instruments/securities into two main types; (i) liquid products – where both the pre- and post-trading data has to be provided, and (ii) illiquid products – where only the post-trading data has to be provided. As freight derivatives fall under illiquid securities, until now, only post-trade data is available, and this mainly includes unit price, quantity traded, date and time of the trade. Though it compiled the regulatory requirement of ESMA, lack of pre-trading quotes and delayed reporting of post-trading information (up to two business days) can generate an unexpected lead-lag relationship between the physical freight rate and the freight options markets, such as the one documented in this study.

Finally, market practitioners could take advantage of the above spillovers between the three investigated markets as follows:

(i) *For investment strategies*: Since freight futures prices react faster to new market information and freight options prices follow with a delay, an increase in futures prices and no increase in options prices indicates that options are underpriced, and will thus become more expensive in the near future. Hence, a rational investor would buy an options contract now and sell it when it is expensive. Further, an increase in the volatility of futures prices indicates that the time-charter or freight options market volatility will shortly increase. Such long trading strategies can be employed by investors to earn higher returns.

(ii) *For financial trading strategies*: Similar to the above, shipowners and charterers can take advantage of the delayed reaction of freight options prices in relationship to freight futures prices. Shipowners looking to hedge freight rate fluctuations using options contracts should respond to a decrease in futures prices by buying put options contracts and holding them until maturity. This will give shipowners the right to exercise the put options and sell the freight service at a high price and earn gains from the possible decrease in freight rates. The opposite is true for charterers.

(iii) *For "traditional" hedging strategies*: Since a bullish or bearish market state is first reflected in freight futures prices and is then transmitted to the time-charter rates, shipowners should get into short-term time-charter agreements when there is an increase in futures prices. Conversely, if there is a decrease in futures prices, shipowners should favour long-term time-charter agreements. The opposite is true for charterers (see Axarloglou et al., 2013). This trading signal stemming from the freight futures market can be utilised to improve chartering performance in anticipation of a volatile shipping business cycle.

4.4.1. Economic significance of spillover effects

In this study, we have documented that new market information is first assimilated in the freight futures market, before it is transmitted first to the time-charter market and, subsequently, to the freight options market. In addition to the spillover effects in returns and volatilities between the three respective markets, in this section we also investigate the potential of employing profitable trading strategies based on these findings. To that end, we utilise the information from the spillovers in returns and volatilities of the futures market as a combined signal to take trading positions in the time-charter (T/C) or freight options markets. Subsequently, the profitability of this trading strategy is assessed taking transaction costs into account (brokerage and clearing fees).

The trading strategies follow the frameworks of both: (a) Wu (2001) and Kavussanos et al. (2014), where due to a "*volatility feedback effect*" an increase in volatility of the informationally leading market *i* (freight futures) drives an increase in the volatility of the trailing market *j* (time-charter or freight options), which in turn causes a decrease in prices (negative returns) in market *j*; and (b) Alizadeh and Nomikos (2007), where the timing of market trading is dictated by a 5-day simple moving average process in returns, in order to capture the market trend over a period of time. Accordingly, we estimate a 5-day simple moving average of returns' spillover between market *i* (freight futures) and market *j* (time-charter or freight options).

The cross-market trading strategies employed involve utilising the return and volatility spillovers in Tables 4.4 and 4.5 as combined signals to take the following trading positions:

Good news – Taking a long position in market *j* when: (a) there is a decreasing volatility spillover in market *i*, leading to a decrease in the volatility and subsequent increase in prices in market *j*, and (b) there is an increasing moving average of returns in market *i*, leading to an increase in the returns in market *j*.

Bad news – Taking a short position in market *j* when: (a) there is an increasing volatility spillover in market *i*, leading to an increase in the volatility and subsequent decrease in prices in market *j*, and (b) there is a decreasing moving average of returns in market *i*, leading to a decrease in the returns in market *j*.

VECM- and VAR-BEKK GARCH models are estimated for an in-sample period (April 2013–January 2016), with the profitability of a given cross-market trading strategy being evaluated for an out-of-sample setting (February 2016–August 2016) in cases where there is evidence of statistically significant return and volatility spillovers from market *i* to market *j*. A profitable trading strategy is one that produces a positive return after accounting for transactions costs.

Table 4.7 presents the aggregate profitability (returns) of each cross-market trading strategy. Overall, the empirical results indicate a positive return in most cases, when taking a position in the trailing T/C or freight options market based on the information received from the leading freight futures market.[36] Moreover, the results also indicate that trading positions based on information from Capesize freight futures generate higher returns on average relative to trading positions triggered by information from Panamax and Supramax freight futures. This is likely due to the higher liquidity of the Capesize freight futures market; i.e. the higher the liquidity, the stronger the information flow, resulting in higher profitability on average.

Finally, summarizing the trading strategy results of Table 4.7, it can be seen that out of the 21 cases, taking trading positions in the physical T/C market following good news received from the freight futures market generates 20 profitable cases, whereas taking trading positions in the physical T/C market following bad news generates only 16 profitable cases. Similarly,

[36] However, we note that due to the illiquidity of the freight options market, one limitation here is that a single options trade could potentially "*move*" the market and render these freight options strategies unsustainable.

taking trading positions in the freight options market following good news from the freight futures market generates 15 profitable cases, whereas taking trading positions in the freight options market following bad news generates 14 profitable cases. In general, it seems that good news generates more cases of profitable strategies than bad news, especially from the freight futures to the T/C market. This is in line with the general investment sentiment that investors delay entering in a trading strategy until "good news" arrives in the market, leading to a higher expectation for profits.[37]

It is interesting to observe that the freight options market, by reacting more slowly to new market information than the physical T/C market, generates less profitable trading cases than the physical market when using information from the freight futures market. This result could be explained by the more pronounced market frictions in the freight options market, such as low market liquidity, and higher transaction costs (option premium, brokerage and clearing fees) than in the physical freight market. As discussed above, higher market frictions create slower information absorption. In line with this, the freight options market informationally lags behind the physical T/C market. As the relative transaction costs for freight options trading are higher than for physical T/C trading, trading in the physical T/C market seems to generate more profitable positions – after receiving information from the futures market – compared to trading in the freight options market.

[37] After also using an asymmetric GJR-GARCHmpdel, a volatility leverage effect is evidenced for all three markets; that is, a negative shock is generated by higher volatility, as compared to a positive shock of the same magnitude. The leverage effect is then used to investigate if high market price volatility in freight futures could lead to high volatility in T/C and options' markets, creating a drop in market prices (bad news) for the latter two markets and, thus, generate profits. The (untabulated) results once again indicate evidence of profitability in the trading strategies.

Table 4.7 Profitability of Trading Strategies from Economic Cross-market Spillovers

Good news								
	Futures to T/C Rates							
	F_M1→T/C	F_M2→T/C	F_Q1→T/C	F_Q2→T/C	F_Q3→T/C	F_C1→T/C	F_C2→T/C	**Avg**
Capesize	1.675	1.451	1.848	1.232	-0.022	2.134	2.141	**1.494**
Panamax	1.173	1.185	1.090	0.742	0.833	0.939	1.279	**1.034**
Supramax	0.300	0.379	0.441	0.382	0.451	0.080	0.122	**0.308**
	Futures to Options							
	F_M1→O_M1	F_M1→O_M2	F_M1→O_Q1	F_M1→O_Q2	F_M1→O_Q3	F_M1→O_C1	F_M1→O_C2	**Avg**
Capesize	0.573	0.156	0.436	-0.145	0.335	-0.076	-0.093	**0.169**
Panamax	1.217	0.541	0.047	0.045	-0.285	0.344	-0.223	**0.241**
Supramax	0.027	0.054	-0.088	0.121	0.064	0.007	0.098	**0.040**

Bad news								
	Futures to T/C Rates							
	F_M1→T/C	F_M2→T/C	F_Q1→T/C	F_Q2→T/C	F_Q3→T/C	F_C1→T/C	F_C2→T/C	**Avg**
Capesize	0.909	0.625	0.816	1.057	0.559	0.439	0.455	**0.694**
Panamax	0.203	0.208	0.146	-0.175	-0.090	0.030	0.024	**0.050**
Supramax	-0.042	0.145	0.140	0.030	-0.018	0.096	-0.039	**0.045**
	Futures to Options							
	F_M1→O_M1	F_M1→O_M2	F_M1→O_Q1	F_M1→O_Q2	F_M1→O_Q3	F_M1→O_C1	F_M1→O_C2	**Avg**
Capesize	3.881	1.675	0.828	-0.312	0.537	0.149	0.018	**0.968**
Panamax	1.357	0.603	0.317	-0.006	-0.085	-0.065	-0.240	**0.269**
Supramax	0.290	0.170	-0.136	-0.131	0.053	0.008	0.278	**0.076**

Notes: The table reports the profitability (combined returns) of trading strategies after taking into account the transaction costs (brokerage and clearing fees) involved in taking positions in the T/C and freight options markets, after using information from the freight futures market. The cross-market trading strategies involve taking long (short) positions in either the T/C or freight options markets based on the good (bad) news signal received from the informationally leading futures market. Return and volatility spillovers from Tables 4.4 and 4.5 are used as signals to establish the cross-market trading strategies. The transaction cost for the T/C market is 1.25% of the economic value of the charter contract, while for the freight options market it is 1.5% of the economic value of the options contract plus a $8 clearing fee per lot.

4.5. Conclusion

This study examines the spillover effects of T/C rates, freight futures and options prices, and their association with trading activities and market liquidity of freight futures contracts, for Capesize, Panamax and Supramax vessels. A strong interaction between T/C rates, freight futures and options prices are documented, which relates to the arrival of new market information. This study contributes to the existing literature as follows: (i) to the best of our knowledge this is the first study to investigate the information spillover of returns and volatilities between T/C rates, freight futures and freight options markets; (ii) it examines whether the level of information transmission of freight derivative markets is related to concurrent market conditions, such as trading volume and open interest; (iii) by using a tri-variate model that captures the dynamics of all three markets together, it better captures the cross-market information spillover mechanisms; and (iv) it examines an emerging derivatives market, which may be less efficient in assimilating new market information into prices than other more mature markets.

The results support the existence of significant information transmission (in both returns and volatilities) between T/Crates, freight futures and freight options markets for all vessel types examined. Freight futures prices react faster in assimilating new market information, as there are lower transaction costs for futures contracts than in the physical freight market for fixing vessels. In contrast, freight options prices are the slowest to react to new market information, partially due to the high illiquidity of this market, compared to the freight futures market. The results also indicate market liquidity to be the primary factor for the increase in volatility of the investigated markets. Finally, it is found that the spillover results uncovered in this study can generate on average economically profitable trading strategies. The new spillover effect results, documented for the first time in this study, have important implications for practitioners, as they can help gain a better understanding of the interactions between three related markets. The results can be utilised in hedging and investment strategies since by observing the informationally leading market practitioners can draw inferences about the future (short-run) direction of other markets. The volatility interactions between the three related markets can provide an effective risk prediction mechanism, which can enhance investors' decision-making. Finally, the results of this study can act as a benchmark for researchers and regulators to gain a better understanding of the freight derivatives markets. The results of the freight options call for further investigations in that market.

5. Shipping Risk Management Practice Revisited: A New Portfolio Approach

5.1. Introduction

One of the fundamental characteristics of the international shipping industry is its distinctively volatile nature, which is manifested in significant cash flow and return variability for key shipping market practitioners, such as shipowners, charterers (shippers), operators and investors, amongst others. Although volatility in vessel prices, bunker fuel prices, foreign exchange and interest rates all contribute towards an environment of heightened uncertainty, freight rate variability is considered as the most important factor. Accordingly, minimising freight rate fluctuations – either through utilising traditional physical market-based diversification with charterparty contracts of different duration or by employing financial hedging strategies with derivatives contracts – has become imperative for shipping businesses.[38] In this study, we argue that utilising derivatives contracts over and above holding a well-diversified portfolio of physical freight rates should offer shipping practitioners the opportunity to further minimise their freight rate risk exposures and ultimately lead to superior risk management performance.

Existing studies have examined the performance of hedging strategies involving freight futures in dry-bulk markets (see Thuong and Visscher (1990); Kavussanos and Nomikos, 2000a, 2000b, 2000c; Kavussanos and Visvikis (2004a) as well as in tanker markets (see Alizadeh et al. (2015a), and point to lower hedging effectiveness (40–60% variance reduction) relative to what we typically observe in financial and commodity markets.[39,40] The methodologies employed by previous studies have been based on an asset-by-asset

[38] Typically, traditional freight rate risk management involves diversifying holdings in different vessel types (larger vs. smaller) and market sectors (tramp vs. liner), and charterparties of different duration (voyage vs. timecharter) in order to minimize (spread) the risks (see Kavussanos and Visvikis, 2006a).

[39] The relatively low hedging performance documented has been primarily attributed to the high basis risk associated with freight futures' contracts due to the non-storable nature of the underlying freight service, which allows for no cost-of-carry arbitrage parity trades (see Kavussanos and Nomikos, 2000a and Kavussanos and Visvikis, 2004b).

[40] Adland and Jia (2017), for the first time, argue that if a freight futures hedge is kept until the settlement (expiration) date, then there is no financial basis risk but rather only physical basis risk from the mismatch between the income stream of the actual vessel and the spot rate index. They argue that this mismatch may be due to technical specifications, deviation in operating speeds and bunker fuel consumption, trading patterns of the global fleet, timing of fixtures and duration of actual trips, and vessel unemployment. Their results indicate that physical basis risk decreases as the fleet size increases and the hedging durations are longer, but it does not disappear completely.

framework, whereby each (physical) freight rate exposure is hedged against the corresponding (derivatives) futures' contract (henceforth referred to as "*direct hedge*"). This study employs for the first time, to the best of our knowledge, a portfolio approach that follows a modern portfolio theory multi-asset framework in the spirit of Markowitz (1952).[41] It utilises a mixed portfolio of different freight futures contracts to hedge the price fluctuations of a well-diversified portfolio, comprising physical freight rates (henceforth referred to as "*cross hedge*"). The main methodological novelty of this portfolio approach is that it considers the correlations and co-variances between the freight futures contracts allowing us to further reduce the total risk associated with shipping freight markets, thereby improving freight rate risk management. In a recent study, Tsouknidis (2016) finds a strong correlation between freight rates among various shipping segments. In addition, freight rates and corresponding freight futures are typically found tied in long-run equilibrium (cointegrating) relationship and, therefore, spillovers in returns and volatilities within different freight markets have been observed in the dry-bulk market (Alexandridis et al. (2017) as well as in the tanker market (Li et al. (2014). This suggests that there may also exist correlations between freight futures' contracts corresponding to different physical freight rates. Accordingly, this study takes into account the correlations between a portfolio of physical freight rates and a corresponding portfolio of freight futures' contracts to examine the risk management performance of (i) well-diversified physical freight portfolios, (ii) *direct hedge* freight futures' portfolios and (iii) *cross hedge* freight futures' portfolios (see Section 2.2 for definitions).

Freight derivative contracts were first introduced in the early 1990s for tramp (dry-bulk and tanker) shipping as forward contracts (Forward Freight Agreements or FFAs) traded over-the-counter (OTC) and tailored to their users' needs. More recently, standardised freight forward contracts (hereafter, "*freight futures' contracts*") have been cleared at various clearing-houses (such as LCH.Clearnet in London, SGX AsiaClear in Singapore and Nasdaq

[41] The Modern Portfolio Theory (MPT), as developed by Markowitz, H. 1952. Portfolio selection. *The journal of finance,* 7**,** 77-91., quantifies the diversification of multiple risky assets in portfolios by utilizing the correlations and covariances between the assets to estimate mean (return)–variance (risk) efficient frontiers; that is, a set of portfolios which satisfies the condition that no other portfolio exists with a higher expected return at the same level of risk. Past research in diversification of risky assets includes Brennan, M. J., Schwartz, E. S. & Lagnado, R. 1997. Strategic asset allocation. *Journal of Economic Dynamics and Control,* 21**,** 1377-1403., Cass, D. & Stiglitz, J. E. 1970. The structure of investor preferences and asset returns, and separability in portfolio allocation: A contribution to the pure theory of mutual funds. *Journal of Economic Theory,* 2**,** 122-160. and Roques, F. A., Newbery, D. M. & Nuttall, W. J. 2008. Fuel mix diversification incentives in liberalized electricity markets: A Mean–Variance Portfolio theory approach. *Energy Economics,* 30**,** 1831-1849., amongst many others. Cullinane, K. 1995. A portfolio analysis of market investments in dry bulk shipping. *Transportation Research Part B: Methodological,* 29**,** 181-200. uses the portfolio theory to analyze the mean and variances of physical freight rates in dry-bulk shipping.

Clearing in Norway, amongst others) circumventing any counterparty default risk.[42] The dry-bulk Capesize (160,000–180,000 deadweight (dwt) vessels), Panamax (74,000 dwt), Supramax (52,000 dwt) and Handysize (28,000 dwt) freight indices quoted in US$/day or US$/metric ton, as well as tanker dirty and clean freight indices quoted in Wordscale points or Time-charter Equivalent (TCE), are produced by the Baltic Exchange in London and serve as the underlying assets for the corresponding dry-bulk and tanker futures, respectively.[43] Such freight indices accurately reflect current market conditions as they are estimated from the average freight rates quotations provided by a panel of international shipbrokers (the Panellists) appointed by the Baltic Exchange. Freight futures contracts are cash-settled contracts between an agreed futures price and a settlement price that is calculated as the average of the underlying physical freight rates during all business days of the maturity (settlement) month.[44]

The typically oligopolistic liner (container) shipping market started to exhibit perfect competition characteristics after the abolition of liner (price fixing) conferences in 2008, exposing the liner companies and shippers to significant freight rate volatilities. The Container Swap Forward Agreements (CFSA) contracts began trading OTC in 2010, through freight derivatives brokers, and are settled against the 15 freight routes of the Shanghai Containership Freight Index (SCFI) provided by the Shanghai Shipping Exchange (SSE). They are quoted as US$/TEU (Twenty-foot Equivalent Unit) or US$/FEU (Forty-foot Equivalent Unit). To eliminate counterparty (credit) risk, these contracts are cleared in the SGX AsiaClear clearing-house. Our study employs for the first time a sample that includes container derivatives, thus providing new evidence of hedging performance within this emerging market of the shipping industry. Such markets have long posed a challenge for financial research. More specifically, Kavussanos *et al.* (2008) report that "*emerging market returns are characterised by low liquidity, thin trading, higher sample averages, low correlations with developed market returns, non-normality, better predictability, higher volatility and short samples. In addition, market imperfections, high transaction and*

[42] NOS Clearing merged with NASDAQ OMX in 2014, and the freight derivatives clearing portfolio is managed by NASDAQ Clearing.
[43] World-scale rates are estimated assuming that a "*nominal*" tanker exists on round voyages between assigned ports. The Baltic Exchange was established in 1883 in London to establish an organized market for market practitioners that wish to buy and sell freight services (for more details, see Kavussanos and Visvikis, 2006b).
[44] An example of how they are used in practice is the following: if a shipowner (charterer) sells (buys) one contract of Capesize Time-Charter (T/C) futures at US$8,000/day on 1st March 2016, with a settlement of US$7,000/day on 31st May 2016, the shipowner (charterer) would gain (lose) US$1,000 in the freight derivative's position, which will then be used to cover the loss (profit) of the underlying freight rate position.

insurance costs, less informed rational traders and investment constraints may also affect the risks and returns involved" (see also Kavussanos and Visvikis, 2008). Emerging market returns can thus exhibit different characteristics to those in developed markets, making the empirical investigation of the rather illiquid container FFA market important regarding offering valuable insights (for a detailed discussion on the special features of emerging market, see Bakaert and Harvey, 1997 and Antoniou and Ergul, 1997).[45]

To implement our portfolio approach, we first derive a *well-diversified* freight rate portfolio, where the weights of individual assets are optimized using Markowitz's risk–return theory (Markowitz, 1952) and compare them with an undiversified freight rate portfolio, where the weights of individual assets are identical, for seven different physical freight rate route scenarios involving the following: (a) dry bulk – Capesize, Panamax and Supramax time-charter rates; (b) tanker – TD3 (Middle East Gulf to Japan) and TC2 (Europe to US Atlantic Coast) route voyage rates; and (c) container – Shanghai to US West Coast (USWC) and Shanghai to North West Europe (NWE) spot rates; we then measure the degree of variance reduction and utility increase due to portfolio diversification. As a second step, we extend our analysis and use *direct hedge* and *cross hedge* freight futures portfolios (as defined in Section 2.2) to hedge the *well-diversified* (optimal) freight rate portfolio. We then measure the additional (to the physical freight rate diversification) variance reduction and utility increase stemming from financial hedging with derivatives contracts.

Along these lines, Johnson (1960) and Stein (1961) use a modern portfolio theory (MPT) framework to estimate the weights of futures contracts required per unit weight of underlying physical assets to obtain a minimum variance portfolio. This ratio of futures contracts weights corresponding to the unit weights of physical assets is referred to as the Minimum Variance Hedge Ratio (MVHR), while the variance reduction or the utility increase in the unhedged physical position to the hedged futures position is the hedging effectiveness.[46] Ederington (1979) and Franckle (1980) apply this framework to examine the hedging performance of futures' contracts written on US T-Bills. Subsequently, Figlewski (1984), Figlewski (1985) and Lindahl (1992), amongst others, estimate optimal hedge ratios and corresponding hedging performances for stock index futures. We also estimate and compare various constant and time-varying (dynamic) hedge ratio models both in-sample and out-of-

[45] Given the relatively low trading volume of container derivatives in the most recent years of our sample we have also repeated our analysis by excluding this segment completely and find quantitatively similar results in terms of the improvement in risk minimization (see Section 2.4).
[46] Detailed estimations of MVHR and the variance reduction measure are presented in Section 2.2.

sample. In-sample tests are mainly based on past (historical) information, while the out-of-sample performance of hedge ratios is more relevant to practitioners (see Kavussanos and Visvikis, 2008). It has been documented in the literature that dynamic hedge ratio models tend to outperform constant ones in foreign exchange and agriculture commodity futures' markets (see Kroner and Sultan (1993), Bera et al. (1997), whereas the opposite holds in live cattle futures' markets (Mcnew and Fackler, 1994).

Our results indicate that the portfolio diversification reduces freight rate fluctuations up to 35% for mixed portfolios of container, dry-bulk and tanker freight rate routes. Furthermore, the results from using freight futures contracts in a portfolio approach point to a further freight rate risk reduction up to 23%. The constant hedge ratio models seem to outperform time-varying ones in most examined cases, both in-sample and out-of-sample, indicating that the risk minimisation positions do not need to be updated when new information arrives in the market.

This study contributes to the existing literature on freight rate risk management as follows. First, it is the first study to examine optimal hedge ratios for all three major shipping sub-sectors, namely, the dry-bulk, tanker and the newly developing container futures. Our results offer new insights on the effectiveness of financial risk management practices in the container sector, which could ultimately result in alleviating transportation costs for consumer goods carried in containers, thereby reducing the cost for the end consumer (Tsai *et al.*, 2011). Second, we utilise mixed portfolios of the container, dry-bulk and tanker freight futures along with corresponding well-diversified portfolios of physical freight rates to further improve the efficacy of risk minimisation for shipping market practitioners. Our results corroborate that utilising a mixed portfolio (*cross hedge*) of futures contracts significantly decreases freight rate risk relative to *well-diversified* portfolios of physical freight rates, contributing to the existing research on shipping risk management. The documented hedging performance improvements have important implications for overall business, operating and chartering strategies in the shipping industry, and they can ultimately result in more liquid and efficient freight futures markets.

The remainder of the study is organised as follows: Section 5.2 develops the theoretical framework and presents the methodology used to estimate the *direct hedge* and *cross hedge* portfolios based on various scenarios. The data and preliminary analysis are presented in Section 5.3. Section 5.4 presents the empirical results, and Section 5.5 concludes the study.

5.2. Theoretical Framework and Methodology

5.2.1. Minimum variance and utility maximising hedge ratios

A shipowner (charterer) can hedge a short (long) position in the physical freight market by taking a long (short) position in the freight futures market. Thus, a loss (gain) in the physical freight market can be offset by a gain (loss) in the futures' market. Equation (1) represents the freight return generated by a portfolio comprising of physical freight rates, and freight futures contracts and Equation (2) represents the variance of the corresponding portfolio return:

$$R_{H,t} = \Delta S_t - \gamma_t \Delta F_t \tag{1}$$

$$\begin{aligned} Var_t\left(R_{H,t}\right) &= Var_t(\Delta S_t - \gamma_t \Delta F_t) \\ &= Var_t(\Delta S_t) + \gamma_t^2 Var_t(\Delta F_t) - 2\gamma_t Cov_t(\Delta S_t, \Delta F_t) \end{aligned} \tag{2}$$

where $R_{H,t}$ represents the conditional return of the hedged portfolio (H); $\Delta S_t = S_t - S_{t-1}$ represents the logarithmic change in freight rates between time periods $t-1$ and t; $\Delta F_t = F_t - F_{t-1}$ represents the logarithmic change in futures' prices between time periods $t-1$ and t; and γ_t is the hedge ratio expressed as the value of freight futures contracts over the value of the underlying freight rate exposure at time (t). In Equation (2), $Var_t(R_{H,t})$ is the variance of the return of the hedged portfolio $(R_{H,t})$ as defined in Equation (1). $Var_t(\Delta S_t)$ and $Var_t(\Delta F_t)$ are the conditional variances of underlying freight rates and freight futures returns, respectively; and $Cov_t(\Delta S_t, \Delta F_t)$ is the covariance of freight rates and freight futures returns.

When $\gamma_t = 0$, the physical freight rate position remains completely unhedged, while when $\gamma_t = 1$, the futures position is equal in magnitude, but opposite in direction, to the freight rate exposure. This so-called "*naïve*" (one-to-one) hedge ratio provides a perfect hedge only if the freight rates and the freight futures prices are perfectly correlated, and the risks (variances) of each of the two markets are equal. In practice, however, given the presence of market frictions, the variabilities of freight futures' prices and their underlying freight rates are not the same and, therefore, they do not involve the same level of risk. Thus, in reality, the estimated hedge ratios are typically different from unity.

The Minimum Variance Hedge Ratio (MVHR) is estimated by minimising the variance of the hedged portfolio, $Var_t(R_{H,t})$ from Equation (2):

$$\frac{\partial[Var_t(R_{H,t})]}{\partial[\gamma_t]} = 0$$

Substituting the value of $Var_t(R_{H,t})$ from Equation (2):

$$2\gamma_t Var_t(\Delta F_t) - 2Cov_t(\Delta S_t, \Delta F_t) = 0$$

Solving for γ_t:

$$\gamma_t^* = \frac{Cov_t(\Delta S_t, \Delta F_t)}{Var_t(\Delta F_t)} = \rho_{(\Delta S)(\Delta F),t} \frac{\sigma_{(\Delta S),t}}{\sigma_{(\Delta F),t}} \qquad (3)$$

where γ_t^* is the MVHR which corresponds to the minimum value of the variance of the hedged portfolio, $Var_t(R_{H,t})$; $\rho_{(\Delta S)(\Delta F),t}$ is the correlation coefficient between the freight rate returns (ΔS) and the futures returns (ΔF), while $\sigma_{(\Delta S),t}$ and $\sigma_{(\Delta F),t}$ are the respective standard deviations.

A highly risk-averse market practitioner would typically prefer to eliminate as much risk as possible by taking a futures position that generates relatively lower returns. In contrast, a risk-seeking practitioner would prefer to maximise her return at the expense of bearing more risk. Most market practitioners can be broadly categorised regarding risk aversion within the range of these two extreme cases. Therefore, it is necessary to consider the practitioners' degree of risk aversion when estimating the corresponding optimal hedge ratio that maximises the expected utility, $E_t U(R_{H,t+1})$ of the hedged portfolio at any given point in time, *t*. Consider the following mean–variance expected utility function:

$$E_t U(R_{H,t+1}) = E_t(R_{H,t+1}) - kVar_t(R_{H,t+1}) \qquad (4)$$

where k is the coefficient of risk aversion indicating the degree of risk of a given individual practitioner; that is, a higher (lower) value of k indicates a higher (lower) risk aversion.[47] The formula assumes a quadratic utility function and the portfolio return is normally distributed according to the Markowitz (1968) framework (see Levy and Markowitz (1979) for more details on the quadratic utility function).

[47] k being infinite and zero indicates pure risk-averse and pure risk-seeking practitioners, respectively.

The expected utility function $E_t U(R_{H,t+1})$ from Equation (4), by varying the hedge ratio (γ_t), the Utility Maximizing Hedge Ratio (UMHR - y_t^{**}) is estimated as follows:

$$\frac{\partial[E_t U(R_{H,t+1})]}{\partial[\gamma_t]} = 0$$

Substituting the value of $E_t U(R_{H,t+1})$ from Equation (4):

$$\frac{\partial[E_t(R_{H,t+1})]}{\partial[\gamma_t]} - \frac{\partial[kVar_t(R_{H,t+1})]}{\partial[\gamma_t]} = 0$$

From Equation (1) and (2):

$$-\Delta F_{t+1} - 2k\gamma_t Var_t(\Delta F_{t+1}) + 2kCov_t(\Delta S_{t+1}, \Delta F_{t+1}) = 0$$

$$\gamma_t = \frac{Cov_t(\Delta S_{t+1}, \Delta F_{t+1})}{Var_t(\Delta F_{t+1})} - \frac{\Delta F_{t+1}}{2kVar_t(\Delta F_{t+1})}$$

From Equation (3):

$$y_t^{**} = \gamma_t^* + \left[\frac{-\Delta F_{t+1}}{2kVar_t(\Delta F_{t+1})}\right] = \gamma_t^* + \left[\frac{-Bias_{t+1}}{2kVar_t(\Delta F_{t+1})}\right] \quad (5)$$

where $Bias_{t+1} = E_t(\Delta F_{t+1}) = E_t(F_{t+1}) - F_t$ represents the bias in futures prices between periods t and $t+1$. The UMHR (y_t^{**}) in Equation (5) has two components; the first is a pure hedging component derived from Equation (3): the MVHR (γ_t^*). The second is a speculative component, which depends on the risk aversion of the individual practitioner and the efficiency level of the futures market (see Kavussanos and Visvikis, 2008 for more details). There are two cases to consider:

Case 1: If the coefficient of risk aversion is very large, the speculative component in Equation (5) will be negligible. Hence, for a high risk-averse practitioner, the MVHR is equal to the UMHR. This indicates that market practitioners are not concerned about higher returns but are rather only interested in minimising the variance of their portfolios. So, the utility function from Equation (4) is not relevant for highly risk-averse practitioners.

Case 2: If the futures' returns follow a martingale process, – that is, futures prices are unbiased, and the risk-averse coefficient (k) is finite, the second term in Equation (5) will not be significantly different from zero.[48] This implies that the speculative positions using futures' contracts will have an equal probability of generating profits and losses. This case arises in an efficient market where the returns of the futures contract follow a stochastic process with no deterministic trend. For these types of cases $y_t^* = \gamma_t^{**}$: that is, the MVHR is also equal to the UMHR. The futures markets constitute both deterministic and stochastic components. Practitioners use the price biasness generated from the deterministic component of the futures' markets to develop various investment/speculative strategies.

5.2.2. Freight route scenarios and portfolio formation

In practice, shipping practitioners typically trade in more than one risky asset class (i.e. a mix of freight routes that correspond to different vessel types) and hence are exposed to various freight rate risks. In addition, individual market practitioners have various advantages in operating in particular sectors of the shipping industry, following their experience in maritime operations of vessels and as part of their business strategy. Thus, besides following the market fundamentals to diversify their freight rate portfolio, they also follow their competitive advantages for choosing the weights of particular market sectors and types of vessels. This creates infinite possible combinations of freight rates, which in practice, makes the exact calculation of all the efficient portfolios difficult to establish. However, to institute a practical approach of freight rate diversification, we have considered that if a shipping practitioner is operating a specific portfolio of freight rates (say, tanker and dry-bulk), then she has an equal competitive advantage in each of the freight markets used (that is, tanker and dry-bulk). So, a traditional hedging strategy is developed utilising a mean-variance portfolio framework to estimate the optimal weights for each risky freight rate in the physical portfolio, generating an efficient frontier *well-diversified* portfolio. A financial risk management strategy is then formulated to hedge this *well-diversified* portfolio of freight rates by taking positions in multiple futures' contracts, capturing the correlations and covariances between them and, therefore, minimising risk more effectively. To this end, we employ various freight rate route scenarios to account for the wide range of shipping market practitioners with different physical freight rate exposures:

[48] A *martingale process* is a process in which the conditional expectation of the price in the next period is equal to the price in the current period, given knowledge of all past observed prices.

Base Scenario – A freight rate portfolio with all three major sub-sectors; that is, container (NWE & USWC), dry-bulk (Capesize, Panamax, and Supramax) and tanker (TC2 and TD3) freight routes. In this scenario, the efficient frontier is derived using the returns generated from all seven freight rate routes; Scenario 1 – Container (NWE & USWC) and dry-bulk (Capesize, Panamax and Supramax) freight rate routes; Scenario 2 – Dry-bulk (Capesize, Panamax and Supramax) and tanker (TC2 and TD3) freight rate routes; Scenario 3 – Tanker (TC2 and TD3) and container (NWE & USWC) freight rate routes; Scenario 4 – Only container (NWE & USWC) freight rate routes; Scenario 5 – Only dry-bulk (Capesize, Panamax and Supramax) freight rate routes; and Scenario 6 – Only tanker (TC2 and TD3) freight rate routes.

The following portfolios are then formed for each of the above seven freight rate route scenarios:

Portfolio 1 – ***Well-diversified* physical freight rate portfolio**: An efficient frontier is estimated only with risky physical freight rates, based on the following constraints:

Constraint A – No short positions: The participant is only allowed to hold positive weights on the freight rate returns. For example, this prevents a shipowner from becoming a charterer (and vice versa):

$$W_{s,i} \geq 0 \; (for \; \forall \; i)$$

Constraint B – Total investment: The sum of all the weights of the freight rate returns is equal to one, indicating that the shipowner intends to generate her entire profit from shipping operations by chartering out vessels:[49]

$$\sum_{i=1}^{n} W_{s,i} = 1 \; (where \; n = number \; of \; freight \; rates \; to \; hedge)$$

[49] This restrictive assumption is taken deliberately to isolate the risks and returns only to freight rates. Relaxing the assumption allows for the inclusion of risks from positions in other assets in shipping or from positions in other industry sectors, but this is left for future research.

The return and variance of the *well-diversified* portfolio of freight rates are determined as follows:

$$R_{WD} = \omega_s' R_s \quad (6)$$

$$\sigma_{WD}^2 = \omega_s' V \omega_s \quad (7)$$

where $\omega_s = (\omega_{s,1}\omega_{s,2} \ldots \omega_{s,n})'$ is an $(n \times 1)$ vector of the portfolio proportions, such that $\omega_{s,i}$ is the proportion of freight rate return for the i^{th} vessel type; $R_s = (R_{s,1}R_{s,2} \ldots R_{s,n})'$ is a $(n \times 1)$ vector of the expected freight rate returns; and V is a $(n \times n)$ covariance matrix, which is also symmetric and positive definite. In our study, $n = 7$ since we consider seven different freight rate route scenarios.

Portfolio 2 – *Direct hedge* freight futures portfolio: This is the typical futures hedging model, where futures contracts are used to minimise the variance of the corresponding physical freight rate exposures. The MVHR is estimated from Equation (3) to determine the weights of the freight futures contracts for hedging the *well-diversified* freight rate portfolio. Along with the two constraints (Constraint A and B) used in the *well-diversified* (unhedged) portfolio (Portfolio 1), there is one additional constraint for obtaining the weights of the *direct hedge* portfolio:

Constraint C – Futures weight ratio: The weight of the futures contracts is the product of the weight of the corresponding freight rates and MVHR:

$$\omega_{f,i} = \gamma_{t,i}^* \times \omega_{s,i}$$

where $\gamma_{t,i}^*$ is the MVHR for a freight rate i that is calculated from Equation (3); and $\omega_{f,i}$ refers to the weight of freight futures contracts used to hedge the freight rate exposure. The return and variance of the *direct hedge* portfolio are determined as follows:

$$R_{DH} = \omega_T' R_T \quad (8)$$

$$\sigma_{DH}^2 = \omega_T' V \omega_T \quad (9)$$

where $R_T = (R_{s,1}\ R_{s,2} \ldots R_{s,n}\ R_{f,1}\ R_{f,2} \ldots R_{f,n})'$ is a $(2n \times 1)$ vector of the returns of n freight rates and n futures contracts; V is a $(2n \times 2n)$ covariance matrix of returns of n freight rates and n futures contracts that is also symmetric and positive definite; $\omega_T =$

$(\omega_{s,1}\ \omega_{s,2} \dots \omega_{s,n}\ \omega_{f,1}\ \omega_{f,2} \dots \omega_{f,n})'$ is a $(2n \times 1)$ vector of the portfolio proportions, such that $\omega_{s,i}$ is the weight of the i^{th} freight rate determined in the *well-diversified* portfolio, $\omega_{f,i}$ is the weight of the i^{th} futures contracts traded (short position) by the shipowner to hedge the freight rate exposure, while $\omega_{f,i}$ is determined using Constraint C.

Portfolio 3 – *Cross hedge* freight futures portfolio: A *cross hedge* solution is introduced where the multi-freight rate exposures are hedged using multiple freight futures contracts; that is, hedging freight rate i using freight futures j, for all values of i and j. The sets of portfolios are optimized to minimize the risks (variance) of the returns generated from both physical freight rates and freight futures contracts. Along with the first two constraints (Constraint A and B) used in the *well-diversified* portfolio (Portfolio 2), one additional constraint exists when obtaining the weights of the *cross hedge* portfolio:

Constraint D – Short futures position: The shipowner is only allowed to act as a hedger and can only take short (sell) positions in freight futures contracts (speculation is not allowed):

$$W_{f,j} \leq 0\ (for\ \forall\ j)$$

The return and variance of the *cross hedge* portfolio are determined as follows:

$$R_{CH} = \omega_T' R_T \tag{10}$$

$$\sigma_{CH}^2 = \omega_T' V \omega_T \tag{11}$$

where $R_T = (R_{s,1}\ R_{s,2} \dots R_{s,n}\ R_{f,1}\ R_{f,2} \dots R_{f,n})'$ is a $(2n \times 1)$ vector of the returns of n futures contracts used to hedge n freight rate exposures; V is the $(2n \times 2n)$ covariance matrix of returns of n freight rates and n futures contracts that is also symmetric and positive definite; $\omega_T = (\omega_{s,1}\ \omega_{s,2} \dots \omega_{s,n}\ \omega_{f,1}\ \omega_{f,2} \dots \omega_{f,n})'$ be a $(2n \times 1)$ vector of the portfolio proportions, such that $\omega_{s,i}$ is the proportion of weights of the i^{th} freight rate determined in the *well-diversified* portfolio of freight rates and $\omega_{f,i}$ is the weight of the i^{th} futures contracts traded (short position) by the shipowner to hedge the freight rate fluctuations.

5.2.3. Estimation of optimal hedge ratios

The coefficient of ΔF_t (slope coefficient) is used to estimate the conventional (constant) MVHR for *direct hedge* and *cross hedge* portfolios in the following Ordinary Least Squares (OLS) regression:

$$\Delta S_t = h_0 + \gamma^* \Delta F_t + \varepsilon_t, \qquad \varepsilon_t \sim iid(0, \sigma^2) \tag{12}$$

A potential issue that arises with the constant MVHR is that it fails to capture the time-varying distributions of freight rates and futures prices. In addition, if cointegration exists between freight rates (S_t) and futures prices (F_t), an Error-correction term (ECT) should be added to Equation (6), since neglecting it leads to an omitted variable problem, resulting in a biased coefficient γ^* (Kroner and Sultan, 1993). Finally, the price discovery function in derivatives markets suggests that there should be is a strong information transmission flow from the freight futures market (ΔF_t) to the freight rate market (ΔS_t) (see Kavussanos and Visvikis, 2004b). However, Alexandridis *et al*. (2017) argue that there is also a weak information feedback from freight rates to freight futures' markets, which could potentially create an endogeneity problem. The potential omitted variable biasness and the endogeneity problem can be both mitigated by using a bivariate Vector-Error Correction Model (VECM) to estimate γ_t^*, where the explained variable is regressed against the ECT and lags of the explanatory variable. If freight rates (S_t) and freight futures (F_t) are non-stationary variables then there may exist a long-run equilibrium cointegration relationship between them. In such case, the Johansen (1988) test is used to determine whether a cointegrating vector exists with a linear combination of freight rate and freight futures prices. If no long-run relationship between the two series is present, the ECT term from Equation (7) is omitted and a Vector Autoregressive (VAR) model is estimated instead.

The VECM constant MVHR (y_t^*) in Equation (7) is computed as the ratio of the covariance of the error-terms of freight rates and freight futures returns (Cov($\varepsilon_{S,t}$, $\varepsilon_{F,t}$)) over the variance of the error-term of the futures returns (Var($\varepsilon_{F,t}$)):

$$\gamma_t^* = \frac{\mathrm{Cov}(\varepsilon_{S,t}, \varepsilon_{F,t})}{\mathrm{Var}(\varepsilon_{F,t})} = \frac{\sigma_{S,F,t}}{\sigma_{F,t}^2} \tag{13a}$$

Time-varying conditional distributions of freight rates and freight futures returns are used to compute dynamic (time-varying) optimal hedge ratios. As participants are interested in the out-of-sample performance of the model, a one-step-ahead hedge ratio is estimated as follows:

$$\gamma_{t+1}^{*} \mid \Omega_t = \frac{\mathrm{Cov}(\varepsilon_{S,t+1},\varepsilon_{F,t+1})}{\mathrm{Var}(\varepsilon_{F,t+1})} = \frac{\sigma_{S,F,t+1}}{\sigma_{F,t+1}^{2}} \quad (13b)$$

where the MVHR for one period ahead (γ_{t+1}^{*}) is estimated from all the information available at the present time (Ω_t). The variance–covariance matrix (H) of error-terms from the bivariate VECM in Equation (13) becomes time-varying (H_t) following a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) framework (Bollerslev, 1987). Similar conditional variance approaches on error-terms are used by Park and Switzer (1995a) and Kroner and Sultan (1993), amongst others, to estimate time-varying optimal hedge ratios. Following the estimations of the VAR- (or VECM-) GARCH model, time-varying covariances and variances are used to calculate MVHRs. The UMHRs can be estimated using the $Bias_{t+1}$ and $Var_t(PF_{m,t+1})$ along with the MVHRs, as in Equation (5). The optimal weights for the *cross hedge* portfolio are estimated using a non-linear convex optimization technique (see Tuy *et al.*, 1998 and Bertsekas *et al.*, 2003 for more details) to minimize the total risks (variance) associated with the freight rate and freight futures' returns.

5.2.4. Evaluation of portfolio performance

In this section, we present the criteria used to evaluate the performance of the various models. A comparative analysis is also conducted to select the most effective model.

5.2.4.1. Performance of well-diversified portfolio of freight rates

We compare an equally weighted (undiversified) portfolio of freight rates with the estimated *well-diversified* portfolio of freight rates which maximises the return for each level of risk. The portfolio performance is measured as the percentage variance reduction (*VR*) of the *well-diversified* portfolio of freight rates over and above the equally weighted portfolio of freight rates:[50]

$$VR_{WD\_EW} = \frac{Var(R_{EW})-Var(R_{WD})}{Var(R_{EW})} \times 100 \quad (14)$$

[50] The variance of the global minimum variance portfolio is used against the equally weighted portfolio, as a *well-diversified* portfolio can provide various sets of portfolios producing different returns at different level of risks. As the *VR* measure aims to minimize the risk of exposure, we have considered the global minimum variance portfolio as a measure to estimate the decrease in variance due to diversification.

where $Var(R_{EW})$ and $Var(R_{WD})$ represent the variance of the *equally weighted* and *well-diversified* portfolio returns, respectively. A higher *VR* corresponds to greater diversification performance.

5.2.4.2. Performance of direct hedge using freight futures

Various alternative constant and time-varying hedge ratio specifications are estimated to evaluate the hedging performance of the *direct hedging* portfolio corresponding to MVHRs and UMHRs.[51] For each of the vessel-type sub-sectors, three different hedge ratios are estimated; that is, two constant hedge ratios are estimated from OLS and VECM models, while a time-varying hedge ratio is estimated from a VECM-GARCH model. In addition to the three computed hedge ratios for each sub-sector, a naïve hedge ratio is also used as a benchmark, where the hedge ratio is equal to one ($\gamma_t^* = 1$). The following two measures are used to estimate the hedging effectiveness of the various models:

Variance Reduction (VR): This measure compares the reduction of the variance of the hedged portfolio ($Var(R_{H,t})$) over the variance of the unhedged portfolio, ($Var(\Delta S_t)$) as follows:

$$VR = \frac{Var(\Delta S_t) - Var(R_{H,t})}{Var(\Delta S_t)} \times 100 \tag{15}$$

Between the alternative competing models, the one with the highest *VR* is the one with the highest hedging effectiveness. For the OLS model, the *VR* of the hedged portfolio is computed by the coefficient of determination (R^2) of the OLS regression; that is, the higher the R^2 the greater the hedging effectiveness.

Utility Increase (UI): This measure considers the hedger's risk-averse attitude through a utility function, as in Equation (4). Consider the following utility increase equation:

$$UI = E_t U\left(R_{H,t+1}\right) - E_t U(\Delta S_{t+1}) \tag{16}$$

The model with the higher *UI* has the greater performance at a certain level of risk. The *VR* and *UI* measures are used to determine which of the models is more suitable for reducing risk and increasing utility from hedging, respectively.

[51] If the freight rates corresponding to freight futures returns are time-varying, then the optimal hedge ratio needs to be periodically (say, weekly or monthly) adjusted with new information arriving in the market.

5.2.4.3. Performance of cross hedge using freight futures

The model with highest hedging effectiveness estimated from the *direct hedge* portfolio is utilised to generate a portfolio comprising of all seven different freight futures as well as the corresponding physical freight rates. Restrictions on freight rates are imposed in all scenarios, as discussed above. The performance of the *cross hedge* portfolio is evaluated using both the *VR* and *UI* criteria as follows:

Variance Reduction (VR): The variance of the *cross hedge* portfolio return, $Var(R_{CH})$, is compared with the variance of the *well-diversified* portfolio, $Var(R_{WD})$ using:

$$VR_{CH\_WD} = \frac{Var(R_{WD}) - Var(R_{CH})}{Var(R_{WD})} \times 100 \tag{17}$$

where the variances of returns are estimated for both the *cross hedge* and the *well-diversified* portfolios for the various scenarios. If VR_{CH_WD} is positive – the variance of the *cross hedge* portfolio is lower than the *well-diversified* portfolio – then this indicates that the *cross hedge* outperforms the *well-diversified* portfolio. A higher hedging performance of the *cross hedge* portfolio would be reflected in a higher VR_{CH_WD}.

Utility Increase (UI): The expected utility increase of the *cross hedge* portfolio returns over and above the *well-diversified* portfolio return indicates an increase in the satisfaction level due to holding the *cross hedge* portfolio, as compared to only holding the *well-diversified* portfolio:

$$UI_{CH\_WD} = E_t[U(R_{CH,t+1})] - E_t[U(R_{WD,t+1})] \tag{18}$$

A higher level of satisfaction corresponds to a higher *UI* level (UI_{CH_WD}).

5.2.4.4. Comparative analysis of performance: direct hedge vs. cross hedge

The *VR* and *UI* of the *direct hedge* portfolio are estimated with respect to the *well-diversified* portfolio using Equation (19) and (20), respectively:

$$VR_{DH\_WD} = \frac{Var(R_{WD}) - Var(R_{DH})}{Var(R_{WD})} \times 100 \tag{19}$$

$$UI_{DH\_WD} = E_t\left[U\left(R_{DH,t+1}\right)\right] - E_t\left[U\left(R_{WD,t+1}\right)\right] \tag{20}$$

where VR_{DH_WD} and UI_{DH_WD} represent the *VR* and *UI* of the *direct hedge* portfolio, respectively. The *direct hedge* portfolio (P_{DH}) of futures contracts is formed by applying Constraint C on the *well-diversified* portfolio (P_{WD}) of freight rates. Finally, the *VR* and *UI* of the *cross hedge* portfolio with respect to the *direct hedge* portfolio are obtained using Equations (21) and (22), respectively:

$$VR_{CH\_DH} = \frac{Var(R_{DH}) - Var(R_{CH})}{Var(R_{DH})} \times 100 \tag{21}$$

$$UI_{CH\_DH} = E_t\left[U\left(R_{CH,t+1}\right)\right] - E_t\left[U\left(R_{DH,t+1}\right)\right] \tag{22}$$

A positive VR_{CH_DH} and UI_{CH_DH} would indicate that the *cross hedge* portfolio outperforms the *direct hedge* portfolio.

5.3. Data Description

This study utilizes weekly (Friday) closing prices of physical freight rates for: (i) Shanghai – North West Europe (NWE) and Shanghai–US West Coast (USWC) container SCFI routes of SSE, as reported by Clarksons Shipping Intelligence Network (SIN); (ii) Time-Charter Equivalent (TCE) rates for Capesize, Panamax and Supramax dry-bulk vessels, as reported by the Baltic Exchange; and (iii) Rotterdam–US East Coast (TC2) and Middle East–Japan (TD3) tanker routes, as reported by the Baltic Exchange.[52] These freight rate routes are selected as they are the most liquid in terms of trading in the three shipping sub-sectors. Corresponding weekly (Friday) freight futures prices are used for the aforementioned freight

[52] The choice of Friday observations is due to the restriction of reporting of container data, as SSE produces the SCFI index every Friday at 15:00hrs Beijing Time. Also, as one reviewer mentioned, the freight revenue from a portfolio of operated vessels does not need to be related only to a specific day of the week (Friday), as physical charters could last several weeks. However, the “optimal” hedge rebalancing frequency is left for future research, and so a weekly frequency is selected which is in accordance with both the general finance and freight derivatives literature.

routes: Container derivatives prices are provided by LCH.Clearnet and Freight Investor Services (FIS), while dry-bulk and tanker futures prices are provided by the Baltic Exchange.[53]

A total of 263 weekly observations, from February 2011 to June 2016 are used for all three sub-sectors. Where a holiday occurs on Friday, then the Thursday observation is used instead.[54] Rolling near-month and second near-month maturity freight futures contracts are used in the ensuing analysis.[55] All prices are transformed into natural logarithms. The choice of a weekly data frequency is justified by the fact that it is not very realistic in practice to rebalance hedge positions on a daily basis, due to excessively high transaction costs.[56] Further, as freight futures contracts suffer from liquidity, bid-ask spreads tend to be relatively high and, as such, daily repositioning of the hedge positions are found to be not cost-effective (Alizadeh *et al.*, 2015b). The weekly hedge frequency is also in line with the past literature (Kavussanos and Nomikos (2000a) Kavussanos and Visvikis (2010).

This study uses three different types of freight rates to create a physical *well-diversified* portfolio; that is, dry-bulk time-charter (T/C) rates (quoted in US$/day), tanker voyage charter rates (quoted in US$/tonne) and container spot charter rates (quoted in US$/TEU). The choice of freight rates in each sector (say dry-bulk, tanker and container) is based on the liquidity of their corresponding freight futures contracts. T/C futures are more liquid for Capesize, Panamax and Supramax markets where TD2 and TC3 route futures and Shanghai–North West Europe and Shanghai–US West coast futures are more liquid for the tanker and container segment, respectively. As dry-bulk T/C rates are global averages of several freight rate routes, while tanker and container rates represent a single freight route, we employ a control process to verify that there is no discrepancy between holding mixed portfolios of these freight rates. We, therefore, conduct correlation tests between dry-bulk T/C rates and major dry-bulk single routes, with results indicating high correlations in all cases. This

[53] At the time of writing, dry-bulk derivatives prices are provided to the Baltic Exchange by: BRS Brokers, Clarkson Securities Ltd., Freight Investor Services Ltd., BRS Brokers, Clarkson Securities Ltd., Freight Investor Services Ltd., GFI Brokers, Pasternak Baum & Company Inc., and Simpson Spence & Young Ltd, Pasternak Baum & Company Inc., and Simpson Spence & Young Ltd. Similarly, tanker derivatives prices are reported to the Baltic Exchange by: ACM–GFI joint venture group, Marex Spectron and Howe Robinson Partners.

[54] Thursday prices are considered as the SSE also reports their container index on Thursday when there is a holiday on Friday.

[55] Near-month contracts refer to the monthly-averaged futures contracts, which start from the beginning of next month and mature at the end of next month. Second near-month contracts start in the second following month and settle at the end of the second next month. A perpetual contract rollover technique is used at the last trading day of the month, to avoid any price jumps at the expiration period of the derivatives contracts.

[56] We assume a total transaction cost of 1.5% for each futures trade, which includes 1% administrative and brokerage fees (as also assumed by Alizadeh and Nomikos, 2009) plus 0.5% clearing fees.

implies that the T/C rates can be safely used instead of route-specific freight rates for the dry-bulk segment.

Table 5.1 reports the descriptive statistics and stationarity test results of logarithmic freight rates and corresponding near-month and second near-month freight futures contracts for the container, dry-bulk, and tanker sub-sectors. The physical freight rates and freight futures returns are presented in Panels A and B, respectively. The results indicate that unconditional volatilities of both freight rate and freight futures returns for the NWE route are higher than those for the USWC route. Similarly, the Capesize is the most volatile dry-bulk sub-sector, followed by the Panamax and Supramax sub-sectors. In the tanker segment, the TD3 route is more volatile than the TC2 route. Near-month freight futures contracts are more volatile than second near-month futures' contracts, which may be due to the surge in last moment trading activities as contracts approach maturity. The stationarity for each returns is determined by the ADF (Dickey and Fuller, 1981) and PP (Phillips and Perron, 1988) unit root tests. The results suggest that all log-prices are non-stationary in levels and stationary in first-differences, indicating that the variables are integrated of order one, $I(1)$. After applying the Johansen (1988) cointegration test, the results indicate that for all non-stationary price pairs tested, a cointegrating vector exists with a linear combination of freight rates and corresponding freight futures prices.

Table 5.2 presents the (i) correlations coefficients between the physical freight rates (Panel A), (ii) correlations between freight rates and near-month futures contracts (Panel B) and (iii) correlations between freight rates and second near-month freight futures' prices (Panel C). High correlations are observed between the freight rates of each sub-sector; that is, the North East Europe (NWE) and US West Coast (USWC) container routes are 41.7% correlated while the correlation between the Capesize (CAPE), Panamax (PANA) and Supramax (SUPRA) freight rates lies between 25% and 52%. Correlations between the TC2 and TD3 tanker freight rates, conversely, are very low, which could be the result of the lead-lag relationships between the demand for crude oil and product tankers. The correlations between the three sub-sectors are very low or negative, highlighting the potential diversification benefits from holding a mixed portfolio of sectoral freight rates. Panel B and C indicate that there exists a high correlation between freight rates and their corresponding freight futures contracts, in addition to significant cross-correlations between freight rates and freight futures contracts within the sub-sector. The cross-correlation within the container and dry-bulk sectors are as high as 18% and 38% respectively, whereas the cross-correlation within the tanker sector is relatively low, with the highest cross-correlation of only 10%. This preliminary analysis provides us with an intuition that *cross hedge* using freight futures contracts can be used to hedge freight rate fluctuations along with a direct hedge to improve hedging effectiveness.

	T	Mean	Std. Dev.	Skew	Kurt	*Q*(4)	*Q*(12)	$Q^2(4)$	$Q^2(12)$	ARCH (4)	ARCH (12)	J-B	ADF (lev)	PP (lev)
Panel A: Freight Rate Returns														
NWE_*S*	202	-0.00545	0.156	2.891	17.639	9.254	28.752	1.828	27.199	1.710	22.740	2084.924	-13.548	-13.548

Table 5.1 Descriptive Statistics of Weekly Logarithms for Freight Rate and Freight Futures

USWC_S	202	-0.00047	0.054	1.541	7.453	12.158	26.577	1.152	9.715	1.117	9.904	246.855	-13.119	-13.119
CAPE_S	202	-0.00146	0.230	0.325	4.264	31.565	78.491	8.172	19.244	7.888	18.541	16.998	-9.992	-9.992
PANA_S	202	-0.00517	0.132	2.171	14.532	15.807	24.430	0.043	0.984	0.042	0.958	1278.001	-11.748	-11.748
SUPRA_S	202	-0.00399	0.060	-0.170	6.684	79.241	100.477	14.673	21.110	13.874	17.179	115.209	-7.391	-7.391
TC2_S	202	-0.00017	0.116	0.831	5.264	2.306	12.665	0.468	10.997	0.478	15.230	66.380	-15.040	-15.040
TD3_S	202	0.00130	0.109	0.122	5.840	14.086	26.826	32.906	33.893	27.306	29.165	68.404	-15.429	-15.429
<u>Panel B: Freight Futures Returns</u>														
NWE_F_1	202	-0.00254	0.076	0.317	9.427	5.721	14.540	5.084	12.352	5.151	11.176	351.033	-12.359	-12.359
NWE_F_2	202	-0.00156	0.060	1.121	15.259	9.515	18.439	4.212	6.044	4.267	6.800	1307.236	-12.526	-12.526
USWC_F_1	202	-0.00047	0.039	0.897	10.130	1.233	20.192	1.198	8.427	1.161	8.734	454.938	-13.878	-13.878
USWC_F_2	202	-0.00022	0.038	-0.837	12.457	5.600	14.592	8.293	13.800	16.511	20.643	776.337	-16.250	-16.250
CAPE_F_1	202	-0.00316	0.175	-0.064	3.278	9.108	24.035	0.570	8.502	0.789	9.371	0.789	-14.499	-14.499
CAPE_F_2	202	-0.00423	0.135	-0.429	4.823	6.410	16.226	0.419	2.730	0.426	2.453	34.170	-14.884	-14.884
PANA_F_1	202	-0.00527	0.107	0.651	6.482	2.724	6.840	2.706	3.624	2.333	2.956	116.319	-14.903	-14.903
PANA_F_2	202	-0.00561	0.078	0.744	5.477	1.733	9.524	11.903	20.837	11.248	20.468	70.271	-13.604	-13.604
SUPRA_F_1	202	-0.00390	0.071	0.083	3.550	6.554	14.442	4.230	8.103	3.438	7.227	2.781	-14.245	-14.245
SUPRA_F_2	202	-0.00408	0.061	-0.687	5.614	6.347	11.686	8.366	12.793	8.744	12.763	73.406	-13.192	-13.192
TC2_F_1	202	-0.00002	0.074	0.048	4.000	10.739	22.933	6.202	11.263	5.095	10.457	8.504	-17.394	-17.394
TC2_F_2	202	-0.00038	0.053	-0.304	5.195	17.419	39.904	24.874	25.954	26.529	28.003	43.675	-19.390	-19.390
TD3_F_1	202	0.00030	0.080	0.630	6.358	12.020	15.862	19.435	23.248	16.235	19.611	108.243	-16.067	-16.067
TD3_F_2	202	-0.00010	0.055	0.973	6.994	8.134	10.508	5.517	8.734	5.097	8.116	166.134	-15.336	-15.336

Notes: S and F_1 (F_2) represent corresponding freight rates and near-month (second near-month) freight futures returns, respectively. For example, NWE_S and USWC_F_2 represent the NWE (North West Europe) freight rate and USWC (US West Coast) the second near-month futures returns, respectively. T is the number of observations. Mean and Std. Dev. are the sample mean and standard deviation of the series, respectively. Skew and Kurt are the estimated centralized third (skewness) and fourth (kurtosis) moments of the data, respectively. J-B is the Jarque and Bera (1980) test for normality. $Q(4)$ and $Q^2(4)$ are the Ljung and Box (1978) Q-statistic on the first 4 lags of the sample autocorrelation function of the raw price series and the squared price series, respectively; the statistic is distributed as $\chi^2(4)$. ARCH(4) is the Engle (1982) test for ARCH effects; the statistic is distributed as $\chi^2(4)$; Similar tests are also conducted for 12 lags with qualitatively the same results.

Panel A: Freight Rates							
	NWE_S	**USWC_S**	**CAPE_S**	**PANA_S**	**SUPRA_S**	**TC2_S**	**TD3_S**
NWE_S	1						
USWC_S	0.417	1					
CAPE_S	0.025	-0.101	1				
PANA_S	-0.102	-0.105	0.329	1			
SUPRA_S	-0.057	-0.138	0.250	0.519	1		
TC2_S	0.053	0.032	0.016	-0.066	-0.022	1	
TD3_S	-0.087	-0.117	0.104	0.136	0.071	-0.011	1
Panel B: Freight Rates and Near-month Futures							
	NWE_S	**USWC_S**	**CAPE_S**	**PANA_S**	**SUPRA_S**	**TC2_S**	**TD3_S**
NWE_F_1	0.314	0.179	-0.066	-0.071	-0.027	-0.028	-0.149
USWC_F_1	0.081	0.382	-0.115	-0.011	-0.080	0.032	-0.094
CAPE_F_1	0.091	0.015	0.641	0.198	0.098	-0.010	0.084
PANA_F_1	-0.080	-0.071	0.298	0.548	0.181	-0.049	0.076
SUPRA_F_1	-0.121	-0.119	0.237	0.433	0.476	-0.028	0.050
TC2_F_1	0.076	0.031	-0.036	-0.035	-0.050	0.520	0.099
TD3_F_1	0.035	-0.035	0.056	0.136	0.045	-0.082	0.641
Panel C: Freight Rates and Second near-month Futures							
	NWE_S	**USWC_S**	**CAPE_S**	**PANA_S**	**SUPRA_S**	**TC2_S**	**TD3_S**
NWE_F_2	0.223	0.122	-0.010	-0.134	-0.142	-0.005	-0.075
USWC_F_2	0.073	0.244	-0.118	-0.082	-0.120	0.081	-0.095

Table 5.2 Correlations between Weekly Logarithm of Freight Rates and Freight Futures

CAPE_F_2	-0.011	0.011	0.493	0.106	0.066	-0.014	-0.011
PANA_F_2	-0.081	-0.050	0.291	0.464	0.133	-0.066	0.027
SUPRA_F_2	-0.198	-0.066	0.235	0.377	0.355	-0.027	-0.037
TC2_F_2	-0.013	-0.045	-0.012	-0.009	-0.036	0.284	0.094
TD3_F_2	-0.049	-0.059	0.130	0.204	0.039	-0.084	0.524

Notes: See the notes to Table 5.1 for the definitions of the variables.

5.4. Empirical Results

Both in-sample and out-of-sample tests are performed to investigate the performance of the *well-diversified* portfolio comprising physical freight rates, as well as the *direct hedge* and *cross hedge* portfolios also comprising freight futures. In-sample tests are performed from February 2011 to April 2015 based on a total of 202 observations (weekly), while weekly rolling out-of-sample tests are conducted from April 2015 to June 2016 based on 60 observations.

5.4.1. Performance of well-diversified portfolio of freight rates

Due to the negative correlations between the container, dry-bulk, and tanker freight rates, as seen in Table 5.2, we investigate if shipping market practitioners can minimise their freight rate exposure through holding a *well-diversified* portfolio of freight routes. The *VR* and *UI* of the *well-diversified* portfolio, over and above an equally weighted portfolio of freight rates, are presented in Table 5.3.[57] In-sample and out-of-sample tests are reported in Panels A and B, respectively. The results indicate that there is a significant decrease in the variance of the *well-diversified* portfolio relative to an equally weighted portfolio in all the scenarios examined. In-sample and out-of-sample tests suggest that the *well-diversified* portfolio reduces freight rate risks between 28–48% and 32–48%, respectively, except scenario 6. [58] The w*ell-diversified* portfolio for the base scenario, comprising freight rates in all three sub-sectors, produces a *VR* out-of-sample of up to 42%. Moreover, we document a utility increase in all scenarios (except again in scenario 6 for out-of-sample observations) for the *well-diversified* portfolio. Overall, the findings suggest that the traditional freight rate risk management through portfolio diversification can be an effective risk management solution.

[57] An equally weight portfolio of freight rates is used as a benchmark.
[58] Scenario 6, TC2 and TD3 freight rate routes produce very low correlation, as presented in Table 5.2. This results in no effective reduction of variance through diversification.

	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Panel A: In-Sample Performance							
$\boldsymbol{\sigma^2_{EW}}$	0.05612	0.07070	0.07434	0.06002	0.09011	0.11049	0.07767
$\boldsymbol{\sigma^2_{WD}}$	0.03320	0.03699	0.04821	0.04324	0.05425	0.05974	0.07754
$\boldsymbol{VR_{WD\_EW}}$	40.84%	47.68%	35.16%	27.96%	39.80%	45.93%	0.17%
$\boldsymbol{U_{EW}}$	-0.00535	-0.00831	-0.00742	-0.00480	-0.01108	-0.01575	-0.00547
$\boldsymbol{U_{WD}}$	-0.00267	-0.00349	-0.00469	-0.00197	-0.00349	-0.00756	-0.00540
$\boldsymbol{UI_{WD\_EW}}$	0.00268	0.00482	0.00274	0.00282	0.00759	0.00819	0.00006
Panel B: Out-of-Sample Performance							
$\boldsymbol{\sigma^2_{EW}}$	0.06194	0.07911	0.07658	0.07279	0.12401	0.11110	0.08191
$\boldsymbol{\sigma^2_{WD}}$	0.03626	0.04147	0.04874	0.04928	0.06802	0.05950	0.08168
$\boldsymbol{VR_{WD\_EW}}$	41.49%	47.61%	36.35%	32.25%	45.03%	46.45%	0.27%
$\boldsymbol{U_{EW}}$	-0.00598	-0.00923	-0.00762	-0.00693	-0.01878	-0.01520	-0.00682
$\boldsymbol{U_{WD}}$	-0.00365	-0.00468	-0.00499	-0.00365	-0.00669	-0.00737	-0.00685
$\boldsymbol{UI_{WD\_EW}}$	0.00233	0.00455	0.00263	0.00328	0.01209	0.00783	-0.00004

Table 5.3 Performance of *Well-Diversified* Portfolio of Freight Rates

Notes: σ^2_{EW} (σ^2_{WD}) and U_{EW} (U_{WD}) denote the variances and utilities of an equally weighted (*well-diversified*) portfolio of freight rates, respectively. U_{EW} and U_{WD} are calculated for the coefficient of risk aversion (*k*) equal to 1. VR_{WD_EW} and UI_{WD_EW} are the variance reduction (*VR*) and utility increase (*UI*) of the *well-diversified* portfolio with respect to an equally weighted portfolio of freight rates.

5.4.2. Performance of direct hedge portfolio

Results for in-sample and out-of-sample *VR* (and *UI*) for both near-month and second near-month freight futures contracts are presented in Tables 5.4 (along with Table 5.4 cont.), respectively. In the container USWC route, the time-varying and naïve hedge ratio seem to produce the highest *VR* of 10.88% (4.48%) and 21.33% (12.50%) for in-sample and out-of-sample near-month (second near-month) freight futures, respectively. The opposite is found for the container NWE route, with the time-varying VECM-GARCH model outperforming all other specifications, with a *VR* of 10.30% (10.16%) and 10.10% (3.02%) for in-sample and out-of-sample near-month (second near-month) freight futures, respectively. [59] Overall, near-month freight futures perform better than second near-month freight futures for the container sub-sector. This may be attributed to an increase in last minute trading activity on

[59] Except for second near-month NWE futures contracts, where the conventional OLS model generates the highest *VR* of 10.77%

the back of more market information typically incorporated in near-month futures contracts approaching maturity compared to second near-month contracts. Further, the USWC freight futures perform better than the NWE freight futures (for out-of-sample analysis), reflected in the higher freight rate variance of the latter route. This may be driven by the lower number of liner services in the Shanghai–US route, pointing to a more stable freight rate environment in this case.[60]

In-sample tests for the dry-bulk sub-sector suggest that the conventional OLS model generates the highest hedging effectiveness for Capesize and Panamax freight futures, with a *VR* of 38.13% (22.76%) and 31.20% (23.48%) for near-month (second near-month) freight futures, respectively. In contrast, for Supramax freight futures, the VECM-GARCH model exhibits the highest *VR* of 19.25% (14.62%) for near-month (second near-month) freight futures contracts. Out-of-sample tests suggest that the VECM-GARCH (VECM) model produces the highest *VR* of 33.48% (13.38%) for near-month (second near-month) Supramax freight futures. Further, a naïve hedge ratio model performs better for Capesize freight rates with a *VR* of 47.51% (27.44%) for near-month (second near-month) freight futures contracts. Panamax freight futures generate highest hedging effectiveness using an OLS (VECM-GARCH) model for near-month (second near-month) contracts with a *VR* of 21.91% (10.26%). Overall, the Capesize freight futures have the highest performance due to their higher liquidity in terms of trading volume. It appears that similar to container futures, near-month dry-bulk freight futures perform better than second near-month freight futures.

A time-varying hedge ratio using a VECM-GARCH model generates the highest hedging effectiveness for in-sample analysis with tanker freight futures contracts, with a *VR* of 27.52% (10.04%) and 48.22% (32.47%) for near-month (second near-month) TC2 and TD3 futures contracts, respectively. In contrast, constant hedge ratios perform better for out-of-sample analysis, with a *VR* of as high as 29.17% (19.03%) and 34.31% (23.45%) for near-month (second near-month) TC2 and TD3 futures contracts, respectively. TD3 freight futures contracts perform better than TC2 freight futures contracts.

In general, the results suggest that the *VR* for all models and across all different freight futures is relatively low, with an average of around 20%. In addition, all freight futures prices seem to follow a martingale process, with the MVHR equal to the UMHR for all coefficients

[60] During the sample period (2011–2016), Europe imported on average 34 million TEU containers annually, whereas the US imported on average only 21 million.

of risk aversion. This limits the usefulness of freight futures contracts for investment/speculative purposes, which could be attributed to the low market liquidity, creating sticky (stale) prices. Thus, the *UI* criterion is estimated only for the case of the risk-neutral (k = 1) participant as a measure of the increase of the utility function due to hedging. In-sample tests indicate that both the OLS and VECM-GARCH models perform similarly, whereas out-of-sample tests indicate that the OLS model performs best in most scenarios.

Finally, we investigate if the risks associated with the *well-diversifying* portfolio of physical freight rates are further reduced when using freight futures. To this end, freight futures contracts are added to the *well-diversified* portfolio, where the weights of these futures contracts are estimated using the MVHR of Equation (3) (see Portfolio 2, Constraint C, in Section 5.2). The decision to keep the weights of the physical freight rates unchanged, while hedging the freight rate exposure, is motivated by the fact that practitioners tend to use open positions in the physical freight market by considering the risk-return trade-off of this market, rather than that of the freight derivatives market.

Table 5.4 Direct Hedge Performance: In-sample Tests

	Near-Month Contracts							Second Near-Month Contracts						
	Container		Dry Bulk			Tanker		Container		Dry Bulk			Tanker	
	NWE_1	USWC_1	CAPE_1	PANA_1	SUPRA_1	TC2_1	TD3_1	NWE_2	USWC_2	CAPE_2	PANA_2	SUPRA_2	TC2_2	TD3_2
Panel 1a: Minimum Variance Hedge Ratio – MVHR														
Naïve	1	1	1	1	1	1	1	1	1	1	1	1	1	1
OLS	0.54	0.45	0.81	0.69	0.36	0.80	0.95	0.85	0.29	0.82	0.82	0.34	0.53	1.10
VECM	0.51	0.45	0.81	0.73	0.39	0.87	0.95	0.85	0.27	0.87	0.91	0.38	0.74	1.08
VECM-GARCH	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panel 1b: Variance of Hedged Portfolio														
Unhedged	0.02432	0.00295	0.05313	0.01733	0.00357	0.01345	0.01195	0.02432	0.00295	0.05313	0.01733	0.00357	0.01345	0.01195
Naïve	0.02379	0.00311	0.03384	0.01304	0.00493	0.00996	0.00626	0.02179	0.00357	0.04168	0.01346	0.00475	0.01276	0.00831
OLS	0.02260	0.00264	0.03287	0.01192	0.00289	0.00975	0.00624	0.02170	0.00282	0.04104	0.01326	0.00313	0.01234	0.00828
VECM	0.02261	0.00264	0.03287	0.01194	0.00289	0.00977	0.00624	0.02170	0.00282	0.04110	0.01331	0.00313	0.01238	0.00829
VECM-GARCH	0.02182	0.00263	0.03291	0.01196	0.00288	0.00975	0.00619	0.02185	0.00282	0.03972	0.01326	0.00305	0.01210	0.00807
Panel 1c: Variance Reduction – *VR*														
Naïve	2.19%	-5.48%	36.31%	24.76%	-38.17%	25.97%	47.62%	10.42%	-20.98%	21.56%	22.34%	-32.99%	5.08%	30.45%
OLS	7.09%	10.43%	38.13%*	31.20%*	19.00%	27.54%	47.76%	10.77%*	4.20%	22.76%	23.48%*	12.39%	8.21%	30.68%
VECM	7.06%	10.43%	38.13%	31.08%	18.92%	27.34%	47.76%	10.77%	4.17%	22.63%	23.18%	12.20%	7.92%	30.67%
VECM-GARCH	10.30%*	10.88%*	38.05%	31.02%	19.25%*	27.52%*	48.22%*	10.16%	4.48%*	25.24%*	23.47%	14.62%*	10.04%*	32.47%*
Panel 2a: Expected Utility (*k* = 1)														
Unhedged	-0.02953	-0.00328	-0.05539	-0.02290	-0.00782	-0.01432	-0.01107	-0.02953	-0.00328	-0.05539	-0.02290	-0.00782	-0.01432	-0.01107
Naïve	-0.02633	-0.00298	-0.03101	-0.01289	-0.00478	-0.01096	-0.00512	-0.02533	-0.00368	-0.03909	-0.01313	-0.00469	-0.01412	-0.00709
OLS	-0.02636	-0.00277	-0.03106	-0.01357	-0.00555	-0.01075	-0.00512	-0.02550	-0.00310	-0.03939	-0.01400	-0.00592	-0.01354	-0.00703
VAR	-0.02646	-0.00277	-0.03103	-0.01336	-0.00546	-0.01078	-0.00512	-0.02549	-0.00310	-0.03917	-0.01352	-0.00576	-0.01365	-0.00704
VAR-GARCH	-0.02383	-0.00285	-0.03134	-0.01316	-0.00548	-0.01047	-0.00480	-0.02400	-0.00334	-0.03984	-0.01386	-0.00515	-0.01194	-0.00754
Panel 2b: Utility Increase – *UI* (*k* = 1)														
Naïve	0.00320	0.00030	0.02437*	0.01001*	0.00304*	0.00336	0.00594	0.00420	-0.00040	0.01629*	0.00977*	0.00313*	0.00021	0.00397
OLS	0.00317	0.00051	0.02433	0.00933	0.00227	0.00357	0.00594	0.00403	0.00018*	0.01600	0.00890	0.00190	0.00078	0.00404*
VAR	0.00307	0.00052*	0.02436	0.00955	0.00236	0.00355	0.00594	0.00404	0.00018	0.01622	0.00939	0.00206	0.00068	0.00403

VAR-GARCH	0.00570*	0.00043	0.02405	0.00974	0.00234	0.00385*	0.00626*	0.00553*	-0.00006	0.01555	0.00904	0.00267	0.00238*	0.00353

Table 5.4 Direct Hedge Performance: Out-of-sample Tests

	Near-Month Contracts							**Second Near-Month Contracts**						
	Container		**Dry Bulk**			**Tanker**		**Container**		**Dry Bulk**			**Tanker**	
	NWE_1	**USWC_1**	**CAPE_1**	**PANA_1**	**SUPRA_1**	**TC2_1**	**TD3_1**	**NWE_2**	**USWC_2**	**CAPE_2**	**PANA_2**	**SUPRA_2**	**TC2_2**	**TD3_2**
Panel 1a: Variance of Hedged Portfolio														
Unhedged	0.18372	0.01811	0.09001	0.00852	0.00429	0.00935	0.04127	0.18372	0.01811	0.09001	0.00852	0.00429	0.00935	0.04127
Naïve	0.15919	0.01425	0.04725	0.00975	0.00378	0.00701	0.02711	0.17899	0.01585	0.06531	0.00955	0.00522	0.00772	0.03184
OLS	0.16568	0.01548	0.04773	0.00666	0.00289	0.00663	0.02730	0.17962	0.01704	0.06600	0.00786	0.00372	0.00769	0.03159
VECM	0.16562	0.01525	0.04741	0.00681	0.00290	0.00671	0.02725	0.17976	0.01701	0.06563	0.00827	0.00372	0.00757	0.03160
VECM-GARCH	0.16517	0.01557	0.04769	0.00693	0.00286	0.00678	0.02935	0.17816	0.01674	0.06671	0.00765	0.00377	0.00778	0.03216
Panel 1b: Variance Reduction – *VR*														
Naïve	13.35%	21.33%*	47.51%*	-14.43%	12.00%	25.10%	34.31%*	2.58%	12.50%*	27.44%*	-12.04%	-21.48%	17.50%	22.84%
OLS	9.82%	14.55%	46.98%	21.91%*	32.68%	29.17%*	33.85%	2.23%	5.90%	26.67%	7.83%	13.37%	17.84%	23.45%*
VECM	9.85%	15.81%	47.33%	20.12%	32.56%	28.32%	33.97%	2.16%	6.09%	27.09%	3.00%	13.38%*	19.03%*	23.44%
VECM-GARCH	10.10%*	14.01%	47.02%	18.70%	33.48%*	27.56%	28.88%	3.02%*	7.55%	25.89%	10.26%*	12.15%	16.86%	22.08%
Panel 2a: Expected Utility (*k* = 1)														
Unhedged	-0.17483	-0.03091	-0.08335	-0.01001	-0.00528	-0.01744	-0.05204	-0.17483	-0.03091	-0.08335	-0.01001	-0.00528	-0.01744	-0.05204
Naïve	-0.14284	-0.01573	-0.04443	-0.00908	-0.00361	-0.00825	-0.02999	-0.16000	-0.01696	-0.06221	-0.01051	-0.00498	-0.01073	-0.03504
OLS	-0.15213	-0.02249	-0.04369	-0.00653	-0.00390	-0.00923	-0.02985	-0.16179	-0.02608	-0.06252	-0.00897	-0.00444	-0.01241	-0.03339
VECM	-0.15190	-0.02190	-0.04347	-0.00660	-0.00363	-0.00888	-0.02983	-0.16156	-0.02614	-0.06247	-0.00938	-0.00435	-0.01178	-0.03342
VAR-GARCH	-0.15087	-0.02109	-0.04386	-0.00533	-0.00426	-0.00906	-0.03175	-0.14977	-0.02228	-0.06449	-0.00908	-0.00407	-0.01096	-0.03513
Panel 2b: Utility Increase – *UI* (*k* = 1)														
Naïve	0.03199*	0.01518*	0.03891	0.00092	0.00166*	0.00919*	0.02205	0.01483	0.01395*	0.02114*	-0.00050	0.00029	0.00671*	0.01699
OLS	0.02270	0.00842	0.03966	0.00347	0.00137	0.00821	0.02219	0.01305	0.00483	0.02083	0.00104*	0.00083	0.00503	0.01865*
VECM	0.02294	0.00901	0.03987*	0.00341	0.00164	0.00856	0.02220*	0.01327	0.00477	0.02088	0.00062	0.00093	0.00566	0.01862
VECM-GARCH	0.02397	0.00982	0.03949	0.00467*	0.00102	0.00838	0.02029	0.02507*	0.00863	0.01886	0.00092	0.00121*	0.00648	0.01691

Notes: NWE_1 and NWE_2 are the NWE container freight routes hedged with corresponding near-month and second near-month freight futures, respectively. Similarly, USWC_1 (USWC_2), CAPE_1 (CAPE_2), PANA_1 (PANA_2), SUPRA_1 (SUPRA_2), TC2_1 (TC2_2) and TD3_1 (TD3_2) are USWC, Capesize, Panamax, Supramax, TC2 and TD3 freight routes hedged with corresponding near- (second near-) month freight futures contracts, respectively. * denotes the model with the highest variance reduction (*VR*) and utility increase (*UI*) per hedge model. *k* is the coefficient of risk aversion.

Table 5.5 presents the *VR* and *UI* of the direct hedge portfolio over and above the *well-diversified* portfolio of freight rates, for both in-sample and out-of-sample tests, Equations (19) and (20). Results indicate that the *direct hedge* portfolio using freight futures further decrease the freight rate risk associated with the *well-diversified* portfolio of freight rates up to as high as 17.52% (observed in the out-of-sample analysis for scenario 6). We also observe that the *UI* for all the scenarios are positive indicating that use of freight futures contracts with a *direct hedge* approach increases the satisfaction level of the hedgers in addition to the traditional optimal diversification. Further, near-month freight futures contracts produce higher *VR* as compared to second near-month futures contracts. Overall, the models in-sample and out-of-sample perform similarly, with the highest *VR* observed in Scenario 6. This indicates that market participants with a mixed portfolio of tanker freight rate routes will receive the highest risk minimisation through freight futures hedging.

	Base	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**

Table 5.5 Direct Hedge vs. Well-diversified Portfolio Performance

	Scenario						
Panel A: In-Sample Performance							
$\boldsymbol{\sigma^2_{WD}}$	0.03320	0.03699	0.04821	0.04324	0.05425	0.05974	0.07754
$\boldsymbol{\sigma^2_{DH,1}}$	0.02978	0.03395	0.04335	0.03793	0.05135	0.05379	0.06497
$\boldsymbol{VR_{DH\_WD,1}}$	10.31%	8.23%	10.08%	12.28%	5.34%	9.97%	16.21%
$\boldsymbol{\sigma^2_{DH,2}}$	0.03114	0.03489	0.04581	0.04088	0.05308	0.05600	0.07259
$\boldsymbol{VR_{DH\_WD,2}}$	6.20%	5.70%	4.98%	5.45%	2.14%	6.26%	6.38%
$\boldsymbol{U_{WD}}$	-0.00267	-0.00349	-0.00469	-0.00197	-0.00349	-0.00756	-0.00540
$\boldsymbol{U_{DH,1}}$	-0.00185	-0.00247	-0.00338	-0.00145	-0.00295	-0.00546	-0.00375
$\boldsymbol{UI_{DH\_WD,1}}$	0.00083	0.00102	0.00131	0.00052	0.00053	0.00210	0.00165
$\boldsymbol{U_{DH,2}}$	-0.00194	-0.00261	-0.00352	-0.00168	-0.00328	-0.00573	-0.00451
$\boldsymbol{UI_{DH\_WD,2}}$	0.00073	0.00088	0.00117	0.00029	0.00021	0.00182	0.00090
Panel B: Out-of-Sample Performance							
$\boldsymbol{\sigma^2_{WD}}$	0.03626	0.04147	0.04874	0.04928	0.06802	0.05950	0.08168
$\boldsymbol{\sigma^2_{DH,1}}$	0.03281	0.03813	0.04324	0.04343	0.06390	0.05311	0.06736
$\boldsymbol{VR_{DH\_WD,1}}$	9.50%	8.04%	11.27%	11.73%	5.89%	10.70%	17.52%
$\boldsymbol{\sigma^2_{DH,2}}$	0.03468	0.03932	0.04607	0.04719	0.06593	0.05573	0.07541
$\boldsymbol{VR_{DH\_WD,2}}$	4.01%	4.83%	5.42%	3.68%	2.40%	6.29%	7.56%
$\boldsymbol{U_{WD}}$	-0.00365	-0.00468	-0.00499	-0.00365	-0.00669	-0.00737	-0.00685
$\boldsymbol{U_{DH,1}}$	-0.00231	-0.00302	-0.00346	-0.00232	-0.00482	-0.00514	-0.00466
$\boldsymbol{UI_{DH\_WD,1}}$	0.00134	0.00166	0.00153	0.00133	0.00186	0.00223	0.00220
$\boldsymbol{U_{DH,2}}$	-0.00261	-0.00335	-0.00378	-0.00287	-0.00554	-0.00556	-0.00574
$\boldsymbol{UI_{DH\_WD,2}}$	0.00103	0.00133	0.00121	0.00078	0.00115	0.00181	0.00111

Notes: $\sigma^2_{DH,1}(U_{DH,1})$ and $\sigma^2_{DH,2}$ $(U_{DH,2})$ are the variances (utilities) of the near-month and second near-month returns of the *direct hedge* portfolios, respectively. $VR_{DH\_WD,1}$ $(UI_{DH\_WD,1})$ and $VR_{DH\_WD,2}$ $(UI_{DH\_WD,2})$ are the *VR* and *UI* of the *direct hedge* over and above the *well-diversified* portfolio. See the notes to Table 5.3 for the definitions of the other variables.

5.4.3. Performance of cross hedge portfolio

As the last step, we estimate a *cross-hedge* portfolio of freight futures to hedge the risks associated with the *well-diversified* portfolio of physical freight rates without changing the weights of the freight rates within the latter portfolio.[61] Similar to the previous section, *VR* and *UI* are used as measures of hedging performance of the *cross hedge* portfolio over and above the *well-diversified* portfolio of freight rates. The results presented in Table 5.6 indicate that the *cross hedge* portfolio using freight futures can further reduce the risks associated with the *well-diversified* portfolio of freight rates. The results are qualitatively similar both in-sample and out-of-sample.[62] Further, near-month futures contracts generate higher hedging effectiveness than second-month futures contracts. Similar to the *direct hedge*

[61] Details of the freight rate weights of the *cross hedge* portfolios are presented in Section5.2.
[62] Following a comment by a reviewer, we have replicated the cross hedge analysis again with only dry-bulk and tanker futures' contracts (without including container futures). The results suggest that for several scenarios, including container futures yields higher variance reductions, which is consistent with the view that including this segment adds value to the strategy.

portfolio, the *UI* of the *cross hedge* portfolio over and above the *well-diversified* portfolio is positive for all the scenarios.

	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Panel A: In-Sample Performance							
σ^2_{WD}	0.03320	0.03699	0.04821	0.04324	0.05425	0.05974	0.07754
$\sigma^2_{CH,1}$	0.02954	0.03356	0.04319	0.03789	0.05092	0.05375	0.06450
$VR_{CH\_WD,1}$	11.01%	9.29%	10.41%	12.38%	6.14%	10.02%	16.82%
$\sigma^2_{CH,2}$	0.03073	0.03420	0.04572	0.04070	0.05234	0.05584	0.07223
$VR_{CH\_WD,2}$	7.45%	7.54%	5.16%	5.88%	3.50%	6.53%	6.84%
U_{WD}	-0.00267	-0.00349	-0.00469	-0.00197	-0.00349	-0.00756	-0.00540
$U_{CH,1}$	-0.00184	-0.00244	-0.00340	-0.00138	-0.00277	-0.00547	-0.00366
$UI_{CH\_WD,1}$	0.00084	0.00105	0.00128	0.00059	0.00072	0.00209	0.00174
$U_{CH,2}$	-0.00178	-0.00236	-0.00364	-0.00140	-0.00255	-0.00572	-0.00445
$UI_{CH\_WD,2}$	0.00089	0.00113	0.00105	0.00058	0.00094	0.00184	0.00095
Panel B: Out-of-Sample Performance							
σ^2_{WD}	0.03626	0.04147	0.04874	0.04928	0.06802	0.05950	0.08168
$\sigma^2_{CH,1}$	0.03268	0.03796	0.04313	0.04328	0.06362	0.05309	0.06682
$VR_{CH\_WD,1}$	9.87%	8.47%	11.49%	12.02%	6.29%	10.75%	18.19%
$\sigma^2_{CH,2}$	0.03455	0.03918	0.04604	0.04714	0.06597	0.05566	0.07509
$VR_{CH\_WD,2}$	4.80%	5.62%	5.54%	4.31%	3.00%	6.45%	8.06%
U_{WD}	-0.00365	-0.00468	-0.00499	-0.00365	-0.00669	-0.00737	-0.00685
$U_{CH,1}$	-0.00241	-0.00307	-0.00348	-0.00230	-0.00456	-0.00513	-0.00456

Table 5.6 Cross Hedge vs. Well-diversified Portfolio Performance

$\boldsymbol{UI_{CH\_WD,1}}$	0.00124	0.00161	0.00151	0.00135	0.00213	0.00224	0.00229
$\boldsymbol{U_{CH,2}}$	-0.00272	-0.00340	-0.00389	-0.00275	-0.00505	-0.00555	-0.00565
$\boldsymbol{UI_{CH\_WD,2}}$	0.00093	0.00127	0.00110	0.00090	0.00163	0.00182	0.00121

Notes: $\sigma^2_{CH,1}(U_{CH,1})$ and $\sigma^2_{CH,2}$ $(U_{CH,2})$ are the variances (utilities) of the near-month and second near-month returns of the *cross hedge* portfolios, respectively. $VR_{CH\_WD,1}$ $(UI_{CH\_WD,1})$ and $VR_{CH\_WD,2}$ $(UI_{CH\_WD,2})$ are the *VR* and *UI* of the *cross hedge* over and above the *well-diversified* portfolio. See the notes to Table 5.3 for the definitions of the other variables.

A comparative analysis of the cross hedge and the direct hedge portfolios is also performed, based on the *VR* and *UI* criteria calculated from Equations (21) and (22), respectively. The weights of the physical freight rates in both portfolios are the same as in the *well-diversified* portfolio of freight rates, as shown in Constraints C and D (in Section 5.2). In-sample and out-of-sample tests are presented in Table 5.7, indicating that the *cross hedge* portfolio marginally outperforms the direct hedge portfolio by reducing the variance of the portfolio up to 1.96% (for in-sample analysis in Scenario 1).

	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Panel A: In-Sample Performance							
$\sigma^2_{DH,1}$	0.02978	0.03395	0.04335	0.03793	0.05135	0.05379	0.06497
$\sigma^2_{CH,1}$	0.02954	0.03356	0.04319	0.03789	0.05092	0.05375	0.06450
$VR_{CH\_DH,1}$	0.78%	1.15%	0.38%	0.11%	0.84%	0.06%	0.73%
$\sigma^2_{DH,2}$	0.03114	0.03489	0.04581	0.04088	0.05308	0.05600	0.07259
$\sigma^2_{CH,2}$	0.03073	0.03420	0.04572	0.04070	0.05234	0.05584	0.07223
$VR_{CH\_DH,2}$	1.34%	1.96%	0.19%	0.45%	1.39%	0.28%	0.49%
$U_{DH,1}$	-0.00185	-0.00247	-0.00338	-0.00145	-0.00295	-0.00546	-0.00375
$U_{CH,1}$	-0.00184	-0.00244	-0.00340	-0.00138	-0.00277	-0.00547	-0.00366
$UI_{CH\_DH,1}$	0.00001	0.00003	-0.00002	0.00007	0.00019	-0.00001	0.00009
$U_{DH,2}$	-0.00194	-0.00261	-0.00352	-0.00168	-0.00328	-0.00573	-0.00451
$U_{CH,2}$	-0.00178	-0.00236	-0.00364	-0.00140	-0.00255	-0.00572	-0.00445
$UI_{CH\_DH,2}$	0.00016	0.00025	-0.00012	0.00029	0.00073	0.00002	0.00005
Panel B: Out-of-Sample Performance							
$\sigma^2_{DH,1}$	0.03281	0.03813	0.04324	0.04343	0.06390	0.05311	0.06736

Table 5.7 Cross Hedge vs. Direct Hedge Portfolio Performance

$\boldsymbol{\sigma^2_{CH,1}}$	0.03268	0.03796	0.04313	0.04328	0.06362	0.05309	0.06682
$\boldsymbol{VR_{CH\_DH,1}}$	0.41%*	0.47%*	0.25%*	0.33%*	0.42%*	0.05%*	0.81%*
$\boldsymbol{\sigma^2_{DH,2}}$	0.03468	0.03932	0.04607	0.04719	0.06593	0.05573	0.07541
$\boldsymbol{\sigma^2_{CH,2}}$	0.03455	0.03918	0.04604	0.04714	0.06597	0.05566	0.07509
$\boldsymbol{VR_{CH\_DH,2}}$	0.88%*	0.87%*	0.14%*	0.71%*	0.63%*	0.18%*	0.60%*
$\boldsymbol{U_{DH,1}}$	-0.00231	-0.00302	-0.00346	-0.00232	-0.00482	-0.00514	-0.00466
$\boldsymbol{U_{CH,1}}$	-0.00241	-0.00307	-0.00348	-0.00230	-0.00456	-0.00513	-0.00456
$\boldsymbol{UI_{CH\_DH,1}}$	-0.00011	-0.00005	-0.00002	0.00002	0.00026	0.00001	0.00009
$\boldsymbol{U_{DH,2}}$	-0.00261	-0.00335	-0.00378	-0.00287	-0.00554	-0.00556	-0.00574
$\boldsymbol{U_{CH,2}}$	-0.00272	-0.00340	-0.00389	-0.00275	-0.00505	-0.00555	-0.00565
$\boldsymbol{UI_{CH\_DH,2}}$	-0.00009	-0.00005	-0.00019	0.00001	0.00022	-0.00028	0.00014

Notes: $VR_{CH\_DH,1}$ ($UI_{CH\_DH,1}$) and $VR_{CH\_DH,2}$ ($UI_{CH\_DH,2}$) are the *VR* (and *UI*) of the *cross hedge* over and above the *direct hedge* portfolio, respectively. See the notes to Tables 5.5 and 5.6 for the definitions of the other variables. * denotes significance at 99% level for out-of-sample *VR*.

The out-of-sample *VR* of the cross hedge over and above the direct hedge is found to be statistically significant at the 99% level. This indicates that a marginal benefit of the *cross hedge* with the use of futures contracts is observed over the *direct hedge*. Moreover, the *cross hedge* portfolio performs relatively better for second near-month futures contracts compared to near-month futures contracts. Second near-month futures contracts produce a further *VR* as high as 1.96% (0.88%), whereas near-month futures contracts produce the highest *VR* of 1.15% (0.81%) in-sample (out-of-sample).

5.5. Conclusion

This study develops for the first time a new portfolio approach combining the physical diversification of freight rates and the financial hedging of freight derivatives, in three major sub-sectors (container, tanker and dry-bulk) of the international shipping industry. It is also the first to provide insights on the hedging performance of the recently developed container futures market, with the underlying container segment of the shipping industry corresponding up to 60% of the overall value of goods transported by sea. The examination of container freight derivatives becomes relevant given the emerging nature of this market, potentially making corporate owners and operators reluctant to utilise it for hedging their freight rate exposures. This is reflected in its relatively low liquidity, which in turn leads to the inferior hedging effectiveness of the container freight futures contracts relative to more mature shipping futures markets (dry-bulk and tanker). The results point to a decrease in freight rate risk up to 48% by holding a diversified portfolio of freight rates, and an additional decrease of up to 8% by hedging freight rate risk with futures contracts. This study highlights that practitioners can realise additional benefits (minimising their risk exposure) by holding freight futures' contracts together with a well-diversified portfolio of freight rates. The results can also act as a yardstick for researchers to gain a better understanding of the correlations between freight futures and underlying freight rate markets and, thus, help to improve hedging strategies. The findings have important implications for overall business, commercial and hedging strategies in the shipping industry, and can encourage the trading of freight futures contracts, which can potentially lead to improvements in freight futures markets liquidity.

6. Conclusion

6.1. Summary and Concluding Remarks

This thesis provides a wide-ranging methodology and unfolds new findings in derivatives and risk management for shipping and commodities. The work aims to investigate and explore some of the unchartered and overlooked investment opportunities for shipowners and charterers and provide effective risk management solutions. These risk management strategies are developed through market anticipation (Chapter 3 and 4) and hedging market fluctuations (Chapter 5). A strong underpinning of the research is provided by an extensive literature review that covers the development of information transmission and hedging of both equities and commodities (including freight) markets. This is important for readers who do not have expertise in this specialised area, creating a path for a better understanding of the flow of the research. The three empirical chapters (Chapters 3–5) also provide more a more specific literature review, aiming to motivate the respective research topics.

The spillover effect between futures, options and underlying physical freight rates are investigated in Chapter 3, which demonstrates that options contracts, despite being derivative contracts, suffer from market liquidity and fail to react to new market information. The results suggest that freight futures contracts absorb new market information and spill it to freight rates, followed by freight options contracts. This provides valuable information for investors and hedgers, who can use options contracts for generating returns and to hedge freight rate fluctuations, respectively.

This is the first study to investigate the lead-lag relationships between freight rates and their corresponding futures and options prices. Most of the research in the area of freight options have focused on the pricing of options contracts. This is the first study of freight options markets to focus on the information transmission of such markets along with physical freight and futures markets. This is also the first research to investigate the price movement of commodity options in relation to commodity prices, as freight is considered a non-storable commodity where e freight options are calculated using Black (1976) with freight futures as the underlying asset instead of physical freight rates, as estimated using Black and Scholes (1973). The findings suggest that, despite not having any theoretical linkage between freight rates and freight options prices, there exist bi-directional information flows between the two markets. Chapter 3 reports the strong information spillover and existence of such bi-directional information flows between freight rates, freight futures and freight options markets, whereby new information is first absorbed into futures markets and then is transmitted to the physical freight market followed by the freight options markets. It also suggests that the slow reaction of the freight options markets can be attributed to the higher market friction caused by market illiquidity.

Based on the lead-lag relationships between derivatives (including futures and options) and physical freight rate markets, investment and hedging strategies for maximising the return on investment and minimising the risks of freight rate fluctuation are developed. The aim is to help understand the price movements of the unexplored options markets and encourage hedgers and investors to trade in options contracts. They can take advantage of the slow-moving options' markets and thereby improve market liquidity. These findings add value for not just practitioners but are also of interest to academic researchers. The price discrepancy in the freight options markets is observed, which should encourage research not just into a better options pricing model but also into the unseen arbitrage opportunities available in the current Black (1976) option pricing model. Most importantly, this work provides a stepping stone for new academic research for emerging on freight options contracts, which will create an awareness amongst market players about the use of freight options contracts as an important hedging instrument.

The extension of the lead-lag relationship between freight derivatives contracts and physical freight rates for only dry-bulk markets is extended to capture the lead-lag relationship between the various maritime commodities and freight rates, along with their futures contracts. This chapter utilises a total of 65 variables at various frequencies (daily, weekly and monthly observations) to estimate a reference variable for a group of economically significant variables. This helps to calculate the leading and lagging variables in that group. The outcome supports the theory of derived demand for freight rate and freight futures contracts where the prices are derived from the physical commodity and commodity futures prices, as investigated by Kavussanos et al. (2014), although the previous findings were only limited to dry-bulk commodity and shipping markets whereas this research captures both dry and wet commodity and shipping markets. While the previous models mostly used a vector autoregressive (VAR) model to investigate the spillover effect between the variables where only a few variables can be together for fear of losing the degree of freedom, this model utilizes a dynamic multi-factor model where all the variables can be regressed together without losing the degree of freedom due to addition of variables. Overall, it can be observed that crude oil (including its derivative products) prices drive the prices of metal and agricultural commodities. The commodity futures, and their underlying spot prices, also govern freight futures and underlying freight rates, respectively.

One of the major reason for the crude oil market driving commodity and transportation costs is that crude oil is the major source of energy around the globe, and hence any crude oil price fluctuation strongly affects all macroeconomic variables. These results are valuable for a wide range of market practitioners, including commodity houses, charterers, shipowners, export-import banks, and policy-makers, amongst others. More specifically, commodity houses that trade in metal commodities such as iron ore, steel, etc., agriculture commodities such as wheat, corn, soybeans, corn, barley, etc., along with liquid bulk commodity traders such as petroleum products, can observe the price movements of the crude oil market and hold their positions, as crude oil prices drive other commodity prices. Charterers and shipowners who are exposed to freight rate fluctuations can utilise these research findings to observe the commodity markets before holding a position in the freight markets. For example, if commodity prices are increasing (decreasing), freight prices will subsequently increase (decrease), and hence the charterers and shipowner should hold long (short) and short (long) term time-charter (T/C) contracts, respectively. Government policy-makers involved in the international trade activities of any country can take advantage of this research to understand the fluctuations in both commodity and freight markets and provide a dynamic policy to improve countries' trading activities. Chapter 4 contributes to the literature by providing spillover relationships between a wide range of commodities and freight markets. The interdependencies between the variables are observed, along with an extensive list of previous studies along with new and important findings that have not been investigated in the past. The study considers a dynamic multi-factor model which is widely used in macroeconomic studies. Though commodity and international transportation constitute a major part of macroeconomics, a dynamic multi-factor benchmark is not so widely used for these sectoral studies, especially for freight markets. This chapter acts like such a benchmark by which multi-factor models can be used for freight markets to examine various unexplored areas.

Chapter 5, the third and final empirical chapter, completes the risk management solution by providing both traditional and financial hedging strategies to minimise the variances of the returns generated from freight rates for shipowners. Ocean freight rates are subjected to high fluctuations. To hedge freight rate fluctuations, shipowners use various techniques: (a) a traditional hedging model through the diversification of a portfolio of freight – as the freight markets are cyclical with low correlation between the three major sectors of shipping (dry-bulk, tanker, and container sector), shipowners hold a portfolio of freight rates so that the fluctuation of cash-flow generated through freight rates is decreased; (b) with the recent development of freight derivatives markets for all three major sectors of shipping (dry-bulk, tanker and container sectors) shipowners can also hedge their freight rate fluctuations by the use of freight futures' contracts. There has been no research investigating the reduction in variance due to holding an optimally diversified portfolio of freight rates. So, this is the first study to empirically test the effectiveness of hedging freight rate fluctuations through diversification of freight rates' contracts, and the results suggest that efficient diversification could reduce freight rate fluctuations by up to 48% (for both in-sample and out-of-sample analysis). This study has also tried to improve the hedging performance of the low-performing freight futures contracts through a portfolio hedge model, and the findings demonstrate that the variance of freight rate fluctuations can be reduced up to 8% over and above traditional diversification. It is also the first study to investigate the hedging performance of the newly developed container freight futures contracts. It also demonstrates that a portfolio of futures approach for hedging the underlying freight fluctuation can provide better hedging than conventional direct hedging by calculating optimal hedge ratio of individual freight futures contracts.

Overall, the results suggest that combining traditional hedging strategies by diversifying the freight rate amongst dry-bulk, tanker and container sectors along with a portfolio of freight futures' contracts significantly reduce freight rate variances. This research can not only help the traditional shipowners who do not have expertise in financial derivative markets, but also the modern investors (shipowners) who can use freight futures contracts to minimise their risk exposures. The results can be used by shipowners, investors, banks and other financial institutions which are affected by freight rates fluctuations not only to safeguard themselves from bankruptcy as the entire shipping industry is not performing well (that is, freight rates are extremely low) but also to generate higher and more stable returns. The analysis is also valid for charterers, commodity houses, commodity traders, etc., who buy freights from shipowners. Indeed, Chapter 5 provides an impressive improvement in variance reduction of freight rates. It enhances the hedging performances of freight futures contracts are compared to previous studies (Alizadeh et al., 2015a). These results should not only encourage market players, including shipowners and charterers, to use freight futures contracts to hedge their exposures but can also play a vital role in improving the liquidity of freight futures contracts. As market liquidity of these contracts increases, the performances of freight futures contracts should be expected to increase (Figlewski, 1984, Park and Switzer, 1995b).

6.1.1. Summarizing industry implications

Overall, this thesis should help market practitioners such as shipowners, charterers and investors, amongst others, not only to minimise freight rate fluctuations but also to increase their returns to stay ahead of the competition in the following ways:

(1*) Anticipate the market*: Having a view of future market conditions helps shipowners and charterers to take different contract positions. For example, if the freight market is expected to rise in the future, the shipowner (charterer) should hold short (long) term T/C contracts, and vice versa. Though forecasting the market accurately is impracticable, an understanding the direction of market movement always helps to secure cash-flow for investors. One of the common and widely used methods to anticipate the market is by observing a highly correlated market, which helps a better understanding of the movement of the lagging market by observing the leading one. Chapter 3 and 4 utilise asymmetric information absorption in the various markets to estimate the leading market (the market which absorbs new market information faster) and then understand the price movement of the lagging market (the market which is resistant to new market information and hence reacts slowly to it). The information spillover between dry-bulk freight rates and their corresponding futures and options market is investigated in Chapter 3 to help understand the movement of freight rates by observing futures' and options' prices. Chapter 4 extends this analysis to explore the price movement between freight rates and commodity prices. As ocean freight is derived demand for commodity prices, understanding freight rate movements by observing commodity price movements can provide a holistic view of freight markets.

(2) *Hedging freight rate fluctuations*: Hedging freight rate fluctuations by the use of various traditional and financial hedging techniques are explored in Chapter 5. Traditional hedging involves diversification of freight rates whereas a financial hedging model includes the use of

freight futures/forward contracts.[63] The hedging performance of freight futures' contracts is low and suffers from market liquidity. This restricts traditional shipowners from using freight futures' contracts to hedge freight rate fluctuations. This research thus presents a traditional hedging model by diversifying futures rates between tramp (dry-bulk and tankers) and liner (container) shipping. This research also provides financial hedging strategies using freight futures' contracts to minimise underlying freight rate fluctuations.

This research thus provides an in-depth understanding of constructing risk management solutions for both shipowners and charterers using both forecasting and hedging models. The study is not only important for practitioners but also for academics, as it examines some of the so far unexplored areas, not only contributing to the existing literature but also providing new methodologies.

6.2. Future Research Suggestions

Research is a never-ending process; no matter how efficient and innovative the research work being conducted by academics, there is always the opportunity for improvement. Every piece of research acts as a stepping-stone for future development. Some research work carves a path for future discoveries, as the existing work provides a framework and creates a market for further research. Possible future research work building on the research conducted in this thesis is presented in this section. Chapters 3–5 provide several areas that can be investigated in the future.

6.2.1. Freight options arbitrage opportunity

Chapter 3 investigates the lead-lag relationship between dry-bulk freight rates and their corresponding futures and options contracts. Freight options contracts informatically lag the other two markets, primarily attributable to low market liquidity. There could be a hidden arbitrage opportunity available within the lagged options markets. So, firstly, future researchers could investigate the existence of arbitrage opportunities within the freight options contracts due to asymmetric information availability. This could encourage not only hedgers but also various investors to enter into the exotic Asian options market and thereby lead to an increase in market liquidity.

[63] Freight forward contracts are hereafter referred as "freight futures'" contracts to simplify the text for readers.

As freight options contracts considered to be illiquid markets, investors are sceptical about entering this market if there is a risk of not being able to liquidate their investments. Chapter 3 also measures the liquidity of such freight options contracts for the first time in the literature. This study demands that we construct an optimal pricing model for freight options which needs to consider the illiquidity risk premium for investors who are venturing into freight options contracts. Using the market liquidity as a parameter, the study provides a dynamic pricing model which prices a higher illiquidity risk premium as market liquidity decreases and vice versa. This could provide an innovative pricing model not only for freight options but also for the general options market suffering from market liquidity.

6.2.2. Freight futures pricing

Chapter 5 attempts to provide an improved risk management solution to hedge freight rate volatilities by traditional diversification and by the use of financial hedging technology. As freight futures contracts also lack liquidity as compared to other futures markets, they fail to reflect freight rates efficiently. The difference between freight rates and freight futures contracts is also attributable to the fact that physical freight rates involve higher readjustment costs, and hence the market price reacts slowly to the news. On the other hand, freight futures prices react faster to new market information, which causes a price discrepancy with the underlying freight rates. Freight futures contracts are also monthly averaged types of contracts that are settled at the end of maturity against the average of the maturity month freight rates. Due to price discrepancy and the difference in the settlement process, investigating the correct pricing of futures contracts can provide useful information.

Estimating the correct dynamic pricing of freight rates can help freight futures prices to efficiently move close to freight rates and thereby improve the hedging performance of the freight futures contracts. Dynamic pricing will readjust freight futures prices as the contracts approach maturity. As the contract enters its maturity month, the liquidity of the contract significantly drops and the lognormal distribution breaks. The dynamic pricing of freight futures’ contracts will not only provide a better instrument to hedge such fluctuations efficiently but also could also demonstrate whether the present futures contracts provide investment opportunities. There has also not been any research to investigate whether futures contracts converge at maturity time. As the payoffs of the freight futures contracts are settled against the average of the underlying freight rates of the maturity month, unlike general futures contracts that are settled against their lag value, there could be some possibility of mispricing of freight futures contracts at the maturity month. Finding the existence of underpricing or overprice within freight futures contracts can not only generate interesting investment opportunities but also help to estimate the optimal pricing and thereby improve the hedging performances.

6.3. Limitations

Every academic research is subject to some limitations, which holds true for this thesis as well. The major limitation of the thesis could be attributed to the information biases present in the freight derivatives markets. This information bias is created mainly for two reasons: (i) Most of the derivatives trades are conducted in the over-the-counter (OTC) market and, for regulatory compliances, are documented in various exchanges. So, the counterparties have two business days to document their trading activities according to the Markets in Financial Instruments Directive II (MiFID II) regulation. Hence, instant information is not available to academics although it is available to practitioners; (ii) freight derivatives contracts suffer from market illiquidity, and hence the freight derivatives prices used in Chapter 3 and 4 may not efficiently reflect the market. Nevertheless, the research conducted in Chapter 3 and 4 are stepping-stones, providing information that can be used by practitioners to generate higher profitability and better risk management solutions. This process can, in return, increase awareness about the use of freight derivatives contracts and increase in market liquidity. Similarly, the container freight futures' contracts which were started by Shanghai Shipping Exchange in collaboration with Clarksons and SGX Asiaclear and were later joined by LCH.Clearnet and Freight Investor Services (FIS) to form the Container Freight Derivative Association (CFDA) are not performing very well in terms of trading activities as the container freight market is at an all-time low and shipowners do not want to settle their freight futures' agreements at such low prices. Though the trading activities are low for container futures' contracts now, as the container market revives and volatility increases, the futures trading volume can be expected to increase.

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Appendix

Table 0.1 Spectral Coherence Monthly Reduced (periodicity @ 36 months)

	BCI_TCE	BPI_TCE	BPI_TCE	TC2$	TD3$	BHSI	BDTI	BCTI	4TC_C+1MON	4TC_C+2MON	4TC_P+1MON	4TC_P+2MON	5TC_S+1MON
BCI_TCE	100.0%	27.5%	12.2%	18.7%	1.9%	9.8%	4.0%	5.7%	77.9%	50.6%	34.7%	16.3%	17.4%
BPI_TCE	27.5%	100.0%	89.5%	20.9%	4.2%	24.2%	1.4%	84.5%	55.4%	62.7%	78.2%	55.3%	80.9%
BPI_TCE	12.2%	89.5%	100.0%	36.9%	9.0%	42.7%	9.8%	92.5%	35.5%	41.8%	60.4%	42.8%	86.1%
TC2$	18.7%	20.9%	36.9%	100.0%	8.3%	95.1%	42.4%	27.8%	23.7%	18.5%	17.4%	13.8%	35.5%
TD3$	1.9%	4.2%	9.0%	8.3%	100.0%	7.5%	19.2%	3.0%	11.4%	5.3%	3.0%	0.9%	11.4%
BHSI	9.8%	24.2%	42.7%	95.1%	7.5%	100.0%	28.1%	36.4%	20.2%	21.9%	23.1%	24.0%	42.3%
BDTI	4.0%	1.4%	9.8%	42.4%	19.2%	28.1%	100.0%	5.6%	1.4%	1.4%	3.3%	12.2%	1.7%
BCTI	5.7%	84.5%	92.5%	27.8%	3.0%	36.4%	5.6%	100.0%	26.8%	37.6%	52.2%	41.4%	68.8%
4TC_C+1MON	77.9%	55.4%	35.5%	23.7%	11.4%	20.2%	1.4%	26.8%	100.0%	88.0%	65.1%	46.7%	42.3%
4TC_C+2MON	50.6%	62.7%	41.8%	18.5%	5.3%	21.9%	1.4%	37.6%	88.0%	100.0%	83.8%	77.2%	53.3%
4TC_P+1MON	34.7%	78.2%	60.4%	17.4%	3.0%	23.1%	3.3%	52.2%	65.1%	83.8%	100.0%	89.3%	80.1%
4TC_P+2MON	16.3%	55.3%	42.8%	13.8%	0.9%	24.0%	12.2%	41.4%	46.7%	77.2%	89.3%	100.0%	64.3%
5TC_S+1MON	17.4%	80.9%	86.1%	35.5%	11.4%	42.3%	1.7%	68.8%	42.3%	53.3%	80.1%	64.3%	100.0%
5TC_S+2MON	8.9%	58.4%	54.7%	15.8%	8.5%	26.6%	5.5%	46.2%	37.4%	62.9%	85.7%	90.3%	81.0%
TC2$+1_M	15.2%	22.3%	40.8%	95.9%	21.9%	92.9%	46.0%	29.7%	24.9%	19.4%	18.0%	14.2%	39.8%
TC2$+2_M	14.7%	20.4%	37.9%	83.4%	41.2%	80.2%	43.6%	23.8%	25.9%	18.9%	18.6%	13.6%	42.0%
TD3$+1_M	3.1%	7.8%	15.4%	19.3%	95.8%	19.7%	20.6%	7.2%	16.9%	11.4%	7.5%	5.0%	19.4%
TD3$+2_M	0.3%	8.1%	18.2%	19.7%	88.7%	23.2%	14.3%	9.3%	11.2%	10.2%	9.5%	8.7%	25.3%
Crude	3.0%	6.5%	9.0%	5.1%	5.3%	15.7%	9.9%	11.7%	6.1%	25.5%	19.8%	44.4%	15.9%
Brent	6.0%	4.6%	8.4%	4.8%	7.7%	15.2%	6.5%	10.7%	3.3%	18.7%	14.2%	35.5%	14.0%
Heating_oil	5.8%	6.1%	10.4%	5.4%	8.3%	16.4%	6.4%	12.8%	3.6%	19.9%	16.5%	38.4%	16.8%
Natural_Gas	0.0%	19.9%	29.2%	20.8%	31.8%	33.0%	1.3%	29.8%	18.6%	32.8%	22.2%	33.6%	29.2%
Coal	0.7%	6.7%	15.2%	9.0%	47.4%	14.3%	0.1%	5.3%	3.7%	8.2%	16.5%	19.8%	35.2%
Wheat	24.3%	34.4%	16.6%	2.6%	12.8%	4.8%	20.5%	19.3%	25.7%	39.9%	57.1%	56.1%	26.3%
Soybeans	18.6%	0.1%	3.9%	15.7%	10.0%	22.7%	17.1%	6.3%	2.1%	0.3%	2.7%	0.1%	0.5%
Corn	42.7%	37.8%	23.4%	9.4%	0.2%	9.1%	4.3%	13.5%	37.9%	39.5%	63.9%	47.8%	46.5%
Iron	0.9%	25.8%	28.0%	7.5%	0.2%	21.4%	12.7%	35.9%	9.4%	36.2%	42.5%	69.2%	36.2%
Crude_F1	3.0%	6.4%	8.9%	5.2%	5.3%	15.9%	9.6%	11.7%	5.9%	25.2%	19.5%	44.0%	15.7%
Brent_F1	5.5%	5.0%	8.8%	5.3%	7.8%	16.1%	6.4%	11.1%	3.7%	19.6%	15.1%	36.9%	14.8%

Heating_F1	5.5%	6.1%	10.7%	6.1%	9.0%	17.4%	5.8%	12.7%	3.8%	19.8%	16.6%	38.3%	17.4%
Natural_gas_F1	0.1%	16.5%	26.2%	19.3%	35.9%	30.8%	1.7%	25.6%	15.6%	28.1%	18.8%	29.2%	27.2%
Natural_Gas_F2	10.6%	4.5%	8.3%	1.0%	24.1%	0.1%	9.1%	3.8%	0.0%	3.3%	11.9%	17.7%	21.8%
Coal_F1	3.9%	10.8%	24.8%	12.9%	41.0%	21.8%	0.9%	15.3%	2.4%	8.4%	15.3%	20.9%	38.1%
Coal_F2	2.1%	8.2%	18.6%	9.5%	46.1%	16.3%	0.2%	8.8%	3.0%	8.5%	16.1%	20.8%	36.1%
Wheat_F1	29.7%	29.6%	12.2%	1.9%	9.2%	3.3%	23.3%	12.2%	29.0%	41.6%	57.6%	55.7%	24.9%
Wheat_F2	28.4%	30.8%	12.9%	1.8%	8.5%	3.5%	24.9%	13.5%	30.2%	44.5%	59.7%	59.4%	25.7%
Soybeans_F1	19.0%	0.1%	4.0%	15.9%	8.2%	22.6%	18.8%	6.8%	2.5%	0.6%	3.3%	0.3%	0.4%
Soybeans_F2	20.6%	0.1%	4.2%	14.8%	7.3%	21.1%	20.2%	7.2%	3.4%	1.1%	4.1%	0.6%	0.2%
Corn_F1	39.5%	27.6%	12.6%	1.9%	1.0%	1.5%	9.6%	6.5%	28.3%	28.7%	50.3%	35.3%	29.7%
Corn_F2	39.1%	24.0%	9.3%	0.8%	2.5%	0.5%	10.6%	4.8%	25.0%	24.6%	43.9%	29.7%	23.0%
Iron_F1	0.0%	34.0%	50.1%	33.2%	9.7%	49.3%	2.2%	52.4%	15.0%	31.9%	30.8%	41.9%	46.3%
Iron_F2	0.1%	37.2%	56.5%	41.7%	13.8%	56.4%	5.8%	53.7%	17.1%	31.3%	32.3%	39.2%	53.9%
Copper	11.3%	1.5%	9.3%	6.6%	16.3%	11.3%	3.0%	6.1%	0.0%	1.2%	0.6%	2.9%	9.8%
Copper_F3	11.3%	1.1%	8.5%	6.2%	18.1%	10.5%	3.2%	5.0%	0.0%	0.9%	0.5%	2.4%	9.5%
Sugar	3.1%	11.2%	29.4%	67.7%	34.1%	68.7%	29.3%	14.5%	11.1%	10.1%	13.0%	11.9%	40.3%
Sugar_F1	4.1%	12.4%	30.7%	69.1%	33.5%	69.4%	29.5%	15.1%	12.0%	10.6%	14.4%	12.5%	42.5%
Sugar_F2	2.5%	10.1%	28.2%	67.4%	34.4%	68.2%	31.2%	13.9%	10.0%	8.9%	11.2%	10.3%	37.9%
Rice	32.3%	0.6%	0.0%	0.5%	5.9%	0.7%	2.6%	5.6%	9.3%	0.7%	2.3%	0.6%	3.2%
Rice_F1	30.8%	0.5%	0.0%	0.3%	6.5%	1.1%	3.0%	5.8%	8.6%	0.4%	1.8%	0.9%	2.8%
Rice_F2	31.0%	0.5%	0.0%	0.5%	7.6%	0.6%	2.5%	5.8%	9.3%	0.7%	2.4%	0.4%	3.4%
Barley	43.5%	16.9%	3.6%	0.1%	3.8%	0.8%	12.2%	1.0%	23.6%	19.8%	33.0%	18.6%	13.0%
Barley_F1	1.6%	3.1%	8.3%	16.8%	0.9%	23.1%	10.3%	17.1%	2.4%	5.8%	0.1%	2.3%	1.0%
Barley_F2	2.3%	4.1%	11.1%	14.2%	5.6%	19.0%	14.2%	17.5%	2.5%	4.9%	0.1%	1.1%	2.0%
Canola	14.9%	17.3%	6.8%	2.9%	2.0%	7.8%	23.0%	8.9%	39.6%	62.9%	49.9%	69.2%	17.2%
Canola_F1	12.8%	11.4%	2.0%	0.0%	0.0%	1.2%	39.6%	3.5%	30.0%	51.7%	43.5%	61.8%	10.2%
Canola_F2	26.7%	18.0%	4.7%	0.8%	0.1%	2.6%	29.6%	4.9%	41.1%	57.9%	53.8%	63.5%	16.7%
BDI	44.4%	92.6%	81.4%	32.5%	11.3%	33.8%	3.6%	70.4%	77.3%	78.6%	81.5%	58.6%	80.2%
BLPG1	37.7%	34.6%	46.4%	71.6%	39.8%	59.9%	48.6%	27.1%	45.0%	27.1%	25.9%	11.6%	48.0%
TD3	1.0%	0.9%	3.3%	5.0%	98.2%	4.2%	18.2%	0.5%	7.5%	2.5%	0.5%	0.0%	4.7%
TC2_37	17.1%	19.1%	34.6%	99.0%	4.2%	93.9%	42.9%	27.6%	20.2%	15.7%	14.5%	11.6%	30.9%
Urea	0.1%	7.3%	2.6%	1.5%	71.8%	0.1%	28.2%	8.5%	0.2%	2.7%	9.8%	14.9%	2.2%
DAP	7.2%	1.5%	7.9%	36.3%	67.2%	28.2%	41.1%	0.6%	10.9%	3.0%	1.4%	0.1%	13.4%
Ammonia	12.2%	27.5%	31.2%	20.1%	8.7%	13.3%	28.2%	32.7%	5.1%	1.3%	3.8%	0.0%	11.4%
Scrap VLCC	1.5%	0.4%	1.2%	2.8%	27.1%	9.3%	7.2%	0.6%	5.0%	16.4%	12.2%	29.8%	9.5%
Scrap Cape/Pana	0.2%	1.3%	1.7%	3.2%	24.4%	10.1%	9.2%	1.3%	8.8%	23.0%	17.1%	37.2%	10.7%

Note: The names and sources of the variables are presented in Table 0.11 in the Appendix.

Table 0.1 Spectral Coherence Monthly Reduced (periodicity @ 36 months), cont.

	5TC_S+2MON	TC2$+1_M	TC2$+2_M	TD3$+1_M	TD3$+2_M	Crude	Brent	Heating_oil	Natural_Gas	Coal	Wheat	Soybeans	Corn
BCI_TCE	8.9%	15.2%	14.7%	3.1%	0.3%	3.0%	6.0%	5.8%	0.0%	0.7%	24.3%	18.6%	42.7%
BPI_TCE	58.4%	22.3%	20.4%	7.8%	8.1%	6.5%	4.6%	6.1%	19.9%	6.7%	34.4%	0.1%	37.8%
BPI_TCE	54.7%	40.8%	37.9%	15.4%	18.2%	9.0%	8.4%	10.4%	29.2%	15.2%	16.6%	3.9%	23.4%
TC2$	15.8%	95.9%	83.4%	19.3%	19.7%	5.1%	4.8%	5.4%	20.8%	9.0%	2.6%	15.7%	9.4%
TD3$	8.5%	21.9%	41.2%	95.8%	88.7%	5.3%	7.7%	8.3%	31.8%	47.4%	12.8%	10.0%	0.2%
BHSI	26.6%	92.9%	80.2%	19.7%	23.2%	15.7%	15.2%	16.4%	33.0%	14.3%	4.8%	22.7%	9.1%
BDTI	5.5%	46.0%	43.6%	20.6%	14.3%	9.9%	6.5%	6.4%	1.3%	0.1%	20.5%	17.1%	4.3%
BCTI	46.2%	29.7%	23.8%	7.2%	9.3%	11.7%	10.7%	12.8%	29.8%	5.3%	19.3%	6.3%	13.5%
4TC_C+1MON	37.4%	24.9%	25.9%	16.9%	11.2%	6.1%	3.3%	3.6%	18.6%	3.7%	25.7%	2.1%	37.9%
4TC_C+2MON	62.9%	19.4%	18.9%	11.4%	10.2%	25.5%	18.7%	19.9%	32.8%	8.2%	39.9%	0.3%	39.5%
4TC_P+1MON	85.7%	18.0%	18.6%	7.5%	9.5%	19.8%	14.2%	16.5%	22.2%	16.5%	57.1%	2.7%	63.9%
4TC_P+2MON	90.3%	14.2%	13.6%	5.0%	8.7%	44.4%	35.5%	38.4%	33.6%	19.8%	56.1%	0.1%	47.8%
5TC_S+1MON	81.0%	39.8%	42.0%	19.4%	25.3%	15.9%	14.0%	16.8%	29.2%	35.2%	26.3%	0.5%	46.5%
5TC_S+2MON	100.0%	19.8%	23.3%	16.5%	24.7%	44.1%	38.6%	42.5%	41.2%	44.7%	35.9%	0.3%	45.5%
TC2$+1_M	19.8%	100.0%	94.7%	36.9%	37.4%	8.2%	8.5%	9.4%	31.5%	18.8%	0.6%	21.0%	7.8%
TC2$+2_M	23.3%	94.7%	100.0%	57.2%	57.4%	8.4%	9.2%	10.3%	34.7%	33.2%	0.0%	17.6%	9.8%
TD3$+1_M	16.5%	36.9%	57.2%	100.0%	96.1%	13.3%	16.4%	17.3%	46.6%	55.0%	8.0%	17.2%	0.7%
TD3$+2_M	24.7%	37.4%	57.4%	96.1%	100.0%	22.4%	26.8%	28.3%	54.5%	71.2%	6.7%	22.8%	0.9%
Crude	44.1%	8.2%	8.4%	13.3%	22.4%	100.0%	98.6%	98.5%	76.4%	34.7%	1.6%	33.7%	0.0%
Brent	38.6%	8.5%	9.2%	16.4%	26.8%	98.6%	100.0%	99.8%	79.4%	38.9%	0.0%	42.9%	0.7%
Heating_oil	42.5%	9.4%	10.3%	17.3%	28.3%	98.5%	99.8%	100.0%	80.0%	41.4%	0.2%	41.4%	0.3%
Natural_Gas	41.2%	31.5%	34.7%	46.6%	54.5%	76.4%	79.4%	80.0%	100.0%	41.8%	0.2%	50.8%	0.1%
Coal	44.7%	18.8%	33.2%	55.0%	71.2%	34.7%	38.9%	41.4%	41.8%	100.0%	1.0%	12.2%	6.3%
Wheat	35.9%	0.6%	0.0%	8.0%	6.7%	1.6%	0.0%	0.2%	0.2%	1.0%	100.0%	30.5%	69.4%
Soybeans	0.3%	21.0%	17.6%	17.2%	22.8%	33.7%	42.9%	41.4%	50.8%	12.2%	30.5%	100.0%	37.4%
Corn	45.5%	7.8%	9.8%	0.7%	0.9%	0.0%	0.7%	0.3%	0.1%	6.3%	69.4%	37.4%	100.0%
Iron	65.7%	8.8%	6.8%	3.6%	10.0%	81.9%	77.3%	79.8%	58.5%	23.2%	17.2%	18.0%	4.7%
Crude_F1	43.6%	8.3%	8.5%	13.3%	22.4%	100.0%	98.7%	98.5%	76.6%	34.4%	1.5%	34.3%	0.0%
Brent_F1	39.9%	9.2%	9.9%	16.6%	27.2%	98.8%	100.0%	99.8%	79.6%	39.5%	0.1%	42.1%	0.5%

Heating_F1	42.9%	10.4%	11.4%	18.4%	29.8%	98.3%	99.7%	99.9%	80.6%	43.1%	0.2%	41.6%	0.2%
Natural_gas_F1	38.6%	30.6%	35.0%	50.6%	59.1%	75.2%	79.4%	79.9%	99.4%	46.9%	1.0%	53.3%	0.4%
Natural_Gas_F2	39.6%	0.1%	3.3%	25.4%	40.0%	37.7%	42.2%	44.8%	30.7%	79.1%	0.6%	6.8%	1.8%
Coal_F1	45.1%	23.9%	34.8%	51.5%	69.5%	49.9%	56.6%	59.3%	62.3%	91.0%	2.4%	32.5%	0.8%
Coal_F2	45.8%	19.8%	32.9%	54.9%	72.3%	43.0%	48.4%	51.1%	52.0%	98.2%	1.7%	20.1%	3.1%
Wheat_F1	36.5%	0.4%	0.1%	5.6%	4.9%	1.3%	0.0%	0.1%	0.4%	0.2%	97.6%	37.7%	77.5%
Wheat_F2	39.2%	0.4%	0.1%	4.9%	4.1%	2.6%	0.3%	0.5%	0.0%	0.1%	97.7%	34.3%	75.3%
Soybeans_F1	0.1%	20.6%	16.5%	14.6%	19.6%	30.1%	38.8%	37.4%	47.0%	9.4%	30.6%	99.7%	39.3%
Soybeans_F2	0.0%	19.2%	15.0%	13.0%	17.7%	26.4%	35.0%	33.6%	43.4%	7.8%	31.9%	98.9%	41.5%
Corn_F1	30.2%	0.9%	1.5%	0.6%	0.7%	1.6%	4.7%	3.6%	4.4%	1.0%	73.1%	57.2%	95.5%
Corn_F2	23.2%	0.1%	0.3%	2.3%	2.6%	3.7%	8.1%	6.6%	8.0%	0.0%	74.3%	64.6%	91.3%
Iron_F1	49.3%	39.2%	34.5%	21.5%	30.8%	68.0%	70.2%	72.0%	84.0%	31.9%	0.9%	51.4%	0.2%
Iron_F2	50.5%	48.9%	45.1%	27.2%	37.1%	58.7%	61.5%	63.6%	80.6%	38.5%	0.5%	49.1%	0.8%
Copper	11.0%	11.9%	13.9%	22.8%	33.1%	46.2%	55.9%	55.2%	56.6%	46.0%	20.8%	64.8%	12.0%
Copper_F3	10.5%	11.7%	14.3%	24.5%	35.0%	44.2%	53.9%	53.3%	54.8%	48.7%	22.3%	62.7%	11.5%
Sugar	26.1%	78.2%	84.8%	49.6%	58.0%	17.5%	20.4%	21.7%	38.9%	56.9%	1.4%	28.3%	4.6%
Sugar_F1	27.0%	79.3%	86.0%	48.7%	56.7%	15.3%	17.8%	19.1%	35.8%	56.1%	0.8%	24.4%	6.4%
Sugar_F2	23.8%	78.1%	84.3%	49.8%	58.1%	17.3%	20.5%	21.7%	39.3%	55.7%	2.2%	30.9%	3.2%
Rice	0.0%	0.6%	3.5%	2.9%	1.1%	25.0%	26.8%	25.8%	15.1%	3.5%	0.8%	37.0%	30.1%
Rice_F1	0.0%	0.4%	3.1%	3.1%	1.2%	26.1%	27.5%	26.5%	15.3%	3.5%	0.4%	35.9%	27.6%
Rice_F2	0.1%	0.7%	4.0%	4.1%	1.9%	22.6%	24.2%	23.2%	13.3%	5.0%	0.6%	35.2%	29.9%
Barley	12.7%	0.9%	0.5%	4.7%	6.3%	9.1%	15.4%	13.8%	15.4%	0.8%	62.6%	78.5%	80.1%
Barley_F1	0.9%	17.4%	9.6%	4.6%	5.1%	32.1%	35.6%	33.6%	47.9%	0.0%	6.5%	73.1%	25.5%
Barley_F2	1.2%	17.3%	11.7%	11.1%	12.0%	32.2%	37.6%	35.8%	55.7%	2.0%	14.4%	80.0%	28.9%
Canola	48.9%	3.7%	4.4%	5.7%	6.5%	43.5%	33.1%	33.9%	27.8%	7.1%	43.5%	1.0%	28.2%
Canola_F1	40.2%	0.0%	0.1%	0.7%	1.0%	31.5%	21.9%	22.4%	12.8%	2.9%	52.1%	7.2%	31.9%
Canola_F2	43.2%	0.7%	1.2%	0.9%	0.9%	17.5%	10.0%	10.8%	6.7%	2.8%	65.0%	17.0%	53.3%
BDI	60.3%	35.4%	34.8%	18.0%	16.6%	9.8%	7.3%	8.7%	28.7%	11.1%	29.0%	0.0%	40.3%
BLPG1	20.2%	80.5%	86.9%	50.1%	44.1%	0.5%	0.6%	0.9%	19.2%	21.3%	0.7%	3.7%	19.0%
TD3	3.7%	16.4%	33.9%	91.9%	83.0%	3.8%	6.0%	6.3%	26.7%	39.5%	17.8%	9.9%	0.2%
TC2_37	12.2%	91.9%	76.0%	13.0%	13.3%	3.7%	3.5%	3.9%	17.0%	4.8%	2.8%	16.0%	7.4%
Urea	4.8%	7.3%	18.4%	60.9%	49.2%	0.4%	0.0%	0.0%	5.8%	16.6%	46.7%	8.3%	8.0%
DAP	4.8%	50.6%	67.9%	72.6%	68.9%	2.3%	3.9%	4.1%	21.1%	46.7%	15.1%	14.2%	0.7%
Ammonia	0.1%	12.1%	4.2%	6.8%	9.2%	18.2%	18.8%	17.6%	4.0%	16.4%	5.4%	0.3%	3.0%
Scrap VLCC	36.6%	7.9%	14.4%	37.4%	48.5%	76.0%	76.4%	76.6%	61.2%	58.1%	0.0%	19.7%	0.5%
Scrap Cape/Pana	40.5%	8.0%	14.0%	34.7%	43.9%	74.6%	72.5%	73.0%	59.1%	49.3%	1.0%	13.9%	2.1%

Table 0.1 Spectral Coherence Monthly Reduced (periodicity @ 36 months), cont.

	Iron	Crude_F1	Brent_F1	Heating_F1	Natural_gas_F1	Natural_Gas_F2	Coal_F1	Coal_F2	Wheat_F1	Wheat_F2	Soybeans_F1	Soybeans_F2	Corn_F1
BCI_TCE	0.9%	3.0%	5.5%	5.5%	0.1%	10.6%	3.9%	2.1%	29.7%	28.4%	19.0%	20.6%	39.5%
BPI_TCE	25.8%	6.4%	5.0%	6.1%	16.5%	4.5%	10.8%	8.2%	29.6%	30.8%	0.1%	0.1%	27.6%
BPI_TCE	28.0%	8.9%	8.8%	10.7%	26.2%	8.3%	24.8%	18.6%	12.2%	12.9%	4.0%	4.2%	12.6%
TC2$	7.5%	5.2%	5.3%	6.1%	19.3%	1.0%	12.9%	9.5%	1.9%	1.8%	15.9%	14.8%	1.9%
TD3$	0.2%	5.3%	7.8%	9.0%	35.9%	24.1%	41.0%	46.1%	9.2%	8.5%	8.2%	7.3%	1.0%
BHSI	21.4%	15.9%	16.1%	17.4%	30.8%	0.1%	21.8%	16.3%	3.3%	3.5%	22.6%	21.1%	1.5%
BDTI	12.7%	9.6%	6.4%	5.8%	1.7%	9.1%	0.9%	0.2%	23.3%	24.9%	18.8%	20.2%	9.6%
BCTI	35.9%	11.7%	11.1%	12.7%	25.6%	3.8%	15.3%	8.8%	12.2%	13.5%	6.8%	7.2%	6.5%
4TC_C+1MON	9.4%	5.9%	3.7%	3.8%	15.6%	0.0%	2.4%	3.0%	29.0%	30.2%	2.5%	3.4%	28.3%
4TC_C+2MON	36.2%	25.2%	19.6%	19.8%	28.1%	3.3%	8.4%	8.5%	41.6%	44.5%	0.6%	1.1%	28.7%
4TC_P+1MON	42.5%	19.5%	15.1%	16.6%	18.8%	11.9%	15.3%	16.1%	57.6%	59.7%	3.3%	4.1%	50.3%
4TC_P+2MON	69.2%	44.0%	36.9%	38.3%	29.2%	17.7%	20.9%	20.8%	55.7%	59.4%	0.3%	0.6%	35.3%
5TC_S+1MON	36.2%	15.7%	14.8%	17.4%	27.2%	21.8%	38.1%	36.1%	24.9%	25.7%	0.4%	0.2%	29.7%
5TC_S+2MON	65.7%	43.6%	39.9%	42.9%	38.6%	39.6%	45.1%	45.8%	36.5%	39.2%	0.1%	0.0%	30.2%
TC2$+1_M	8.8%	8.3%	9.2%	10.4%	30.6%	0.1%	23.9%	19.8%	0.4%	0.4%	20.6%	19.2%	0.9%
TC2$+2_M	6.8%	8.5%	9.9%	11.4%	35.0%	3.3%	34.8%	32.9%	0.1%	0.1%	16.5%	15.0%	1.5%
TD3$+1_M	3.6%	13.3%	16.6%	18.4%	50.6%	25.4%	51.5%	54.9%	5.6%	4.9%	14.6%	13.0%	0.6%
TD3$+2_M	10.0%	22.4%	27.2%	29.8%	59.1%	40.0%	69.5%	72.3%	4.9%	4.1%	19.6%	17.7%	0.7%
Crude	81.9%	100.0%	98.8%	98.3%	75.2%	37.7%	49.9%	43.0%	1.3%	2.6%	30.1%	26.4%	1.6%
Brent	77.3%	98.7%	100.0%	99.7%	79.4%	42.2%	56.6%	48.4%	0.0%	0.3%	38.8%	35.0%	4.7%
Heating_oil	79.8%	98.5%	99.8%	99.9%	79.9%	44.8%	59.3%	51.1%	0.1%	0.5%	37.4%	33.6%	3.6%
Natural_Gas	58.5%	76.6%	79.6%	80.6%	99.4%	30.7%	62.3%	52.0%	0.4%	0.0%	47.0%	43.4%	4.4%
Coal	23.2%	34.4%	39.5%	43.1%	46.9%	79.1%	91.0%	98.2%	0.2%	0.1%	9.4%	7.8%	1.0%
Wheat	17.2%	1.5%	0.1%	0.2%	1.0%	0.6%	2.4%	1.7%	97.6%	97.7%	30.6%	31.9%	73.1%
Soybeans	18.0%	34.3%	42.1%	41.6%	53.3%	6.8%	32.5%	20.1%	37.7%	34.3%	99.7%	98.9%	57.2%
Corn	4.7%	0.0%	0.5%	0.2%	0.4%	1.8%	0.8%	3.1%	77.5%	75.3%	39.3%	41.5%	95.5%
Iron	100.0%	81.9%	78.0%	79.0%	54.4%	30.6%	38.0%	30.4%	13.5%	16.5%	16.4%	14.6%	1.0%
Crude_F1	81.9%	100.0%	98.9%	98.3%	75.4%	37.3%	49.7%	42.7%	1.3%	2.5%	30.6%	26.9%	1.8%
Brent_F1	78.0%	98.9%	100.0%	99.8%	79.5%	42.1%	56.9%	48.9%	0.0%	0.4%	38.0%	34.2%	4.1%
Heating_F1	79.0%	98.3%	99.8%	100.0%	80.7%	45.3%	60.9%	52.8%	0.1%	0.5%	37.6%	33.8%	3.4%
Natural_gas_F1	54.4%	75.4%	79.5%	80.7%	100.0%	34.9%	67.4%	57.3%	1.3%	0.6%	49.2%	45.5%	5.8%
Natural_Gas_F2	30.6%	37.3%	42.1%	45.3%	34.9%	100.0%	76.2%	81.2%	0.1%	0.0%	4.9%	4.2%	0.2%
Coal_F1	38.0%	49.7%	56.9%	60.9%	67.4%	76.2%	100.0%	97.0%	1.9%	1.3%	28.7%	26.5%	0.6%

Coal_F2	30.4%	42.7%	48.9%	52.8%	57.3%	81.2%	97.0%	100.0%	0.8%	0.5%	16.7%	14.7%	0.0%
Wheat_F1	13.5%	1.3%	0.0%	0.1%	1.3%	0.1%	1.9%	0.8%	100.0%	99.7%	38.6%	40.8%	81.8%
Wheat_F2	16.5%	2.5%	0.4%	0.5%	0.6%	0.0%	1.3%	0.5%	99.7%	100.0%	35.3%	37.5%	78.8%
Soybeans_F1	16.4%	30.6%	38.0%	37.6%	49.2%	4.9%	28.7%	16.7%	38.6%	35.3%	100.0%	99.7%	58.9%
Soybeans_F2	14.6%	26.9%	34.2%	33.8%	45.5%	4.2%	26.5%	14.7%	40.8%	37.5%	99.7%	100.0%	60.9%
Corn_F1	1.0%	1.8%	4.1%	3.4%	5.8%	0.2%	0.6%	0.0%	81.8%	78.8%	58.9%	60.9%	100.0%
Corn_F2	0.2%	3.9%	7.3%	6.4%	10.0%	0.1%	2.9%	0.6%	82.4%	79.1%	65.8%	67.5%	99.1%
Iron_F1	71.6%	68.2%	70.6%	72.3%	81.5%	23.6%	56.7%	42.4%	0.2%	0.6%	49.6%	47.3%	1.8%
Iron_F2	61.8%	58.9%	62.1%	64.4%	79.0%	24.8%	62.5%	48.5%	0.1%	0.3%	47.2%	45.0%	0.9%
Copper	25.3%	46.2%	55.1%	56.1%	61.8%	42.5%	67.6%	56.0%	21.3%	18.9%	61.6%	59.4%	23.6%
Copper_F3	23.1%	44.2%	53.1%	54.2%	60.3%	44.3%	69.1%	58.3%	22.3%	19.9%	59.4%	57.1%	23.0%
Sugar	12.0%	17.6%	21.2%	23.5%	41.6%	17.0%	59.7%	57.0%	1.0%	0.9%	26.3%	24.1%	0.0%
Sugar_F1	11.0%	15.4%	18.6%	20.8%	38.3%	16.1%	57.5%	55.5%	0.4%	0.4%	22.5%	20.5%	0.4%
Sugar_F2	11.3%	17.3%	21.2%	23.4%	42.2%	16.4%	59.4%	56.2%	1.7%	1.6%	28.9%	26.6%	0.0%
Rice	28.3%	25.5%	26.0%	24.3%	13.2%	0.0%	0.3%	0.5%	4.3%	2.9%	38.6%	39.7%	32.7%
Rice_F1	29.8%	26.6%	26.8%	25.1%	13.3%	0.0%	0.3%	0.5%	3.2%	2.0%	37.5%	38.4%	30.2%
Rice_F2	26.7%	23.1%	23.4%	21.8%	11.4%	0.1%	0.1%	1.1%	3.9%	2.6%	37.1%	38.3%	32.0%
Barley	0.8%	9.4%	14.5%	13.6%	17.8%	1.0%	8.1%	3.2%	72.3%	68.6%	79.6%	81.1%	92.9%
Barley_F1	24.9%	32.7%	35.0%	33.0%	45.3%	0.2%	7.3%	1.6%	11.8%	9.6%	74.6%	74.0%	38.2%
Barley_F2	21.0%	32.6%	36.9%	35.4%	54.8%	0.8%	15.6%	6.5%	20.7%	17.7%	80.7%	80.2%	43.7%
Canola	44.8%	43.3%	34.2%	33.6%	23.8%	5.9%	5.6%	7.1%	47.1%	51.5%	1.7%	2.9%	22.5%
Canola_F1	35.3%	31.2%	22.7%	22.1%	10.1%	4.4%	1.2%	2.5%	57.0%	61.2%	9.0%	11.3%	30.2%
Canola_F2	23.8%	17.2%	10.8%	10.7%	4.7%	2.3%	0.4%	1.7%	72.6%	75.6%	19.6%	22.8%	51.3%
BDI	23.5%	9.7%	7.8%	8.9%	24.9%	3.8%	13.9%	12.1%	27.5%	28.8%	0.0%	0.0%	27.3%
BLPG1	0.7%	0.5%	0.8%	1.2%	19.1%	0.6%	19.4%	19.4%	1.1%	0.9%	3.4%	2.9%	7.6%
TD3	0.1%	3.8%	6.0%	6.8%	30.6%	19.3%	32.9%	38.1%	13.2%	12.4%	8.0%	7.1%	2.7%
TC2_37	6.8%	3.8%	3.9%	4.5%	15.3%	2.9%	8.6%	5.4%	1.8%	1.7%	16.6%	15.7%	1.3%
Urea	14.6%	0.4%	0.0%	0.0%	8.5%	3.5%	10.8%	14.5%	37.0%	37.1%	7.0%	6.4%	13.2%
DAP	0.3%	2.2%	4.1%	4.9%	25.0%	10.6%	38.6%	42.6%	10.2%	10.5%	12.3%	10.9%	0.5%
Ammonia	2.2%	18.0%	18.5%	17.6%	5.6%	25.4%	8.5%	14.4%	2.1%	1.6%	0.0%	0.0%	2.9%
Scrap VLCC	47.8%	75.8%	76.9%	77.4%	63.7%	50.8%	57.6%	60.9%	0.1%	0.5%	15.8%	12.6%	0.4%
Scrap Cape/Pana	50.5%	74.5%	73.2%	73.5%	60.1%	42.3%	47.9%	51.5%	2.1%	3.3%	10.6%	8.0%	0.0%

Table 0.1 Spectral Coherence Monthly Reduced (periodicity @ 36 months), cont.

	Corn_F2	Iron_F1	Iron_F2	Copper	Copper_F3	Sugar	Sugar_F1	Sugar_F2	Rice	Rice_F1	Rice_F2	Barley	Barley_F1
BCI_TCE	39.1%	0.0%	0.1%	11.3%	11.3%	3.1%	4.1%	2.5%	32.3%	30.8%	31.0%	43.5%	1.6%
BPI_TCE	24.0%	34.0%	37.2%	1.5%	1.1%	11.2%	12.4%	10.1%	0.6%	0.5%	0.5%	16.9%	3.1%
BPI_TCE	9.3%	50.1%	56.5%	9.3%	8.5%	29.4%	30.7%	28.2%	0.0%	0.0%	0.0%	3.6%	8.3%
TC2$	0.8%	33.2%	41.7%	6.6%	6.2%	67.7%	69.1%	67.4%	0.5%	0.3%	0.5%	0.1%	16.8%
TD3$	2.5%	9.7%	13.8%	16.3%	18.1%	34.1%	33.5%	34.4%	5.9%	6.5%	7.6%	3.8%	0.9%
BHSI	0.5%	49.3%	56.4%	11.3%	10.5%	68.7%	69.4%	68.2%	0.7%	1.1%	0.6%	0.8%	23.1%
BDTI	10.6%	2.2%	5.8%	3.0%	3.2%	29.3%	29.5%	31.2%	2.6%	3.0%	2.5%	12.2%	10.3%
BCTI	4.8%	52.4%	53.7%	6.1%	5.0%	14.5%	15.1%	13.9%	5.6%	5.8%	5.8%	1.0%	17.1%
4TC_C+1MON	25.0%	15.0%	17.1%	0.0%	0.0%	11.1%	12.0%	10.0%	9.3%	8.6%	9.3%	23.6%	2.4%
4TC_C+2MON	24.6%	31.9%	31.3%	1.2%	0.9%	10.1%	10.6%	8.9%	0.7%	0.4%	0.7%	19.8%	5.8%
4TC_P+1MON	43.9%	30.8%	32.3%	0.6%	0.5%	13.0%	14.4%	11.2%	2.3%	1.8%	2.4%	33.0%	0.1%
4TC_P+2MON	29.7%	41.9%	39.2%	2.9%	2.4%	11.9%	12.5%	10.3%	0.6%	0.9%	0.4%	18.6%	2.3%
5TC_S+1MON	23.0%	46.3%	53.9%	9.8%	9.5%	40.3%	42.5%	37.9%	3.2%	2.8%	3.4%	13.0%	1.0%
5TC_S+2MON	23.2%	49.3%	50.5%	11.0%	10.5%	26.1%	27.0%	23.8%	0.0%	0.0%	0.1%	12.7%	0.9%
TC2$+1_M	0.1%	39.2%	48.9%	11.9%	11.7%	78.2%	79.3%	78.1%	0.6%	0.4%	0.7%	0.9%	17.4%
TC2$+2_M	0.3%	34.5%	45.1%	13.9%	14.3%	84.8%	86.0%	84.3%	3.5%	3.1%	4.0%	0.5%	9.6%
TD3$+1_M	2.3%	21.5%	27.2%	22.8%	24.5%	49.6%	48.7%	49.8%	2.9%	3.1%	4.1%	4.7%	4.6%
TD3$+2_M	2.6%	30.8%	37.1%	33.1%	35.0%	58.0%	56.7%	58.1%	1.1%	1.2%	1.9%	6.3%	5.1%
Crude	3.7%	68.0%	58.7%	46.2%	44.2%	17.5%	15.3%	17.3%	25.0%	26.1%	22.6%	9.1%	32.1%
Brent	8.1%	70.2%	61.5%	55.9%	53.9%	20.4%	17.8%	20.5%	26.8%	27.5%	24.2%	15.4%	35.6%
Heating_oil	6.6%	72.0%	63.6%	55.2%	53.3%	21.7%	19.1%	21.7%	25.8%	26.5%	23.2%	13.8%	33.6%
Natural_Gas	8.0%	84.0%	80.6%	56.6%	54.8%	38.9%	35.8%	39.3%	15.1%	15.3%	13.3%	15.4%	47.9%
Coal	0.0%	31.9%	38.5%	46.0%	48.7%	56.9%	56.1%	55.7%	3.5%	3.5%	5.0%	0.8%	0.0%
Wheat	74.3%	0.9%	0.5%	20.8%	22.3%	1.4%	0.8%	2.2%	0.8%	0.4%	0.6%	62.6%	6.5%
Soybeans	64.6%	51.4%	49.1%	64.8%	62.7%	28.3%	24.4%	30.9%	37.0%	35.9%	35.2%	78.5%	73.1%
Corn	91.3%	0.2%	0.8%	12.0%	11.5%	4.6%	6.4%	3.2%	30.1%	27.6%	29.9%	80.1%	25.5%
Iron	0.2%	71.6%	61.8%	25.3%	23.1%	12.0%	11.0%	11.3%	28.3%	29.8%	26.7%	0.8%	24.9%
Crude_F1	3.9%	68.2%	58.9%	46.2%	44.2%	17.6%	15.4%	17.3%	25.5%	26.6%	23.1%	9.4%	32.7%
Brent_F1	7.3%	70.6%	62.1%	55.1%	53.1%	21.2%	18.6%	21.2%	26.0%	26.8%	23.4%	14.5%	35.0%
Heating_F1	6.4%	72.3%	64.4%	56.1%	54.2%	23.5%	20.8%	23.4%	24.3%	25.1%	21.8%	13.6%	33.0%
Natural_gas_F1	10.0%	81.5%	79.0%	61.8%	60.3%	41.6%	38.3%	42.2%	13.2%	13.3%	11.4%	17.8%	45.3%
Natural_Gas_F2	0.1%	23.6%	24.8%	42.5%	44.3%	17.0%	16.1%	16.4%	0.0%	0.0%	0.1%	1.0%	0.2%
Coal_F1	2.9%	56.7%	62.5%	67.6%	69.1%	59.7%	57.5%	59.4%	0.3%	0.3%	0.1%	8.1%	7.3%

Coal_F2	0.6%	42.4%	48.5%	56.0%	58.3%	57.0%	55.5%	56.2%	0.5%	0.5%	1.1%	3.2%	1.6%
Wheat_F1	82.4%	0.2%	0.1%	21.3%	22.3%	1.0%	0.4%	1.7%	4.3%	3.2%	3.9%	72.3%	11.8%
Wheat_F2	79.1%	0.6%	0.3%	18.9%	19.9%	0.9%	0.4%	1.6%	2.9%	2.0%	2.6%	68.6%	9.6%
Soybeans_F1	65.8%	49.6%	47.2%	61.6%	59.4%	26.3%	22.5%	28.9%	38.6%	37.5%	37.1%	79.6%	74.6%
Soybeans_F2	67.5%	47.3%	45.0%	59.4%	57.1%	24.1%	20.5%	26.6%	39.7%	38.4%	38.3%	81.1%	74.0%
Corn_F1	99.1%	1.8%	0.9%	23.6%	23.0%	0.0%	0.4%	0.0%	32.7%	30.2%	32.0%	92.9%	38.2%
Corn_F2	100.0%	4.2%	2.9%	31.4%	30.8%	0.4%	0.1%	1.0%	31.5%	29.1%	30.5%	95.7%	41.1%
Iron_F1	4.2%	100.0%	97.9%	56.9%	54.0%	43.6%	41.0%	43.8%	19.0%	19.5%	17.9%	11.4%	53.0%
Iron_F2	2.9%	97.9%	100.0%	59.3%	56.9%	56.0%	53.6%	56.2%	10.3%	10.6%	9.4%	9.2%	45.5%
Copper	31.4%	56.9%	59.3%	100.0%	99.8%	39.3%	35.3%	41.1%	6.2%	5.6%	5.1%	37.5%	32.5%
Copper_F3	30.8%	54.0%	56.9%	99.8%	100.0%	40.5%	36.5%	42.2%	4.6%	4.1%	3.7%	36.6%	29.2%
Sugar	0.4%	43.6%	56.0%	39.3%	40.5%	100.0%	99.8%	99.9%	3.5%	3.2%	4.2%	3.4%	8.9%
Sugar_F1	0.1%	41.0%	53.6%	35.3%	36.5%	99.8%	100.0%	99.4%	4.8%	4.4%	5.6%	2.0%	6.9%
Sugar_F2	1.0%	43.8%	56.2%	41.1%	42.2%	99.9%	99.4%	100.0%	2.9%	2.7%	3.6%	4.7%	10.2%
Rice	31.5%	19.0%	10.3%	6.2%	4.6%	3.5%	4.8%	2.9%	100.0%	99.8%	99.8%	40.6%	52.2%
Rice_F1	29.1%	19.5%	10.6%	5.6%	4.1%	3.2%	4.4%	2.7%	99.8%	100.0%	99.7%	38.4%	51.7%
Rice_F2	30.5%	17.9%	9.4%	5.1%	3.7%	4.2%	5.6%	3.6%	99.8%	99.7%	100.0%	39.2%	52.0%
Barley	95.7%	11.4%	9.2%	37.5%	36.6%	3.4%	2.0%	4.7%	40.6%	38.4%	39.2%	100.0%	49.1%
Barley_F1	41.1%	53.0%	45.5%	32.5%	29.2%	8.9%	6.9%	10.2%	52.2%	51.7%	52.0%	49.1%	100.0%
Barley_F2	48.2%	57.2%	52.0%	50.2%	46.9%	13.8%	11.2%	15.5%	38.4%	37.2%	37.8%	54.7%	94.1%
Canola	19.9%	16.6%	12.2%	0.1%	0.1%	1.1%	1.1%	0.7%	2.1%	2.8%	1.7%	13.5%	1.6%
Canola_F1	28.5%	5.9%	3.1%	2.6%	3.0%	0.5%	0.4%	0.9%	1.0%	1.5%	0.8%	22.7%	0.1%
Canola_F2	49.2%	2.8%	1.6%	7.1%	7.4%	0.0%	0.0%	0.2%	1.0%	0.6%	1.2%	42.0%	3.0%
BDI	22.7%	37.1%	41.8%	2.8%	2.5%	21.3%	22.7%	19.8%	3.1%	2.8%	3.1%	16.5%	4.7%
BLPG1	4.8%	19.8%	30.0%	5.5%	5.9%	65.8%	68.4%	64.9%	17.5%	16.9%	18.0%	2.1%	2.7%
TD3	4.8%	5.3%	8.1%	12.7%	14.4%	26.5%	25.8%	27.0%	4.6%	5.1%	6.0%	5.9%	0.8%
TC2_37	0.5%	31.1%	38.6%	5.0%	4.6%	60.4%	61.7%	60.3%	0.1%	0.0%	0.0%	0.3%	19.1%
Urea	15.7%	0.3%	0.0%	8.0%	9.7%	15.8%	14.9%	16.9%	10.1%	11.2%	11.8%	13.1%	0.0%
DAP	2.0%	10.8%	18.9%	24.8%	27.3%	72.5%	72.3%	73.2%	20.0%	20.2%	22.0%	3.2%	1.1%
Ammonia	3.7%	0.9%	2.1%	3.2%	3.9%	0.6%	0.9%	0.6%	0.7%	0.7%	0.2%	3.1%	2.4%
Scrap VLCC	1.8%	35.9%	32.3%	32.2%	32.6%	23.6%	21.6%	23.1%	5.7%	6.1%	4.1%	5.3%	8.8%
Scrap Cape/Pana	0.2%	33.6%	29.3%	21.6%	21.7%	19.0%	17.5%	18.3%	6.2%	6.8%	4.6%	2.2%	8.0%

Table 0.1 Spectral Coherence Monthly Reduced (periodicity @ 36 months), cont.

	Barley_F2	Canola	Canola_F1	Canola_F2	BDI	BLPG1	TD3	TC2_37	Urea	DAP	Ammonia	Scrap VLCC	Scrap Cape/Pana
BCI_TCE	2.3%	14.9%	12.8%	26.7%	44.4%	37.7%	1.0%	17.1%	0.1%	7.2%	12.2%	1.5%	0.2%
BPI_TCE	4.1%	17.3%	11.4%	18.0%	92.6%	34.6%	0.9%	19.1%	7.3%	1.5%	27.5%	0.4%	1.3%
BPI_TCE	11.1%	6.8%	2.0%	4.7%	81.4%	46.4%	3.3%	34.6%	2.6%	7.9%	31.2%	1.2%	1.7%
TC2$	14.2%	2.9%	0.0%	0.8%	32.5%	71.6%	5.0%	99.0%	1.5%	36.3%	20.1%	2.8%	3.2%
TD3$	5.6%	2.0%	0.0%	0.1%	11.3%	39.8%	98.2%	4.2%	71.8%	67.2%	8.7%	27.1%	24.4%
BHSI	19.0%	7.8%	1.2%	2.6%	33.8%	59.9%	4.2%	93.9%	0.1%	28.2%	13.3%	9.3%	10.1%
BDTI	14.2%	23.0%	39.6%	29.6%	3.6%	48.6%	18.2%	42.9%	28.2%	41.1%	28.2%	7.2%	9.2%
BCTI	17.5%	8.9%	3.5%	4.9%	70.4%	27.1%	0.5%	27.6%	8.5%	0.6%	32.7%	0.6%	1.3%
4TC_C+1MON	2.5%	39.6%	30.0%	41.1%	77.3%	45.0%	7.5%	20.2%	0.2%	10.9%	5.1%	5.0%	8.8%
4TC_C+2MON	4.9%	62.9%	51.7%	57.9%	78.6%	27.1%	2.5%	15.7%	2.7%	3.0%	1.3%	16.4%	23.0%
4TC_P+1MON	0.1%	49.9%	43.5%	53.8%	81.5%	25.9%	0.5%	14.5%	9.8%	1.4%	3.8%	12.2%	17.1%
4TC_P+2MON	1.1%	69.2%	61.8%	63.5%	58.6%	11.6%	0.0%	11.6%	14.9%	0.1%	0.0%	29.8%	37.2%
5TC_S+1MON	2.0%	17.2%	10.2%	16.7%	80.2%	48.0%	4.7%	30.9%	2.2%	13.4%	11.4%	9.5%	10.7%
5TC_S+2MON	1.2%	48.9%	40.2%	43.2%	60.3%	20.2%	3.7%	12.2%	4.8%	4.8%	0.1%	36.6%	40.5%
TC2$+1_M	17.3%	3.7%	0.0%	0.7%	35.4%	80.5%	16.4%	91.9%	7.3%	50.6%	12.1%	7.9%	8.0%
TC2$+2_M	11.7%	4.4%	0.1%	1.2%	34.8%	86.9%	33.9%	76.0%	18.4%	67.9%	4.2%	14.4%	14.0%
TD3$+1_M	11.1%	5.7%	0.7%	0.9%	18.0%	50.1%	91.9%	13.0%	60.9%	72.6%	6.8%	37.4%	34.7%
TD3$+2_M	12.0%	6.5%	1.0%	0.9%	16.6%	44.1%	83.0%	13.3%	49.2%	68.9%	9.2%	48.5%	43.9%
Crude	32.2%	43.5%	31.5%	17.5%	9.8%	0.5%	3.8%	3.7%	0.4%	2.3%	18.2%	76.0%	74.6%
Brent	37.6%	33.1%	21.9%	10.0%	7.3%	0.6%	6.0%	3.5%	0.0%	3.9%	18.8%	76.4%	72.5%
Heating_oil	35.8%	33.9%	22.4%	10.8%	8.7%	0.9%	6.3%	3.9%	0.0%	4.1%	17.6%	76.6%	73.0%
Natural_Gas	55.7%	27.8%	12.8%	6.7%	28.7%	19.2%	26.7%	17.0%	5.8%	21.1%	4.0%	61.2%	59.1%
Coal	2.0%	7.1%	2.9%	2.8%	11.1%	21.3%	39.5%	4.8%	16.6%	46.7%	16.4%	58.1%	49.3%
Wheat	14.4%	43.5%	52.1%	65.0%	29.0%	0.7%	17.8%	2.8%	46.7%	15.1%	5.4%	0.0%	1.0%
Soybeans	80.0%	1.0%	7.2%	17.0%	0.0%	3.7%	9.9%	16.0%	8.3%	14.2%	0.3%	19.7%	13.9%
Corn	28.9%	28.2%	31.9%	53.3%	40.3%	19.0%	0.2%	7.4%	8.0%	0.7%	3.0%	0.5%	2.1%
Iron	21.0%	44.8%	35.3%	23.8%	23.5%	0.7%	0.1%	6.8%	14.6%	0.3%	2.2%	47.8%	50.5%
Crude_F1	32.6%	43.3%	31.2%	17.2%	9.7%	0.5%	3.8%	3.8%	0.4%	2.2%	18.0%	75.8%	74.5%
Brent_F1	36.9%	34.2%	22.7%	10.8%	7.8%	0.8%	6.0%	3.9%	0.0%	4.1%	18.5%	76.9%	73.2%
Heating_F1	35.4%	33.6%	22.1%	10.7%	8.9%	1.2%	6.8%	4.5%	0.0%	4.9%	17.6%	77.4%	73.5%
Natural_gas_F1	54.8%	23.8%	10.1%	4.7%	24.9%	19.1%	30.6%	15.3%	8.5%	25.0%	5.6%	63.7%	60.1%
Natural_Gas_F2	0.8%	5.9%	4.4%	2.3%	3.8%	0.6%	19.3%	2.9%	3.5%	10.6%	25.4%	50.8%	42.3%
Coal_F1	15.6%	5.6%	1.2%	0.4%	13.9%	19.4%	32.9%	8.6%	10.8%	38.6%	8.5%	57.6%	47.9%

Coal_F2	6.5%	7.1%	2.5%	1.7%	12.1%	19.4%	38.1%	5.4%	14.5%	42.6%	14.4%	60.9%	51.5%
Wheat_F1	20.7%	47.1%	57.0%	72.6%	27.5%	1.1%	13.2%	1.8%	37.0%	10.2%	2.1%	0.1%	2.1%
Wheat_F2	17.7%	51.5%	61.2%	75.6%	28.8%	0.9%	12.4%	1.7%	37.1%	10.5%	1.6%	0.5%	3.3%
Soybeans_F1	80.7%	1.7%	9.0%	19.6%	0.0%	3.4%	8.0%	16.6%	7.0%	12.3%	0.0%	15.8%	10.6%
Soybeans_F2	80.2%	2.9%	11.3%	22.8%	0.0%	2.9%	7.1%	15.7%	6.4%	10.9%	0.0%	12.6%	8.0%
Corn_F1	43.7%	22.5%	30.2%	51.3%	27.3%	7.6%	2.7%	1.3%	13.2%	0.5%	2.9%	0.4%	0.0%
Corn_F2	48.2%	19.9%	28.5%	49.2%	22.7%	4.8%	4.8%	0.5%	15.7%	2.0%	3.7%	1.8%	0.2%
Iron_F1	57.2%	16.6%	5.9%	2.8%	37.1%	19.8%	5.3%	31.1%	0.3%	10.8%	0.9%	35.9%	33.6%
Iron_F2	52.0%	12.2%	3.1%	1.6%	41.8%	30.0%	8.1%	38.6%	0.0%	18.9%	2.1%	32.3%	29.3%
Copper	50.2%	0.1%	2.6%	7.1%	2.8%	5.5%	12.7%	5.0%	8.0%	24.8%	3.2%	32.2%	21.6%
Copper_F3	46.9%	0.1%	3.0%	7.4%	2.5%	5.9%	14.4%	4.6%	9.7%	27.3%	3.9%	32.6%	21.7%
Sugar	13.8%	1.1%	0.5%	0.0%	21.3%	65.8%	26.5%	60.4%	15.8%	72.5%	0.6%	23.6%	19.0%
Sugar_F1	11.2%	1.1%	0.4%	0.0%	22.7%	68.4%	25.8%	61.7%	14.9%	72.3%	0.9%	21.6%	17.5%
Sugar_F2	15.5%	0.7%	0.9%	0.2%	19.8%	64.9%	27.0%	60.3%	16.9%	73.2%	0.6%	23.1%	18.3%
Rice	38.4%	2.1%	1.0%	1.0%	3.1%	17.5%	4.6%	0.1%	10.1%	20.0%	0.7%	5.7%	6.2%
Rice_F1	37.2%	2.8%	1.5%	0.6%	2.8%	16.9%	5.1%	0.0%	11.2%	20.2%	0.7%	6.1%	6.8%
Rice_F2	37.8%	1.7%	0.8%	1.2%	3.1%	18.0%	6.0%	0.0%	11.8%	22.0%	0.2%	4.1%	4.6%
Barley	54.7%	13.5%	22.7%	42.0%	16.5%	2.1%	5.9%	0.3%	13.1%	3.2%	3.1%	5.3%	2.2%
Barley_F1	94.1%	1.6%	0.1%	3.0%	4.7%	2.7%	0.8%	19.1%	0.0%	1.1%	2.4%	8.8%	8.0%
Barley_F2	100.0%	0.2%	1.5%	6.7%	6.2%	5.1%	4.9%	15.1%	2.4%	5.7%	1.7%	10.2%	7.9%
Canola	0.2%	100.0%	95.4%	89.0%	25.8%	2.1%	1.4%	1.8%	3.4%	0.2%	12.4%	41.9%	54.8%
Canola_F1	1.5%	95.4%	100.0%	94.4%	16.3%	0.0%	0.0%	0.1%	8.1%	3.7%	15.4%	31.4%	43.4%
Canola_F2	6.7%	89.0%	94.4%	100.0%	24.8%	1.5%	0.0%	0.3%	7.4%	1.4%	7.3%	20.1%	30.7%
BDI	6.2%	25.8%	16.3%	24.8%	100.0%	52.3%	5.3%	28.9%	1.1%	9.4%	18.6%	3.4%	5.5%
BLPG1	5.1%	2.1%	0.0%	1.5%	52.3%	100.0%	31.4%	64.5%	17.7%	65.0%	14.1%	2.6%	2.7%
TD3	4.9%	1.4%	0.0%	0.0%	5.3%	31.4%	100.0%	2.1%	79.6%	62.6%	13.2%	26.5%	23.9%
TC2_37	15.1%	1.8%	0.1%	0.3%	28.9%	64.5%	2.1%	100.0%	0.4%	28.8%	25.1%	1.1%	1.4%
Urea	2.4%	3.4%	8.1%	7.4%	1.1%	17.7%	79.6%	0.4%	100.0%	62.3%	13.3%	8.1%	5.5%
DAP	5.7%	0.2%	3.7%	1.4%	9.4%	65.0%	62.6%	28.8%	62.3%	100.0%	0.8%	15.3%	11.2%
Ammonia	1.7%	12.4%	15.4%	7.3%	18.6%	14.1%	13.2%	25.1%	13.3%	0.8%	100.0%	49.8%	47.3%
Scrap VLCC	10.2%	41.9%	31.4%	20.1%	3.4%	2.6%	26.5%	1.1%	8.1%	15.3%	49.8%	100.0%	97.9%
Scrap Cape/Pana	7.9%	54.8%	43.4%	30.7%	5.5%	2.7%	23.9%	1.4%	5.5%	11.2%	47.3%	97.9%	100.0%

Table 0.2 Spectral Coherence Weekly Reduced (periodicity @ 36 months)

	BCI_TCE	BPI_TCE	BPI_TCE	TC2$	TD3$	BHSI	BDTI	BCTI	4TC_C+1MON	4TC_C+2MON	4TC_P+1MON	4TC_P+2MON	5TC_S+1MON
BCI_TCE	100.0%	11.7%	21.2%	11.7%	24.2%	9.6%	38.6%	27.6%	79.5%	58.9%	47.5%	39.5%	31.5%
BPI_TCE	11.7%	100.0%	74.5%	16.8%	9.3%	25.6%	1.9%	59.2%	10.3%	11.8%	22.4%	22.9%	38.8%
BPI_TCE	21.2%	74.5%	100.0%	36.5%	17.7%	35.2%	6.4%	94.5%	15.5%	12.4%	11.4%	12.3%	19.9%
TC2$	11.7%	16.8%	36.5%	100.0%	7.0%	88.3%	19.9%	43.7%	12.7%	9.3%	12.3%	10.8%	5.7%
TD3$	24.2%	9.3%	17.7%	7.0%	100.0%	3.5%	80.3%	24.5%	9.4%	0.5%	3.6%	3.2%	3.0%
BHSI	9.6%	25.6%	35.2%	88.3%	3.5%	100.0%	17.3%	35.8%	19.9%	17.1%	13.6%	12.2%	5.2%
BDTI	38.6%	1.9%	6.4%	19.9%	80.3%	17.3%	100.0%	12.6%	27.3%	8.8%	11.7%	7.7%	10.5%
BCTI	27.6%	59.2%	94.5%	43.7%	24.5%	35.8%	12.6%	100.0%	18.3%	12.5%	12.5%	12.7%	14.9%
4TC_C+1MON	79.5%	10.3%	15.5%	12.7%	9.4%	19.9%	27.3%	18.3%	100.0%	91.8%	76.9%	70.5%	55.1%
4TC_C+2MON	58.9%	11.8%	12.4%	9.3%	0.5%	17.1%	8.8%	12.5%	91.8%	100.0%	86.9%	85.6%	68.5%
4TC_P+1MON	47.5%	22.4%	11.4%	12.3%	3.6%	13.6%	11.7%	12.5%	76.9%	86.9%	100.0%	98.3%	89.2%
4TC_P+2MON	39.5%	22.9%	12.3%	10.8%	3.2%	12.2%	7.7%	12.7%	70.5%	85.6%	98.3%	100.0%	91.0%
5TC_S+1MON	31.5%	38.8%	19.9%	5.7%	3.0%	5.2%	10.5%	14.9%	55.1%	68.5%	89.2%	91.0%	100.0%
5TC_S+2MON	25.7%	27.8%	12.8%	6.9%	4.5%	7.6%	5.5%	9.0%	54.1%	74.5%	90.3%	95.2%	95.1%
TC2$+1_M	44.8%	10.6%	17.5%	47.3%	21.7%	24.7%	37.8%	29.2%	24.7%	16.4%	25.4%	22.2%	24.6%
TC2$+2_M	38.4%	9.3%	11.1%	41.3%	25.9%	19.9%	42.9%	21.6%	20.6%	13.0%	22.1%	18.6%	23.3%
TD3$+1_M	32.7%	12.7%	24.8%	10.2%	92.8%	5.1%	85.5%	33.6%	20.9%	5.4%	7.3%	3.9%	6.0%
TD3$+2_M	42.2%	13.0%	25.1%	12.4%	89.9%	7.4%	87.1%	34.4%	31.1%	11.2%	13.8%	8.7%	10.0%
Crude	28.5%	19.5%	44.7%	7.2%	21.1%	3.4%	19.8%	39.2%	22.9%	16.2%	6.3%	6.4%	12.0%
Brent	16.9%	23.0%	41.1%	8.7%	17.7%	4.8%	17.2%	32.3%	16.8%	12.9%	6.1%	6.6%	14.9%
Heating_oil	19.4%	39.3%	64.3%	12.6%	9.2%	10.5%	5.4%	57.8%	22.6%	20.3%	11.9%	14.1%	21.5%
Natural_Gas	28.8%	38.7%	40.5%	1.7%	18.5%	0.6%	23.1%	41.7%	27.7%	25.9%	30.7%	32.5%	43.9%
Coal	6.7%	4.7%	8.1%	9.1%	19.3%	3.9%	26.3%	3.1%	12.6%	7.5%	4.3%	3.4%	8.1%
Wheat	3.2%	28.3%	9.3%	3.8%	1.1%	14.5%	1.1%	2.8%	4.0%	5.8%	3.2%	4.3%	7.0%
Soybeans	11.3%	0.5%	6.8%	24.3%	1.2%	10.1%	0.5%	11.9%	4.7%	2.8%	8.2%	5.8%	3.9%
Corn	2.2%	23.1%	4.3%	7.2%	0.7%	5.2%	0.2%	0.9%	1.2%	2.3%	10.8%	9.2%	14.3%
Iron	13.6%	28.1%	10.1%	13.3%	7.6%	8.5%	8.5%	4.7%	16.3%	29.1%	51.0%	58.0%	72.4%
Crude_F1	27.7%	19.4%	45.8%	8.0%	21.2%	3.9%	18.7%	40.7%	21.6%	14.9%	5.4%	5.5%	10.8%
Brent_F1	18.3%	21.4%	41.2%	8.8%	17.5%	4.6%	16.3%	33.2%	17.5%	13.4%	5.8%	6.4%	14.1%
Heating_F1	14.3%	22.2%	39.1%	9.0%	17.8%	5.2%	17.6%	30.8%	14.1%	10.5%	4.9%	5.5%	13.7%
Natural_gas_F1	40.0%	38.4%	52.5%	13.3%	37.6%	9.1%	33.0%	58.2%	30.2%	24.4%	30.5%	31.7%	34.1%
Natural_Gas_F2	43.8%	1.0%	2.7%	3.4%	44.2%	8.7%	59.3%	3.0%	31.8%	12.8%	7.5%	4.7%	5.5%

Coal_F1	4.8%	16.5%	16.1%	6.7%	36.6%	3.8%	35.5%	9.7%	7.4%	4.1%	6.1%	4.9%	12.7%
Coal_F2	5.2%	12.1%	12.6%	6.1%	27.6%	2.3%	30.4%	7.1%	11.5%	7.1%	7.0%	6.0%	13.5%
Wheat_F1	2.6%	30.4%	16.4%	2.8%	0.2%	11.3%	1.5%	8.0%	6.0%	8.3%	5.4%	7.2%	10.5%
Wheat_F2	2.7%	28.6%	14.3%	1.9%	0.5%	9.7%	1.4%	6.5%	4.8%	6.9%	4.4%	6.0%	9.4%
Soybeans_F1	9.7%	1.0%	7.8%	24.4%	2.1%	11.9%	0.4%	14.2%	2.0%	0.8%	4.7%	3.2%	2.3%
Soybeans_F2	7.5%	1.8%	3.6%	20.8%	0.7%	8.8%	0.1%	8.0%	1.5%	0.7%	6.2%	4.4%	4.2%
Corn_F1	0.9%	20.4%	5.4%	4.0%	0.1%	2.6%	0.3%	1.0%	0.5%	1.7%	8.0%	7.1%	12.9%
Corn_F2	1.0%	21.3%	5.5%	3.8%	0.1%	3.7%	0.3%	1.0%	0.5%	1.6%	7.3%	6.5%	11.9%
Iron_F1	10.8%	37.4%	23.3%	19.3%	5.2%	25.2%	7.6%	12.7%	2.0%	0.4%	10.4%	11.7%	27.0%
Iron_F2	9.2%	32.3%	45.5%	28.8%	15.5%	30.8%	11.3%	37.0%	4.8%	1.2%	1.5%	2.5%	11.3%
Copper	27.0%	16.5%	54.8%	24.0%	18.9%	14.0%	9.6%	55.9%	15.2%	8.8%	1.7%	1.6%	2.7%
Copper_F3	26.8%	15.8%	53.4%	23.1%	18.4%	13.1%	9.3%	54.3%	14.9%	8.8%	1.5%	1.5%	2.7%
Sugar	62.1%	10.9%	6.6%	1.8%	13.0%	13.4%	22.6%	11.0%	34.8%	24.4%	14.7%	11.5%	14.8%
Sugar_F1	63.3%	11.7%	6.0%	2.3%	12.6%	14.1%	23.7%	10.0%	35.2%	24.0%	15.4%	11.9%	15.8%
Sugar_F2	60.4%	10.8%	6.5%	1.6%	13.4%	13.2%	21.2%	11.1%	33.8%	24.3%	14.0%	10.9%	13.7%
Rice	10.0%	23.5%	33.4%	1.0%	10.7%	0.3%	9.6%	31.5%	9.4%	9.4%	6.0%	9.1%	12.6%
Rice_F1	9.5%	23.6%	33.8%	1.2%	10.8%	0.5%	9.5%	32.2%	8.3%	8.2%	5.3%	8.2%	11.4%
Rice_F2	11.5%	24.0%	35.0%	0.9%	11.0%	0.6%	10.6%	33.1%	10.4%	10.2%	6.6%	9.7%	12.5%
Barley	38.2%	3.4%	12.9%	19.5%	6.9%	9.3%	8.4%	22.8%	39.8%	34.0%	39.3%	33.8%	24.3%
Barley_F1	45.3%	14.2%	5.5%	25.5%	4.2%	25.7%	14.7%	3.6%	23.0%	12.1%	9.1%	5.5%	9.7%
Barley_F2	28.6%	33.5%	35.9%	25.4%	2.3%	42.8%	7.8%	29.2%	35.6%	28.2%	8.6%	8.0%	1.5%
Canola	14.0%	13.4%	8.3%	7.4%	0.4%	3.4%	0.3%	10.9%	15.7%	18.8%	25.9%	25.1%	24.6%
Canola_F1	10.6%	8.3%	7.2%	6.7%	0.6%	2.8%	0.4%	11.1%	9.1%	11.8%	17.6%	18.4%	18.1%
Canola_F2	9.8%	4.3%	3.4%	11.8%	1.6%	4.8%	1.2%	7.0%	9.9%	12.9%	17.4%	16.9%	13.4%
BDI	86.5%	42.5%	50.2%	10.4%	24.1%	1.9%	27.0%	53.1%	64.7%	50.8%	48.6%	42.8%	42.9%
BLPG1	17.0%	22.7%	28.6%	17.1%	48.5%	9.2%	54.8%	33.3%	15.2%	10.8%	10.5%	10.0%	12.1%
TD3	28.5%	7.2%	16.0%	9.3%	99.2%	4.8%	85.2%	23.7%	12.4%	1.2%	5.1%	4.1%	4.4%
TC2_37	9.8%	18.5%	35.9%	98.9%	5.6%	93.7%	20.0%	41.0%	14.4%	11.4%	13.1%	11.7%	6.2%
Urea	60.1%	13.4%	1.8%	13.7%	11.3%	10.4%	21.5%	6.8%	26.0%	13.9%	20.2%	16.4%	23.7%
DAP	6.4%	40.3%	12.8%	5.5%	0.1%	19.0%	2.4%	8.0%	12.4%	11.8%	3.7%	5.7%	9.9%
Ammonia	12.0%	30.8%	43.1%	60.3%	12.5%	70.4%	25.6%	41.0%	13.9%	5.5%	5.2%	2.7%	5.0%

Table 0.2 Spectral Coherence Weekly Reduced (periodicity @ 36 months), cont.

	5TC_S+2MON	TC2$+1_M	TC2$+2_M	TD3$+1_M	TD3$+2_M	Crude	Brent	Heating_oil	Natural_Gas	Coal	Wheat	Soybeans	Corn
BCI_TCE	25.7%	44.8%	38.4%	32.7%	42.2%	28.5%	16.9%	19.4%	28.8%	6.7%	3.2%	11.3%	2.2%
BPI_TCE	27.8%	10.6%	9.3%	12.7%	13.0%	19.5%	23.0%	39.3%	38.7%	4.7%	28.3%	0.5%	23.1%
BPI_TCE	12.8%	17.5%	11.1%	24.8%	25.1%	44.7%	41.1%	64.3%	40.5%	8.1%	9.3%	6.8%	4.3%
TC2$	6.9%	47.3%	41.3%	10.2%	12.4%	7.2%	8.7%	12.6%	1.7%	9.1%	3.8%	24.3%	7.2%
TD3$	4.5%	21.7%	25.9%	92.8%	89.9%	21.1%	17.7%	9.2%	18.5%	19.3%	1.1%	1.2%	0.7%
BHSI	7.6%	24.7%	19.9%	5.1%	7.4%	3.4%	4.8%	10.5%	0.6%	3.9%	14.5%	10.1%	5.2%
BDTI	5.5%	37.8%	42.9%	85.5%	87.1%	19.8%	17.2%	5.4%	23.1%	26.3%	1.1%	0.5%	0.2%
BCTI	9.0%	29.2%	21.6%	33.6%	34.4%	39.2%	32.3%	57.8%	41.7%	3.1%	2.8%	11.9%	0.9%
4TC_C+1MON	54.1%	24.7%	20.6%	20.9%	31.1%	22.9%	16.8%	22.6%	27.7%	12.6%	4.0%	4.7%	1.2%
4TC_C+2MON	74.5%	16.4%	13.0%	5.4%	11.2%	16.2%	12.9%	20.3%	25.9%	7.5%	5.8%	2.8%	2.3%
4TC_P+1MON	90.3%	25.4%	22.1%	7.3%	13.8%	6.3%	6.1%	11.9%	30.7%	4.3%	3.2%	8.2%	10.8%
4TC_P+2MON	95.2%	22.2%	18.6%	3.9%	8.7%	6.4%	6.6%	14.1%	32.5%	3.4%	4.3%	5.8%	9.2%
5TC_S+1MON	95.1%	24.6%	23.3%	6.0%	10.0%	12.0%	14.9%	21.5%	43.9%	8.1%	7.0%	3.9%	14.3%
5TC_S+2MON	100.0%	16.6%	14.1%	0.8%	3.1%	7.8%	10.4%	16.0%	32.9%	4.3%	7.5%	2.8%	11.4%
TC2$+1_M	16.6%	100.0%	97.5%	37.7%	35.8%	2.0%	1.7%	2.7%	26.1%	8.7%	1.0%	18.0%	12.0%
TC2$+2_M	14.1%	97.5%	100.0%	42.9%	39.4%	2.0%	4.9%	1.0%	26.5%	15.5%	1.4%	16.6%	11.5%
TD3$+1_M	0.8%	37.7%	42.9%	100.0%	98.0%	25.6%	22.6%	15.7%	26.2%	24.8%	0.2%	1.6%	0.8%
TD3$+2_M	3.1%	35.8%	39.4%	98.0%	100.0%	26.8%	22.6%	17.2%	27.9%	24.8%	0.2%	3.0%	1.2%
Crude	7.8%	2.0%	2.0%	25.6%	26.8%	100.0%	96.8%	75.8%	43.3%	51.9%	7.8%	22.7%	4.4%
Brent	10.4%	1.7%	4.9%	22.6%	22.6%	96.8%	100.0%	75.3%	42.7%	56.8%	9.3%	22.4%	7.3%
Heating_oil	16.0%	2.7%	1.0%	15.7%	17.2%	75.8%	75.3%	100.0%	56.4%	22.9%	13.0%	17.6%	4.8%
Natural_Gas	32.9%	26.1%	26.5%	26.2%	27.9%	43.3%	42.7%	56.4%	100.0%	16.9%	0.2%	7.5%	0.2%
Coal	4.3%	8.7%	15.5%	24.8%	24.8%	51.9%	56.8%	22.9%	16.9%	100.0%	3.5%	11.4%	5.4%
Wheat	7.5%	1.0%	1.4%	0.2%	0.2%	7.8%	9.3%	13.0%	0.2%	3.5%	100.0%	42.0%	85.2%
Soybeans	2.8%	18.0%	16.6%	1.6%	3.0%	22.7%	22.4%	17.6%	7.5%	11.4%	42.0%	100.0%	70.0%
Corn	11.4%	12.0%	11.5%	0.8%	1.2%	4.4%	7.3%	4.8%	0.2%	5.4%	85.2%	70.0%	100.0%
Iron	73.6%	30.0%	28.1%	0.8%	1.9%	9.1%	17.1%	18.7%	33.6%	6.0%	10.8%	4.7%	16.0%
Crude_F1	6.8%	2.0%	1.6%	25.5%	26.6%	99.9%	96.6%	76.9%	42.9%	50.6%	7.7%	23.5%	4.3%
Brent_F1	10.1%	1.1%	3.5%	22.2%	22.3%	97.7%	99.8%	75.2%	41.1%	56.6%	9.8%	23.4%	7.3%
Heating_F1	9.1%	2.3%	6.2%	22.5%	22.0%	95.3%	99.5%	75.9%	44.7%	54.0%	9.2%	23.2%	7.8%
Natural_gas_F1	26.7%	28.3%	23.0%	37.7%	41.1%	47.3%	39.7%	55.2%	83.9%	7.4%	0.3%	13.1%	0.7%
Natural_Gas_F2	3.9%	4.9%	4.5%	42.4%	48.6%	32.5%	25.5%	7.6%	6.1%	57.6%	2.3%	2.2%	0.6%
Coal_F1	6.1%	23.8%	35.3%	45.0%	40.3%	46.7%	56.5%	26.7%	29.3%	84.3%	2.5%	8.0%	6.3%

Coal_F2	7.5%	16.3%	25.6%	36.3%	34.4%	48.3%	56.3%	25.6%	28.5%	94.7%	2.5%	7.3%	5.3%
Wheat_F1	11.4%	2.1%	1.2%	0.8%	0.6%	12.8%	15.4%	22.1%	2.7%	4.2%	96.8%	37.3%	82.8%
Wheat_F2	10.3%	1.3%	0.9%	0.6%	0.4%	13.0%	15.4%	21.2%	2.1%	4.1%	97.5%	39.9%	83.6%
Soybeans_F1	1.4%	15.9%	14.4%	2.7%	3.7%	23.9%	21.7%	15.9%	8.7%	11.6%	44.2%	97.0%	68.1%
Soybeans_F2	3.0%	15.9%	15.0%	0.8%	1.6%	19.6%	19.6%	12.0%	5.1%	13.3%	51.2%	98.3%	77.2%
Corn_F1	10.1%	9.0%	9.8%	0.6%	0.3%	8.0%	11.6%	9.5%	0.0%	10.6%	83.7%	69.0%	96.9%
Corn_F2	9.6%	7.6%	8.1%	0.3%	0.1%	8.4%	11.7%	9.5%	0.0%	9.2%	87.6%	67.3%	97.7%
Iron_F1	23.7%	13.3%	16.3%	2.6%	3.6%	20.5%	31.0%	36.3%	13.8%	12.7%	20.9%	9.2%	16.2%
Iron_F2	11.3%	3.3%	2.9%	15.6%	16.5%	45.7%	51.3%	62.5%	13.0%	16.4%	18.6%	12.8%	9.5%
Copper	1.8%	10.5%	5.5%	22.3%	23.6%	83.7%	77.1%	77.5%	30.5%	27.0%	10.4%	39.8%	7.7%
Copper_F3	2.0%	9.8%	5.1%	21.6%	22.9%	84.6%	78.0%	76.9%	30.1%	28.2%	10.9%	40.4%	8.3%
Sugar	8.1%	36.4%	37.1%	17.9%	18.4%	22.5%	12.0%	7.0%	28.2%	2.0%	26.8%	17.3%	14.6%
Sugar_F1	8.6%	37.2%	37.6%	17.2%	18.2%	21.1%	10.7%	6.0%	27.0%	2.1%	25.3%	16.3%	13.9%
Sugar_F2	7.4%	37.1%	38.4%	18.6%	18.4%	21.1%	11.1%	6.5%	27.3%	1.4%	28.2%	17.6%	15.3%
Rice	13.6%	7.2%	6.7%	17.5%	15.7%	41.2%	44.0%	48.1%	41.7%	3.3%	38.9%	26.0%	30.5%
Rice_F1	12.4%	7.7%	7.0%	17.5%	15.6%	37.9%	40.4%	46.2%	40.0%	2.1%	39.0%	24.7%	30.5%
Rice_F2	13.5%	9.1%	8.0%	18.3%	16.4%	38.1%	40.0%	46.7%	39.2%	1.9%	40.9%	22.9%	30.4%
Barley	20.8%	21.9%	18.2%	11.1%	17.5%	19.1%	13.8%	24.4%	27.0%	0.4%	20.5%	75.6%	46.0%
Barley_F1	5.2%	42.3%	43.9%	4.7%	7.4%	7.6%	11.0%	15.7%	1.9%	6.1%	21.5%	26.2%	18.5%
Barley_F2	2.6%	5.2%	5.0%	5.2%	8.8%	23.3%	26.1%	50.1%	13.4%	8.4%	31.6%	12.7%	11.2%
Canola	21.1%	16.2%	15.1%	3.5%	4.1%	4.7%	2.2%	6.7%	21.0%	2.3%	33.8%	66.6%	60.8%
Canola_F1	15.8%	17.1%	16.7%	3.6%	3.5%	5.3%	2.7%	7.3%	22.6%	3.9%	26.4%	65.4%	49.8%
Canola_F2	12.6%	16.9%	15.7%	2.8%	2.1%	4.2%	2.6%	4.9%	12.0%	5.5%	30.6%	79.1%	60.8%
BDI	33.6%	46.9%	39.2%	33.2%	39.7%	34.6%	23.9%	30.5%	44.9%	5.9%	0.2%	7.3%	4.3%
BLPG1	9.3%	54.6%	60.2%	67.2%	59.8%	22.7%	26.4%	16.7%	31.9%	41.7%	3.7%	1.5%	6.4%
TD3	5.0%	24.7%	28.2%	93.1%	91.5%	19.8%	15.9%	8.4%	19.1%	17.1%	1.0%	1.6%	0.6%
TC2_37	7.8%	41.1%	35.6%	8.3%	10.6%	6.2%	8.0%	11.5%	0.8%	8.2%	5.7%	19.4%	5.7%
Urea	15.4%	61.1%	60.5%	13.8%	16.0%	3.7%	0.6%	0.6%	15.6%	2.3%	16.5%	19.4%	16.3%
DAP	8.8%	4.7%	6.5%	1.7%	2.0%	13.5%	17.4%	20.6%	17.7%	34.5%	44.6%	12.5%	31.8%
Ammonia	4.6%	10.2%	8.7%	15.1%	18.5%	11.8%	15.1%	32.9%	5.9%	0.0%	5.7%	11.7%	0.7%

Table 0.2 Spectral Coherence Weekly Reduced (periodicity @ 36 months), cont.

	Iron	Crude_F1	Brent_F1	Heating_F1	Natural_gas_F1	Natural_Gas_F2	Coal_F1	Coal_F2	Wheat_F1	Wheat_F2	Soybeans_F1	Soybeans_F2	Corn_F1
BCI_TCE	13.6%	27.7%	18.3%	14.3%	40.0%	43.8%	4.8%	5.2%	2.6%	2.7%	9.7%	7.5%	0.9%
BPI_TCE	28.1%	19.4%	21.4%	22.2%	38.4%	1.0%	16.5%	12.1%	30.4%	28.6%	1.0%	1.8%	20.4%
BPI_TCE	10.1%	45.8%	41.2%	39.1%	52.5%	2.7%	16.1%	12.6%	16.4%	14.3%	7.8%	3.6%	5.4%
TC2$	13.3%	8.0%	8.8%	9.0%	13.3%	3.4%	6.7%	6.1%	2.8%	1.9%	24.4%	20.8%	4.0%
TD3$	7.6%	21.2%	17.5%	17.8%	37.6%	44.2%	36.6%	27.6%	0.2%	0.5%	2.1%	0.7%	0.1%
BHSI	8.5%	3.9%	4.6%	5.2%	9.1%	8.7%	3.8%	2.3%	11.3%	9.7%	11.9%	8.8%	2.6%
BDTI	8.5%	18.7%	16.3%	17.6%	33.0%	59.3%	35.5%	30.4%	1.5%	1.4%	0.4%	0.1%	0.3%
BCTI	4.7%	40.7%	33.2%	30.8%	58.2%	3.0%	9.7%	7.1%	8.0%	6.5%	14.2%	8.0%	1.0%
4TC_C+1MON	16.3%	21.6%	17.5%	14.1%	30.2%	31.8%	7.4%	11.5%	6.0%	4.8%	2.0%	1.5%	0.5%
4TC_C+2MON	29.1%	14.9%	13.4%	10.5%	24.4%	12.8%	4.1%	7.1%	8.3%	6.9%	0.8%	0.7%	1.7%
4TC_P+1MON	51.0%	5.4%	5.8%	4.9%	30.5%	7.5%	6.1%	7.0%	5.4%	4.4%	4.7%	6.2%	8.0%
4TC_P+2MON	58.0%	5.5%	6.4%	5.5%	31.7%	4.7%	4.9%	6.0%	7.2%	6.0%	3.2%	4.4%	7.1%
5TC_S+1MON	72.4%	10.8%	14.1%	13.7%	34.1%	5.5%	12.7%	13.5%	10.5%	9.4%	2.3%	4.2%	12.9%
5TC_S+2MON	73.6%	6.8%	10.1%	9.1%	26.7%	3.9%	6.1%	7.5%	11.4%	10.3%	1.4%	3.0%	10.1%
TC2$+1_M	30.0%	2.0%	1.1%	2.3%	28.3%	4.9%	23.8%	16.3%	2.1%	1.3%	15.9%	15.9%	9.0%
TC2$+2_M	28.1%	1.6%	3.5%	6.2%	23.0%	4.5%	35.3%	25.6%	1.2%	0.9%	14.4%	15.0%	9.8%
TD3$+1_M	0.8%	25.5%	22.2%	22.5%	37.7%	42.4%	45.0%	36.3%	0.8%	0.6%	2.7%	0.8%	0.6%
TD3$+2_M	1.9%	26.6%	22.3%	22.0%	41.1%	48.6%	40.3%	34.4%	0.6%	0.4%	3.7%	1.6%	0.3%
Crude	9.1%	99.9%	97.7%	95.3%	47.3%	32.5%	46.7%	48.3%	12.8%	13.0%	23.9%	19.6%	8.0%
Brent	17.1%	96.6%	99.8%	99.5%	39.7%	25.5%	56.5%	56.3%	15.4%	15.4%	21.7%	19.6%	11.6%
Heating_oil	18.7%	76.9%	75.2%	75.9%	55.2%	7.6%	26.7%	25.6%	22.1%	21.2%	15.9%	12.0%	9.5%
Natural_Gas	33.6%	42.9%	41.1%	44.7%	83.9%	6.1%	29.3%	28.5%	2.7%	2.1%	8.7%	5.1%	0.0%
Coal	6.0%	50.6%	56.6%	54.0%	7.4%	57.6%	84.3%	94.7%	4.2%	4.1%	11.6%	13.3%	10.6%
Wheat	10.8%	7.7%	9.8%	9.2%	0.3%	2.3%	2.5%	2.5%	96.8%	97.5%	44.2%	51.2%	83.7%
Soybeans	4.7%	23.5%	23.4%	23.2%	13.1%	2.2%	8.0%	7.3%	37.3%	39.9%	97.0%	98.3%	69.0%
Corn	16.0%	4.3%	7.3%	7.8%	0.7%	0.6%	6.3%	5.3%	82.8%	83.6%	68.1%	77.2%	96.9%
Iron	100.0%	8.6%	16.2%	17.7%	20.2%	11.8%	11.0%	11.1%	16.0%	15.3%	2.4%	5.0%	14.6%
Crude_F1	8.6%	100.0%	97.5%	95.1%	47.6%	31.4%	45.6%	47.1%	12.6%	12.8%	24.5%	20.1%	7.8%
Brent_F1	16.2%	97.5%	100.0%	99.0%	39.0%	26.4%	54.4%	55.2%	15.6%	15.7%	23.1%	20.6%	11.6%
Heating_F1	17.7%	95.1%	99.0%	100.0%	41.1%	22.9%	56.1%	54.6%	15.3%	15.4%	22.0%	20.1%	11.8%
Natural_gas_F1	20.2%	47.6%	39.0%	41.1%	100.0%	17.2%	16.1%	12.6%	2.9%	2.1%	13.7%	9.3%	0.0%
Natural_Gas_F2	11.8%	31.4%	26.4%	22.9%	17.2%	100.0%	36.6%	46.6%	1.1%	1.3%	3.3%	3.3%	2.1%
Coal_F1	11.0%	45.6%	54.4%	56.1%	16.1%	36.6%	100.0%	95.5%	3.7%	3.4%	5.1%	8.6%	11.2%

Coal_F2	11.1%	47.1%	55.2%	54.6%	12.6%	46.6%	95.5%	100.0%	3.5%	3.3%	5.8%	8.6%	10.3%
Wheat_F1	16.0%	12.6%	15.6%	15.3%	2.9%	1.1%	3.7%	3.5%	100.0%	99.8%	36.8%	45.4%	82.3%
Wheat_F2	15.3%	12.8%	15.7%	15.4%	2.1%	1.3%	3.4%	3.3%	99.8%	100.0%	39.2%	47.8%	83.2%
Soybeans_F1	2.4%	24.5%	23.1%	22.0%	13.7%	3.3%	5.1%	5.8%	36.8%	39.2%	100.0%	98.0%	66.6%
Soybeans_F2	5.0%	20.1%	20.6%	20.1%	9.3%	3.3%	8.6%	8.6%	45.4%	47.8%	98.0%	100.0%	77.2%
Corn_F1	14.6%	7.8%	11.6%	11.8%	0.0%	2.1%	11.2%	10.3%	82.3%	83.2%	66.6%	77.2%	100.0%
Corn_F2	14.1%	8.2%	11.8%	11.9%	0.1%	2.3%	9.2%	8.6%	85.9%	86.9%	65.5%	75.8%	99.6%
Iron_F1	59.9%	21.7%	30.2%	32.1%	1.6%	18.3%	19.3%	18.2%	21.3%	22.3%	3.9%	7.2%	21.4%
Iron_F2	34.9%	47.8%	52.0%	50.9%	10.1%	12.8%	19.2%	19.8%	23.3%	23.8%	8.5%	8.1%	15.4%
Copper	5.4%	85.6%	79.5%	75.3%	42.6%	15.9%	20.2%	22.2%	14.4%	15.6%	40.0%	33.1%	10.4%
Copper_F3	5.7%	86.4%	80.5%	76.2%	41.8%	16.4%	20.8%	23.0%	14.8%	16.0%	40.7%	33.9%	11.0%
Sugar	12.5%	21.8%	13.4%	11.0%	26.1%	29.6%	6.8%	2.2%	15.8%	17.9%	23.8%	19.6%	14.8%
Sugar_F1	14.6%	20.3%	12.0%	9.7%	25.7%	32.4%	6.0%	1.7%	14.5%	16.6%	22.0%	18.3%	14.2%
Sugar_F2	11.2%	20.4%	12.4%	10.1%	24.5%	26.3%	7.9%	2.6%	16.8%	19.1%	24.2%	19.9%	15.4%
Rice	27.0%	41.4%	43.9%	46.7%	32.7%	1.5%	9.9%	8.1%	51.3%	51.5%	23.0%	24.3%	30.3%
Rice_F1	25.4%	38.2%	40.2%	43.0%	32.2%	1.1%	8.2%	6.4%	51.8%	52.0%	21.6%	22.9%	30.2%
Rice_F2	25.1%	38.3%	40.0%	42.3%	32.3%	0.9%	7.8%	6.0%	54.1%	54.0%	20.2%	21.6%	30.5%
Barley	4.4%	20.5%	14.9%	14.9%	35.2%	8.7%	0.0%	0.2%	15.6%	18.2%	67.9%	67.3%	39.6%
Barley_F1	31.5%	8.6%	11.1%	11.6%	1.7%	21.1%	12.3%	7.9%	17.3%	19.4%	17.6%	21.3%	21.5%
Barley_F2	6.6%	24.7%	26.2%	26.6%	17.8%	18.0%	9.2%	9.2%	32.2%	31.9%	5.9%	7.8%	16.4%
Canola	11.5%	4.9%	2.4%	2.1%	17.4%	0.4%	5.3%	4.8%	26.6%	27.6%	66.8%	68.0%	59.9%
Canola_F1	13.2%	5.5%	2.9%	2.7%	18.6%	2.3%	6.2%	5.9%	18.6%	19.7%	68.8%	67.6%	52.7%
Canola_F2	5.3%	4.5%	2.9%	3.0%	12.3%	2.1%	7.4%	5.7%	25.1%	26.2%	77.5%	79.7%	62.2%
BDI	19.7%	33.8%	24.6%	21.1%	55.5%	27.9%	9.9%	8.0%	2.7%	1.7%	8.4%	5.0%	1.1%
BLPG1	9.7%	22.1%	25.4%	26.9%	22.6%	25.2%	62.7%	56.4%	8.2%	6.8%	1.5%	2.4%	7.7%
TD3	9.0%	19.9%	15.7%	15.9%	38.2%	46.5%	31.9%	24.1%	0.4%	0.7%	2.3%	0.9%	0.1%
TC2_37	13.0%	6.8%	8.0%	8.5%	10.8%	4.7%	6.4%	5.6%	4.4%	3.2%	19.8%	16.5%	2.7%
Urea	39.6%	3.9%	1.0%	0.5%	18.0%	29.3%	7.0%	3.1%	9.0%	11.1%	17.3%	18.2%	17.2%
DAP	18.8%	13.3%	17.7%	16.8%	8.7%	30.3%	18.6%	29.3%	38.6%	38.5%	16.1%	19.2%	36.5%
Ammonia	22.4%	13.5%	15.1%	15.9%	7.1%	22.7%	1.6%	0.8%	6.6%	6.7%	9.2%	6.4%	1.9%

Table 0.2 Spectral Coherence Weekly Reduced (periodicity @ 36 months), cont.

	Corn_F2	Iron_F1	Iron_F2	Copper	Copper_F3	Sugar	Sugar_F1	Sugar_F2	Rice	Rice_F1	Rice_F2	Barley	Barley_F1
BCI_TCE	1.0%	10.8%	9.2%	27.0%	26.8%	62.1%	63.3%	60.4%	10.0%	9.5%	11.5%	38.2%	45.3%
BPI_TCE	21.3%	37.4%	32.3%	16.5%	15.8%	10.9%	11.7%	10.8%	23.5%	23.6%	24.0%	3.4%	14.2%
BPI_TCE	5.5%	23.3%	45.5%	54.8%	53.4%	6.6%	6.0%	6.5%	33.4%	33.8%	35.0%	12.9%	5.5%
TC2$	3.8%	19.3%	28.8%	24.0%	23.1%	1.8%	2.3%	1.6%	1.0%	1.2%	0.9%	19.5%	25.5%
TD3$	0.1%	5.2%	15.5%	18.9%	18.4%	13.0%	12.6%	13.4%	10.7%	10.8%	11.0%	6.9%	4.2%
BHSI	3.7%	25.2%	30.8%	14.0%	13.1%	13.4%	14.1%	13.2%	0.3%	0.5%	0.6%	9.3%	25.7%
BDTI	0.3%	7.6%	11.3%	9.6%	9.3%	22.6%	23.7%	21.2%	9.6%	9.5%	10.6%	8.4%	14.7%
BCTI	1.0%	12.7%	37.0%	55.9%	54.3%	11.0%	10.0%	11.1%	31.5%	32.2%	33.1%	22.8%	3.6%
4TC_C+1MON	0.5%	2.0%	4.8%	15.2%	14.9%	34.8%	35.2%	33.8%	9.4%	8.3%	10.4%	39.8%	23.0%
4TC_C+2MON	1.6%	0.4%	1.2%	8.8%	8.8%	24.4%	24.0%	24.3%	9.4%	8.2%	10.2%	34.0%	12.1%
4TC_P+1MON	7.3%	10.4%	1.5%	1.7%	1.5%	14.7%	15.4%	14.0%	6.0%	5.3%	6.6%	39.3%	9.1%
4TC_P+2MON	6.5%	11.7%	2.5%	1.6%	1.5%	11.5%	11.9%	10.9%	9.1%	8.2%	9.7%	33.8%	5.5%
5TC_S+1MON	11.9%	27.0%	11.3%	2.7%	2.7%	14.8%	15.8%	13.7%	12.6%	11.4%	12.5%	24.3%	9.7%
5TC_S+2MON	9.6%	23.7%	11.3%	1.8%	2.0%	8.1%	8.6%	7.4%	13.6%	12.4%	13.5%	20.8%	5.2%
TC2$+1_M	7.6%	13.3%	3.3%	10.5%	9.8%	36.4%	37.2%	37.1%	7.2%	7.7%	9.1%	21.9%	42.3%
TC2$+2_M	8.1%	16.3%	2.9%	5.5%	5.1%	37.1%	37.6%	38.4%	6.7%	7.0%	8.0%	18.2%	43.9%
TD3$+1_M	0.3%	2.6%	15.6%	22.3%	21.6%	17.9%	17.2%	18.6%	17.5%	17.5%	18.3%	11.1%	4.7%
TD3$+2_M	0.1%	3.6%	16.5%	23.6%	22.9%	18.4%	18.2%	18.4%	15.7%	15.6%	16.4%	17.5%	7.4%
Crude	8.4%	20.5%	45.7%	83.7%	84.6%	22.5%	21.1%	21.1%	41.2%	37.9%	38.1%	19.1%	7.6%
Brent	11.7%	31.0%	51.3%	77.1%	78.0%	12.0%	10.7%	11.1%	44.0%	40.4%	40.0%	13.8%	11.0%
Heating_oil	9.5%	36.3%	62.5%	77.5%	76.9%	7.0%	6.0%	6.5%	48.1%	46.2%	46.7%	24.4%	15.7%
Natural_Gas	0.0%	13.8%	13.0%	30.5%	30.1%	28.2%	27.0%	27.3%	41.7%	40.0%	39.2%	27.0%	1.9%
Coal	9.2%	12.7%	16.4%	27.0%	28.2%	2.0%	2.1%	1.4%	3.3%	2.1%	1.9%	0.4%	6.1%
Wheat	87.6%	20.9%	18.6%	10.4%	10.9%	26.8%	25.3%	28.2%	38.9%	39.0%	40.9%	20.5%	21.5%
Soybeans	67.3%	9.2%	12.8%	39.8%	40.4%	17.3%	16.3%	17.6%	26.0%	24.7%	22.9%	75.6%	26.2%
Corn	97.7%	16.2%	9.5%	7.7%	8.3%	14.6%	13.9%	15.3%	30.5%	30.5%	30.4%	46.0%	18.5%
Iron	14.1%	59.9%	34.9%	5.4%	5.7%	12.5%	14.6%	11.2%	27.0%	25.4%	25.1%	4.4%	31.5%
Crude_F1	8.2%	21.7%	47.8%	85.6%	86.4%	21.8%	20.3%	20.4%	41.4%	38.2%	38.3%	20.5%	8.6%
Brent_F1	11.8%	30.2%	52.0%	79.5%	80.5%	13.4%	12.0%	12.4%	43.9%	40.2%	40.0%	14.9%	11.1%
Heating_F1	11.9%	32.1%	50.9%	75.3%	76.2%	11.0%	9.7%	10.1%	46.7%	43.0%	42.3%	14.9%	11.6%
Natural_gas_F1	0.1%	1.6%	10.1%	42.6%	41.8%	26.1%	25.7%	24.5%	32.7%	32.2%	32.3%	35.2%	1.7%
Natural_Gas_F2	2.3%	18.3%	12.8%	15.9%	16.4%	29.6%	32.4%	26.3%	1.5%	1.1%	0.9%	8.7%	21.1%
Coal_F1	9.2%	19.3%	19.2%	20.2%	20.8%	6.8%	6.0%	7.9%	9.9%	8.2%	7.8%	0.0%	12.3%

Coal_F2	8.6%	18.2%	19.8%	22.2%	23.0%	2.2%	1.7%	2.6%	8.1%	6.4%	6.0%	0.2%	7.9%
Wheat_F1	85.9%	21.3%	23.3%	14.4%	14.8%	15.8%	14.5%	16.8%	51.3%	51.8%	54.1%	15.6%	17.3%
Wheat_F2	86.9%	22.3%	23.8%	15.6%	16.0%	17.9%	16.6%	19.1%	51.5%	52.0%	54.0%	18.2%	19.4%
Soybeans_F1	65.5%	3.9%	8.5%	40.0%	40.7%	23.8%	22.0%	24.2%	23.0%	21.6%	20.2%	67.9%	17.6%
Soybeans_F2	75.8%	7.2%	8.1%	33.1%	33.9%	19.6%	18.3%	19.9%	24.3%	22.9%	21.6%	67.3%	21.3%
Corn_F1	99.6%	21.4%	15.4%	10.4%	11.0%	14.8%	14.2%	15.4%	30.3%	30.2%	30.5%	39.6%	21.5%
Corn_F2	100.0%	20.9%	15.5%	10.9%	11.5%	16.3%	15.5%	17.0%	33.1%	33.0%	33.4%	38.8%	20.6%
Iron_F1	20.9%	100.0%	84.1%	29.3%	29.0%	19.6%	22.7%	19.0%	22.3%	21.0%	19.2%	5.7%	71.9%
Iron_F2	15.5%	84.1%	100.0%	64.1%	63.3%	3.1%	4.3%	2.9%	32.1%	30.8%	30.2%	10.8%	51.7%
Copper	10.9%	29.3%	64.1%	100.0%	100.0%	20.7%	19.2%	20.2%	42.3%	40.2%	40.3%	36.7%	22.5%
Copper_F3	11.5%	29.0%	63.3%	100.0%	100.0%	21.3%	19.7%	20.8%	42.4%	40.2%	40.2%	36.2%	22.3%
Sugar	16.3%	19.6%	3.1%	20.7%	21.3%	100.0%	99.7%	99.8%	10.9%	10.2%	11.4%	22.1%	52.3%
Sugar_F1	15.5%	22.7%	4.3%	19.2%	19.7%	99.7%	100.0%	99.2%	8.7%	8.1%	9.3%	21.8%	55.6%
Sugar_F2	17.0%	19.0%	2.9%	20.2%	20.8%	99.8%	99.2%	100.0%	11.3%	10.6%	11.8%	21.7%	52.2%
Rice	33.1%	22.3%	32.1%	42.3%	42.4%	10.9%	8.7%	11.3%	100.0%	99.7%	99.3%	18.7%	7.2%
Rice_F1	33.0%	21.0%	30.8%	40.2%	40.2%	10.2%	8.1%	10.6%	99.7%	100.0%	99.7%	18.0%	6.6%
Rice_F2	33.4%	19.2%	30.2%	40.3%	40.2%	11.4%	9.3%	11.8%	99.3%	99.7%	100.0%	16.1%	5.9%
Barley	38.8%	5.7%	10.8%	36.7%	36.2%	22.1%	21.8%	21.7%	18.7%	18.0%	16.1%	100.0%	26.9%
Barley_F1	20.6%	71.9%	51.7%	22.5%	22.3%	52.3%	55.6%	52.2%	7.2%	6.6%	5.9%	26.9%	100.0%
Barley_F2	17.3%	59.8%	64.4%	36.9%	35.9%	23.2%	24.9%	23.5%	23.4%	22.8%	23.1%	22.8%	67.8%
Canola	57.5%	7.5%	3.2%	8.5%	8.4%	20.0%	19.2%	20.2%	3.5%	3.3%	2.7%	69.6%	7.1%
Canola_F1	49.5%	8.6%	3.3%	10.8%	10.7%	24.0%	22.8%	24.2%	5.4%	5.1%	4.7%	59.5%	7.1%
Canola_F2	59.1%	2.6%	0.3%	11.7%	11.8%	15.1%	14.4%	15.2%	6.3%	6.0%	5.1%	69.2%	10.3%
BDI	0.9%	1.7%	3.6%	30.2%	29.7%	47.4%	47.6%	46.2%	16.8%	16.5%	18.6%	30.3%	19.0%
BLPG1	7.3%	7.8%	14.3%	13.6%	13.1%	11.5%	10.1%	12.9%	27.9%	27.4%	28.3%	3.2%	1.8%
TD3	0.2%	7.1%	17.3%	19.0%	18.5%	14.2%	14.3%	14.2%	11.0%	11.2%	11.6%	8.3%	7.2%
TC2_37	2.8%	20.8%	29.1%	20.5%	19.7%	4.1%	4.7%	3.8%	0.5%	0.6%	0.5%	15.4%	24.7%
Urea	16.6%	53.3%	23.6%	12.7%	12.8%	75.0%	78.0%	74.4%	0.0%	0.0%	0.1%	25.0%	83.7%
DAP	37.4%	46.6%	32.1%	10.1%	10.6%	24.2%	25.7%	24.3%	11.9%	10.8%	10.5%	1.0%	38.0%
Ammonia	1.9%	65.4%	71.8%	33.4%	32.0%	9.9%	12.0%	9.1%	18.6%	18.9%	17.0%	15.1%	48.1%

Table 0.2 Spectral Coherence Weekly Reduced (periodicity @ 36 months), cont.

	Barley_F2	Canola	Canola_F1	Canola_F2	BDI	BLPG1	TD3	TC2_37	Urea	DAP	Ammonia
BCI_TCE	28.6%	14.0%	10.6%	9.8%	86.5%	17.0%	28.5%	9.8%	60.1%	6.4%	12.0%
BPI_TCE	33.5%	13.4%	8.3%	4.3%	42.5%	22.7%	7.2%	18.5%	13.4%	40.3%	30.8%
BPI_TCE	35.9%	8.3%	7.2%	3.4%	50.2%	28.6%	16.0%	35.9%	1.8%	12.8%	43.1%
TC2$	25.4%	7.4%	6.7%	11.8%	10.4%	17.1%	9.3%	98.9%	13.7%	5.5%	60.3%
TD3$	2.3%	0.4%	0.6%	1.6%	24.1%	48.5%	99.2%	5.6%	11.3%	0.1%	12.5%
BHSI	42.8%	3.4%	2.8%	4.8%	1.9%	9.2%	4.8%	93.7%	10.4%	19.0%	70.4%
BDTI	7.8%	0.3%	0.4%	1.2%	27.0%	54.8%	85.2%	20.0%	21.5%	2.4%	25.6%
BCTI	29.2%	10.9%	11.1%	7.0%	53.1%	33.3%	23.7%	41.0%	6.8%	8.0%	41.0%
4TC_C+1MON	35.6%	15.7%	9.1%	9.9%	64.7%	15.2%	12.4%	14.4%	26.0%	12.4%	13.9%
4TC_C+2MON	28.2%	18.8%	11.8%	12.9%	50.8%	10.8%	1.2%	11.4%	13.9%	11.8%	5.5%
4TC_P+1MON	8.6%	25.9%	17.6%	17.4%	48.6%	10.5%	5.1%	13.1%	20.2%	3.7%	5.2%
4TC_P+2MON	8.0%	25.1%	18.4%	16.9%	42.8%	10.0%	4.1%	11.7%	16.4%	5.7%	2.7%
5TC_S+1MON	1.5%	24.6%	18.1%	13.4%	42.9%	12.1%	4.4%	6.2%	23.7%	9.9%	5.0%
5TC_S+2MON	2.6%	21.1%	15.8%	12.6%	33.6%	9.3%	5.0%	7.8%	15.4%	8.8%	4.6%
TC2$+1_M	5.2%	16.2%	17.1%	16.9%	46.9%	54.6%	24.7%	41.1%	61.1%	4.7%	10.2%
TC2$+2_M	5.0%	15.1%	16.7%	15.7%	39.2%	60.2%	28.2%	35.6%	60.5%	6.5%	8.7%
TD3$+1_M	5.2%	3.5%	3.6%	2.8%	33.2%	67.2%	93.1%	8.3%	13.8%	1.7%	15.1%
TD3$+2_M	8.8%	4.1%	3.5%	2.1%	39.7%	59.8%	91.5%	10.6%	16.0%	2.0%	18.5%
Crude	23.3%	4.7%	5.3%	4.2%	34.6%	22.7%	19.8%	6.2%	3.7%	13.5%	11.8%
Brent	26.1%	2.2%	2.7%	2.6%	23.9%	26.4%	15.9%	8.0%	0.6%	17.4%	15.1%
Heating_oil	50.1%	6.7%	7.3%	4.9%	30.5%	16.7%	8.4%	11.5%	0.6%	20.6%	32.9%
Natural_Gas	13.4%	21.0%	22.6%	12.0%	44.9%	31.9%	19.1%	0.8%	15.6%	17.7%	5.9%
Coal	8.4%	2.3%	3.9%	5.5%	5.9%	41.7%	17.1%	8.2%	2.3%	34.5%	0.0%
Wheat	31.6%	33.8%	26.4%	30.6%	0.2%	3.7%	1.0%	5.7%	16.5%	44.6%	5.7%
Soybeans	12.7%	66.6%	65.4%	79.1%	7.3%	1.5%	1.6%	19.4%	19.4%	12.5%	11.7%
Corn	11.2%	60.8%	49.8%	60.8%	4.3%	6.4%	0.6%	5.7%	16.3%	31.8%	0.7%
Iron	6.6%	11.5%	13.2%	5.3%	19.7%	9.7%	9.0%	13.0%	39.6%	18.8%	22.4%
Crude_F1	24.7%	4.9%	5.5%	4.5%	33.8%	22.1%	19.9%	6.8%	3.9%	13.3%	13.5%
Brent_F1	26.2%	2.4%	2.9%	2.9%	24.6%	25.4%	15.7%	8.0%	1.0%	17.7%	15.1%
Heating_F1	26.6%	2.1%	2.7%	3.0%	21.1%	26.9%	15.9%	8.5%	0.5%	16.8%	15.9%
Natural_gas_F1	17.8%	17.4%	18.6%	12.3%	55.5%	22.6%	38.2%	10.8%	18.0%	8.7%	7.1%
Natural_Gas_F2	18.0%	0.4%	2.3%	2.1%	27.9%	25.2%	46.5%	4.7%	29.3%	30.3%	22.7%
Coal_F1	9.2%	5.3%	6.2%	7.4%	9.9%	62.7%	31.9%	6.4%	7.0%	18.6%	1.6%

Coal_F2	9.2%	4.8%	5.9%	5.7%	8.0%	56.4%	24.1%	5.6%	3.1%	29.3%	0.8%
Wheat_F1	32.2%	26.6%	18.6%	25.1%	2.7%	8.2%	0.4%	4.4%	9.0%	38.6%	6.6%
Wheat_F2	31.9%	27.6%	19.7%	26.2%	1.7%	6.8%	0.7%	3.2%	11.1%	38.5%	6.7%
Soybeans_F1	5.9%	66.8%	68.8%	77.5%	8.4%	1.5%	2.3%	19.8%	17.3%	16.1%	9.2%
Soybeans_F2	7.8%	68.0%	67.6%	79.7%	5.0%	2.4%	0.9%	16.5%	18.2%	19.2%	6.4%
Corn_F1	16.4%	59.9%	52.7%	62.2%	1.1%	7.7%	0.1%	2.7%	17.2%	36.5%	1.9%
Corn_F2	17.3%	57.5%	49.5%	59.1%	0.9%	7.3%	0.2%	2.8%	16.6%	37.4%	1.9%
Iron_F1	59.8%	7.5%	8.6%	2.6%	1.7%	7.8%	7.1%	20.8%	53.3%	46.6%	65.4%
Iron_F2	64.4%	3.2%	3.3%	0.3%	3.6%	14.3%	17.3%	29.1%	23.6%	32.1%	71.8%
Copper	36.9%	8.5%	10.8%	11.7%	30.2%	13.6%	19.0%	20.5%	12.7%	10.1%	33.4%
Copper_F3	35.9%	8.4%	10.7%	11.8%	29.7%	13.1%	18.5%	19.7%	12.8%	10.6%	32.0%
Sugar	23.2%	20.0%	24.0%	15.1%	47.4%	11.5%	14.2%	4.1%	75.0%	24.2%	9.9%
Sugar_F1	24.9%	19.2%	22.8%	14.4%	47.6%	10.1%	14.3%	4.7%	78.0%	25.7%	12.0%
Sugar_F2	23.5%	20.2%	24.2%	15.2%	46.2%	12.9%	14.2%	3.8%	74.4%	24.3%	9.1%
Rice	23.4%	3.5%	5.4%	6.3%	16.8%	27.9%	11.0%	0.5%	0.0%	11.9%	18.6%
Rice_F1	22.8%	3.3%	5.1%	6.0%	16.5%	27.4%	11.2%	0.6%	0.0%	10.8%	18.9%
Rice_F2	23.1%	2.7%	4.7%	5.1%	18.6%	28.3%	11.6%	0.5%	0.1%	10.5%	17.0%
Barley	22.8%	69.6%	59.5%	69.2%	30.3%	3.2%	8.3%	15.4%	25.0%	1.0%	15.1%
Barley_F1	67.8%	7.1%	7.1%	10.3%	19.0%	1.8%	7.2%	24.7%	83.7%	38.0%	48.1%
Barley_F2	100.0%	0.2%	0.1%	2.2%	7.4%	5.8%	3.4%	29.0%	34.6%	57.2%	62.4%
Canola	0.2%	100.0%	94.7%	94.6%	17.8%	11.2%	0.2%	5.1%	15.5%	10.4%	2.7%
Canola_F1	0.1%	94.7%	100.0%	93.1%	13.5%	12.0%	0.3%	4.5%	17.9%	12.7%	4.4%
Canola_F2	2.2%	94.6%	93.1%	100.0%	10.3%	10.8%	1.2%	8.7%	12.9%	8.7%	3.3%
BDI	7.4%	17.8%	13.5%	10.3%	100.0%	27.0%	25.9%	6.5%	43.6%	0.1%	0.4%
BLPG1	5.8%	11.2%	12.0%	10.8%	27.0%	100.0%	47.6%	14.5%	9.0%	18.1%	11.8%
TD3	3.4%	0.2%	0.3%	1.2%	25.9%	47.6%	100.0%	7.7%	14.6%	0.0%	16.0%
TC2_37	29.0%	5.1%	4.5%	8.7%	6.5%	14.5%	7.7%	100.0%	11.6%	7.5%	63.9%
Urea	34.6%	15.5%	17.9%	12.9%	43.6%	9.0%	14.6%	11.6%	100.0%	32.5%	21.9%
DAP	57.2%	10.4%	12.7%	8.7%	0.1%	18.1%	0.0%	7.5%	32.5%	100.0%	24.5%
Ammonia	62.4%	2.7%	4.4%	3.3%	0.4%	11.8%	16.0%	63.9%	21.9%	24.5%	100.0%

Table 0.3 Spectral Coherence Daily Reduced (periodicity @ 36 months)

	BCI_TCE	BPI_TCE	BPI_TCE	TC2$	TD3$	BHSI	BDTI	BCTI	4TC_C+1MON	4TC_C+2MON	4TC_P+1MON	4TC_P+2MON	5TC_S+1MON
BCI_TCE	100.0%	82.6%	43.2%	34.2%	31.2%	37.8%	59.4%	54.9%	28.1%	29.4%	27.7%	28.6%	28.8%
BPI_TCE	82.6%	100.0%	38.8%	22.9%	33.7%	25.3%	44.1%	47.0%	15.6%	17.4%	14.8%	15.3%	16.8%
BPI_TCE	43.2%	38.8%	100.0%	9.9%	8.4%	12.0%	16.4%	85.2%	23.5%	28.6%	26.2%	28.2%	25.6%
TC2$	34.2%	22.9%	9.9%	100.0%	36.1%	93.6%	39.8%	6.3%	2.6%	6.7%	6.6%	6.9%	9.1%
TD3$	31.2%	33.7%	8.4%	36.1%	100.0%	28.9%	68.5%	8.6%	3.1%	5.8%	6.1%	6.7%	9.8%
BHSI	37.8%	25.3%	12.0%	93.6%	28.9%	100.0%	43.2%	6.4%	5.0%	8.4%	7.8%	7.7%	10.4%
BDTI	59.4%	44.1%	16.4%	39.8%	68.5%	43.2%	100.0%	18.3%	2.8%	0.4%	0.3%	0.3%	2.0%
BCTI	54.9%	47.0%	85.2%	6.3%	8.6%	6.4%	18.3%	100.0%	30.4%	33.3%	31.6%	34.6%	30.2%
4TC_C+1MON	28.1%	15.6%	23.5%	2.6%	3.1%	5.0%	2.8%	30.4%	100.0%	97.2%	96.0%	93.4%	90.9%
4TC_C+2MON	29.4%	17.4%	28.6%	6.7%	5.8%	8.4%	0.4%	33.3%	97.2%	100.0%	99.2%	97.8%	97.3%
4TC_P+1MON	27.7%	14.8%	26.2%	6.6%	6.1%	7.8%	0.3%	31.6%	96.0%	99.2%	100.0%	99.0%	98.2%
4TC_P+2MON	28.6%	15.3%	28.2%	6.9%	6.7%	7.7%	0.3%	34.6%	93.4%	97.8%	99.0%	100.0%	97.0%
5TC_S+1MON	28.8%	16.8%	25.6%	9.1%	9.8%	10.4%	2.0%	30.2%	90.9%	97.3%	98.2%	97.0%	100.0%
5TC_S+2MON	31.0%	18.3%	28.2%	10.1%	10.6%	11.2%	2.3%	33.2%	90.3%	97.3%	97.8%	98.0%	99.0%
TC2$+1_M	20.0%	26.1%	10.3%	35.7%	14.1%	21.3%	22.0%	10.0%	5.2%	7.2%	6.1%	4.2%	7.6%
TC2$+2_M	20.1%	26.1%	8.9%	37.7%	15.2%	21.9%	22.2%	9.6%	3.3%	4.2%	3.5%	2.1%	4.1%
TD3$+1_M	5.7%	10.3%	1.3%	28.3%	83.0%	19.3%	46.1%	0.0%	26.6%	26.1%	26.5%	26.8%	24.6%
TD3$+2_M	6.3%	14.5%	0.8%	30.8%	77.7%	24.2%	42.6%	0.7%	26.0%	25.3%	26.7%	27.1%	23.8%
Crude	6.8%	5.0%	4.3%	10.1%	8.7%	14.1%	6.7%	2.1%	9.6%	12.5%	13.3%	13.8%	13.1%
Brent	6.5%	4.0%	4.8%	13.1%	12.8%	18.4%	8.1%	3.2%	13.8%	17.7%	19.0%	20.3%	18.6%
Heating_oil	6.0%	6.3%	0.3%	24.7%	72.9%	17.7%	42.6%	0.9%	16.1%	18.1%	18.3%	20.3%	18.9%
Natural_Gas	20.8%	22.4%	21.3%	15.3%	40.5%	19.6%	42.5%	17.5%	6.7%	12.1%	14.3%	12.5%	20.7%
Coal	3.1%	10.8%	1.5%	12.0%	9.9%	20.0%	6.6%	1.6%	11.7%	13.6%	14.8%	13.5%	14.2%
Wheat	8.9%	8.6%	7.6%	23.6%	12.5%	25.0%	12.7%	3.7%	5.6%	3.2%	3.7%	3.7%	3.5%
Soybeans	2.9%	2.5%	1.8%	15.0%	9.3%	14.0%	5.7%	0.7%	8.6%	6.4%	7.0%	6.5%	6.7%
Corn	3.8%	5.3%	3.4%	13.9%	8.0%	14.6%	6.7%	1.6%	10.3%	7.8%	8.4%	8.3%	8.3%
Iron	12.3%	9.4%	12.2%	8.0%	3.9%	11.3%	6.5%	16.4%	3.9%	5.2%	5.4%	3.3%	7.1%
Crude_F1	6.8%	5.0%	4.3%	10.3%	8.7%	14.5%	6.8%	2.0%	9.5%	12.4%	13.2%	13.7%	13.0%
Brent_F1	6.1%	4.4%	3.8%	10.7%	9.2%	15.7%	7.0%	2.1%	10.0%	13.0%	14.0%	14.6%	13.7%
Heating_F1	6.1%	4.4%	3.6%	10.7%	10.2%	15.2%	7.1%	2.0%	10.4%	13.4%	14.4%	15.0%	14.2%
Natural_gas_F1	10.9%	15.8%	1.8%	30.2%	39.0%	37.1%	23.6%	1.8%	13.6%	19.2%	21.0%	21.0%	23.6%
Natural_Gas_F2	7.1%	13.8%	2.7%	15.7%	17.8%	22.9%	11.6%	0.8%	9.8%	12.6%	13.4%	11.9%	13.6%

Coal_F1	4.9%	13.5%	4.3%	15.3%	11.6%	24.0%	6.6%	0.1%	16.7%	19.3%	19.8%	17.6%	19.6%
Coal_F2	4.6%	11.1%	3.3%	14.1%	9.6%	24.9%	6.4%	0.5%	13.6%	15.8%	16.7%	15.2%	16.3%
Wheat_F1	7.0%	8.0%	6.5%	18.1%	9.8%	18.7%	11.2%	3.8%	10.1%	7.3%	8.2%	8.4%	7.8%
Wheat_F2	6.6%	7.7%	6.3%	18.6%	9.9%	18.6%	10.9%	3.6%	10.2%	7.6%	8.7%	8.9%	8.3%
Soybeans_F1	1.9%	2.5%	1.1%	12.6%	7.6%	12.3%	4.3%	0.5%	8.8%	6.6%	7.1%	6.6%	6.9%
Soybeans_F2	2.0%	2.2%	1.4%	12.8%	7.8%	12.4%	4.7%	0.5%	9.1%	7.0%	7.6%	7.2%	7.4%
Corn_F1	3.7%	4.6%	3.0%	13.5%	8.0%	14.6%	6.8%	1.2%	9.7%	7.2%	7.6%	7.5%	7.5%
Corn_F2	4.0%	5.1%	3.4%	14.3%	8.2%	15.0%	7.3%	1.5%	10.4%	7.8%	8.4%	8.4%	8.3%
Iron_F1	6.0%	4.2%	9.3%	14.4%	7.6%	26.0%	8.6%	4.1%	17.5%	21.6%	24.3%	25.4%	23.8%
Iron_F2	27.7%	17.8%	31.3%	22.3%	15.5%	25.0%	16.0%	24.9%	48.2%	58.5%	59.8%	60.8%	63.0%
Copper	6.4%	3.3%	3.7%	12.8%	12.7%	16.6%	7.2%	2.8%	19.9%	24.3%	25.8%	27.3%	25.7%
Copper_F3	6.1%	3.1%	3.6%	12.7%	12.8%	16.4%	7.2%	2.8%	19.9%	24.2%	25.7%	27.2%	25.6%
Sugar	3.9%	7.4%	3.3%	10.2%	15.8%	2.6%	4.8%	2.6%	13.3%	14.9%	12.1%	13.3%	11.8%
Sugar_F1	4.7%	10.8%	2.5%	9.1%	10.6%	1.7%	2.8%	2.4%	9.6%	10.5%	7.6%	7.8%	7.7%
Sugar_F2	4.1%	9.9%	2.3%	8.2%	10.2%	1.4%	2.8%	2.1%	9.8%	10.6%	7.8%	8.0%	7.8%
Rice	0.1%	5.3%	3.9%	6.1%	12.4%	9.5%	8.7%	6.3%	20.8%	23.5%	26.9%	30.3%	26.7%
Rice_F1	0.1%	5.2%	3.7%	6.4%	13.1%	9.8%	9.0%	6.1%	21.0%	23.8%	27.2%	30.6%	27.1%
Rice_F2	0.2%	4.8%	3.8%	5.6%	11.9%	8.8%	8.2%	6.0%	21.7%	24.4%	27.9%	31.4%	27.6%
Barley	40.7%	32.0%	19.8%	55.7%	35.6%	44.1%	18.9%	18.9%	8.0%	13.3%	12.9%	14.7%	16.4%
Barley_F1	32.7%	31.4%	15.6%	2.5%	2.2%	2.8%	0.5%	33.9%	56.3%	58.8%	59.4%	61.9%	59.4%
Barley_F2	33.7%	16.2%	11.8%	19.4%	25.1%	20.8%	11.0%	16.1%	42.0%	51.4%	52.9%	55.9%	55.6%
Canola	5.4%	2.6%	3.4%	18.4%	13.8%	20.7%	7.7%	0.7%	1.7%	0.3%	0.3%	0.1%	0.3%
Canola_F1	5.7%	3.0%	3.5%	19.5%	14.0%	21.0%	7.9%	0.8%	2.0%	0.6%	0.6%	0.4%	0.6%
Canola_F2	4.2%	2.5%	3.1%	17.9%	12.8%	18.8%	6.8%	0.5%	2.8%	1.2%	1.3%	1.0%	1.3%
BDI	98.8%	87.7%	39.9%	31.4%	33.6%	34.7%	59.8%	49.3%	23.8%	24.6%	22.9%	23.9%	23.9%
BLPG1	36.9%	48.2%	17.2%	23.8%	16.1%	13.9%	18.0%	36.0%	3.4%	6.0%	4.1%	4.1%	6.7%
TD3	32.9%	32.7%	8.0%	31.1%	98.7%	25.4%	75.9%	9.1%	2.5%	3.7%	4.1%	4.7%	7.3%
TC2_37	37.7%	25.2%	12.4%	99.2%	33.8%	96.8%	42.4%	7.8%	3.3%	7.5%	7.2%	7.4%	9.9%

Table 0.3 Spectral Coherence Daily Reduced (periodicity @ 36 months), cont.

	5TC_S+2MON	TC2$+1_M	TC2$+2_M	TD3$+1_M	TD3$+2_M	Crude	Brent	Heating_oil	Natural_Gas	Coal	Wheat	Soybeans	Corn
BCI_TCE	31.0%	20.0%	20.1%	5.7%	6.3%	6.8%	6.5%	6.0%	20.8%	3.1%	8.9%	2.9%	3.8%
BPI_TCE	18.3%	26.1%	26.1%	10.3%	14.5%	5.0%	4.0%	6.3%	22.4%	10.8%	8.6%	2.5%	5.3%
BPI_TCE	28.2%	10.3%	8.9%	1.3%	0.8%	4.3%	4.8%	0.3%	21.3%	1.5%	7.6%	1.8%	3.4%
TC2$	10.1%	35.7%	37.7%	28.3%	30.8%	10.1%	13.1%	24.7%	15.3%	12.0%	23.6%	15.0%	13.9%
TD3$	10.6%	14.1%	15.2%	83.0%	77.7%	8.7%	12.8%	72.9%	40.5%	9.9%	12.5%	9.3%	8.0%
BHSI	11.2%	21.3%	21.9%	19.3%	24.2%	14.1%	18.4%	17.7%	19.6%	20.0%	25.0%	14.0%	14.6%
BDTI	2.3%	22.0%	22.2%	46.1%	42.6%	6.7%	8.1%	42.6%	42.5%	6.6%	12.7%	5.7%	6.7%
BCTI	33.2%	10.0%	9.6%	0.0%	0.7%	2.1%	3.2%	0.9%	17.5%	1.6%	3.7%	0.7%	1.6%
4TC_C+1MON	90.3%	5.2%	3.3%	26.6%	26.0%	9.6%	13.8%	16.1%	6.7%	11.7%	5.6%	8.6%	10.3%
4TC_C+2MON	97.3%	7.2%	4.2%	26.1%	25.3%	12.5%	17.7%	18.1%	12.1%	13.6%	3.2%	6.4%	7.8%
4TC_P+1MON	97.8%	6.1%	3.5%	26.5%	26.7%	13.3%	19.0%	18.3%	14.3%	14.8%	3.7%	7.0%	8.4%
4TC_P+2MON	98.0%	4.2%	2.1%	26.8%	27.1%	13.8%	20.3%	20.3%	12.5%	13.5%	3.7%	6.5%	8.3%
5TC_S+1MON	99.0%	7.6%	4.1%	24.6%	23.8%	13.1%	18.6%	18.9%	20.7%	14.2%	3.5%	6.7%	8.3%
5TC_S+2MON	100.0%	7.7%	4.2%	24.4%	23.3%	13.5%	19.5%	20.4%	17.9%	12.9%	2.7%	5.3%	7.2%
TC2$+1_M	7.7%	100.0%	98.0%	12.7%	14.4%	9.0%	5.0%	9.3%	11.7%	21.4%	0.1%	2.2%	1.3%
TC2$+2_M	4.2%	98.0%	100.0%	14.4%	17.0%	6.1%	3.1%	9.2%	9.5%	24.9%	1.0%	0.4%	0.1%
TD3$+1_M	24.4%	12.7%	14.4%	100.0%	96.0%	7.3%	13.6%	75.3%	28.3%	15.8%	13.8%	12.8%	10.9%
TD3$+2_M	23.3%	14.4%	17.0%	96.0%	100.0%	12.8%	21.6%	69.4%	30.4%	30.7%	17.9%	15.6%	14.3%
Crude	13.5%	9.0%	6.1%	7.3%	12.8%	100.0%	96.3%	29.9%	32.8%	45.3%	16.7%	24.1%	19.7%
Brent	19.5%	5.0%	3.1%	13.6%	21.6%	96.3%	100.0%	37.1%	39.6%	57.3%	13.8%	17.5%	15.5%
Heating_oil	20.4%	9.3%	9.2%	75.3%	69.4%	29.9%	37.1%	100.0%	59.1%	10.8%	10.5%	7.7%	9.3%
Natural_Gas	17.9%	11.7%	9.5%	28.3%	30.4%	32.8%	39.6%	59.1%	100.0%	30.0%	11.5%	4.4%	8.1%
Coal	12.9%	21.4%	24.9%	15.8%	30.7%	45.3%	57.3%	10.8%	30.0%	100.0%	12.2%	9.1%	9.0%
Wheat	2.7%	0.1%	1.0%	13.8%	17.9%	16.7%	13.8%	10.5%	11.5%	12.2%	100.0%	92.4%	97.6%
Soybeans	5.3%	2.2%	0.4%	12.8%	15.6%	24.1%	17.5%	7.7%	4.4%	9.1%	92.4%	100.0%	95.8%
Corn	7.2%	1.3%	0.1%	10.9%	14.3%	19.7%	15.5%	9.3%	8.1%	9.0%	97.6%	95.8%	100.0%
Iron	4.3%	0.0%	0.1%	3.0%	5.0%	58.2%	49.4%	9.3%	35.3%	34.3%	34.9%	35.4%	31.6%
Crude_F1	13.3%	8.6%	5.8%	7.2%	13.0%	100.0%	96.5%	29.6%	33.0%	46.4%	16.5%	23.7%	19.3%
Brent_F1	14.0%	6.3%	4.0%	8.4%	15.1%	99.4%	98.1%	30.3%	35.1%	52.5%	16.3%	22.7%	18.8%
Heating_F1	14.4%	6.8%	4.4%	9.3%	16.0%	99.6%	98.0%	32.6%	35.8%	50.3%	16.6%	22.9%	19.1%
Natural_gas_F1	22.8%	9.0%	8.6%	38.1%	50.4%	65.4%	77.5%	57.2%	67.7%	66.9%	16.5%	13.1%	14.0%
Natural_Gas_F2	12.2%	12.2%	13.9%	19.8%	34.5%	62.2%	71.1%	19.3%	34.8%	93.6%	15.0%	12.6%	11.2%
Coal_F1	18.2%	29.3%	33.2%	19.8%	34.4%	28.0%	39.5%	7.3%	25.2%	95.1%	11.9%	7.5%	7.8%

Coal_F2	15.1%	19.3%	22.2%	15.2%	29.8%	42.8%	55.0%	9.7%	29.0%	99.0%	12.3%	8.1%	8.5%
Wheat_F1	6.8%	0.5%	1.5%	12.3%	16.5%	20.3%	17.6%	12.3%	14.9%	12.5%	98.2%	91.0%	97.9%
Wheat_F2	7.1%	0.7%	2.3%	13.0%	17.4%	21.1%	18.7%	12.0%	15.4%	13.8%	97.6%	90.9%	97.3%
Soybeans_F1	5.7%	3.5%	0.6%	10.9%	13.6%	24.9%	17.5%	6.4%	3.5%	7.7%	91.4%	99.5%	95.7%
Soybeans_F2	6.0%	3.1%	0.5%	11.4%	14.3%	26.0%	19.0%	7.5%	4.8%	8.8%	92.2%	99.7%	96.3%
Corn_F1	6.5%	2.3%	0.2%	10.6%	13.8%	20.0%	15.2%	9.4%	7.2%	8.2%	97.1%	96.7%	99.7%
Corn_F2	7.1%	1.4%	0.2%	11.2%	14.6%	20.3%	16.0%	9.8%	8.5%	9.1%	97.6%	96.2%	100.0%
Iron_F1	23.4%	4.0%	4.8%	11.3%	23.2%	69.5%	79.6%	18.1%	36.3%	83.0%	14.9%	15.5%	14.4%
Iron_F2	63.8%	21.4%	14.5%	17.4%	20.3%	56.9%	61.3%	25.8%	34.8%	28.6%	8.4%	15.7%	13.8%
Copper	26.5%	7.3%	4.3%	15.1%	22.2%	94.6%	96.6%	40.3%	40.7%	48.7%	21.3%	27.9%	25.7%
Copper_F3	26.4%	7.2%	4.2%	15.3%	22.4%	94.5%	96.6%	40.6%	40.9%	48.8%	21.5%	28.1%	25.9%
Sugar	15.0%	42.0%	40.0%	16.2%	10.3%	40.6%	34.9%	51.0%	19.0%	1.1%	11.0%	11.5%	15.1%
Sugar_F1	9.9%	57.4%	55.3%	9.5%	5.0%	32.4%	24.0%	35.6%	8.7%	4.2%	11.2%	13.1%	15.5%
Sugar_F2	10.1%	55.2%	52.8%	9.2%	4.8%	33.4%	24.9%	36.2%	9.7%	4.0%	12.8%	14.5%	17.2%
Rice	27.9%	21.5%	24.3%	25.4%	33.9%	18.4%	32.2%	32.4%	53.1%	46.2%	7.3%	3.0%	7.1%
Rice_F1	28.2%	21.5%	24.3%	26.3%	34.9%	18.9%	32.8%	33.2%	53.7%	46.8%	7.1%	2.9%	7.0%
Rice_F2	28.9%	21.4%	24.3%	25.2%	33.4%	17.7%	31.3%	31.9%	52.1%	44.9%	7.1%	2.9%	7.0%
Barley	17.6%	51.1%	53.2%	18.1%	14.7%	24.8%	20.9%	32.6%	10.9%	0.9%	5.3%	4.0%	2.3%
Barley_F1	61.0%	2.2%	4.2%	5.9%	5.6%	4.3%	8.1%	5.6%	6.3%	4.3%	6.0%	4.3%	8.2%
Barley_F2	59.8%	1.6%	0.7%	25.4%	23.6%	25.6%	38.0%	40.5%	38.7%	20.1%	1.8%	1.0%	0.3%
Canola	0.1%	6.0%	2.3%	15.3%	16.8%	6.3%	3.7%	8.9%	1.7%	6.6%	79.0%	84.8%	79.2%
Canola_F1	0.2%	4.1%	1.1%	15.8%	17.5%	8.3%	4.8%	8.5%	1.4%	6.0%	84.5%	89.9%	84.7%
Canola_F2	0.6%	4.3%	1.1%	15.4%	17.2%	10.2%	5.9%	8.1%	1.0%	5.5%	85.6%	92.2%	86.8%
BDI	26.1%	20.3%	20.7%	7.4%	8.6%	6.8%	6.1%	6.4%	19.8%	4.1%	9.7%	3.3%	4.7%
BLPG1	7.4%	66.6%	69.4%	8.7%	12.2%	0.5%	1.9%	3.2%	7.6%	43.1%	2.9%	1.0%	1.5%
TD3	8.0%	12.9%	13.8%	80.6%	73.7%	7.9%	11.6%	74.0%	43.9%	7.0%	10.8%	7.6%	6.8%
TC2_37	10.8%	32.9%	34.3%	24.8%	28.0%	11.4%	14.5%	21.6%	17.2%	13.9%	24.2%	14.5%	14.0%

Table 0.3 Spectral Coherence Daily Reduced (periodicity @ 36 months), cont.

	Iron	Crude_F1	Brent_F1	Heating_F1	Natural_gas_F1	Natural_Gas_F2	Coal_F1	Coal_F2	Wheat_F1	Wheat_F2	Soybeans_F1	Soybeans_F2	Corn_F1
BCI_TCE	12.3%	6.8%	6.1%	6.1%	10.9%	7.1%	4.9%	4.6%	7.0%	6.6%	1.9%	2.0%	3.7%
BPI_TCE	9.4%	5.0%	4.4%	4.4%	15.8%	13.8%	13.5%	11.1%	8.0%	7.7%	2.5%	2.2%	4.6%
BPI_TCE	12.2%	4.3%	3.8%	3.6%	1.8%	2.7%	4.3%	3.3%	6.5%	6.3%	1.1%	1.4%	3.0%
TC2$	8.0%	10.3%	10.7%	10.7%	30.2%	15.7%	15.3%	14.1%	18.1%	18.6%	12.6%	12.8%	13.5%
TD3$	3.9%	8.7%	9.2%	10.2%	39.0%	17.8%	11.6%	9.6%	9.8%	9.9%	7.6%	7.8%	8.0%
BHSI	11.3%	14.5%	15.7%	15.2%	37.1%	22.9%	24.0%	24.9%	18.7%	18.6%	12.3%	12.4%	14.6%
BDTI	6.5%	6.8%	7.0%	7.1%	23.6%	11.6%	6.6%	6.4%	11.2%	10.9%	4.3%	4.7%	6.8%
BCTI	16.4%	2.0%	2.1%	2.0%	1.8%	0.8%	0.1%	0.5%	3.8%	3.6%	0.5%	0.5%	1.2%
4TC_C+1MON	3.9%	9.5%	10.0%	10.4%	13.6%	9.8%	16.7%	13.6%	10.1%	10.2%	8.8%	9.1%	9.7%
4TC_C+2MON	5.2%	12.4%	13.0%	13.4%	19.2%	12.6%	19.3%	15.8%	7.3%	7.6%	6.6%	7.0%	7.2%
4TC_P+1MON	5.4%	13.2%	14.0%	14.4%	21.0%	13.4%	19.8%	16.7%	8.2%	8.7%	7.1%	7.6%	7.6%
4TC_P+2MON	3.3%	13.7%	14.6%	15.0%	21.0%	11.9%	17.6%	15.2%	8.4%	8.9%	6.6%	7.2%	7.5%
5TC_S+1MON	7.1%	13.0%	13.7%	14.2%	23.6%	13.6%	19.6%	16.3%	7.8%	8.3%	6.9%	7.4%	7.5%
5TC_S+2MON	4.3%	13.3%	14.0%	14.4%	22.8%	12.2%	18.2%	15.1%	6.8%	7.1%	5.7%	6.0%	6.5%
TC2$+1_M	0.0%	8.6%	6.3%	6.8%	9.0%	12.2%	29.3%	19.3%	0.5%	0.7%	3.5%	3.1%	2.3%
TC2$+2_M	0.1%	5.8%	4.0%	4.4%	8.6%	13.9%	33.2%	22.2%	1.5%	2.3%	0.6%	0.5%	0.2%
TD3$+1_M	3.0%	7.2%	8.4%	9.3%	38.1%	19.8%	19.8%	15.2%	12.3%	13.0%	10.9%	11.4%	10.6%
TD3$+2_M	5.0%	13.0%	15.1%	16.0%	50.4%	34.5%	34.4%	29.8%	16.5%	17.4%	13.6%	14.3%	13.8%
Crude	58.2%	100.0%	99.4%	99.6%	65.4%	62.2%	28.0%	42.8%	20.3%	21.1%	24.9%	26.0%	20.0%
Brent	49.4%	96.5%	98.1%	98.0%	77.5%	71.1%	39.5%	55.0%	17.6%	18.7%	17.5%	19.0%	15.2%
Heating_oil	9.3%	29.6%	30.3%	32.6%	57.2%	19.3%	7.3%	9.7%	12.3%	12.0%	6.4%	7.5%	9.4%
Natural_Gas	35.3%	33.0%	35.1%	35.8%	67.7%	34.8%	25.2%	29.0%	14.9%	15.4%	3.5%	4.8%	7.2%
Coal	34.3%	46.4%	52.5%	50.3%	66.9%	93.6%	95.1%	99.0%	12.5%	13.8%	7.7%	8.8%	8.2%
Wheat	34.9%	16.5%	16.3%	16.6%	16.5%	15.0%	11.9%	12.3%	98.2%	97.6%	91.4%	92.2%	97.1%
Soybeans	35.4%	23.7%	22.7%	22.9%	13.1%	12.6%	7.5%	8.1%	91.0%	90.9%	99.5%	99.7%	96.7%
Corn	31.6%	19.3%	18.8%	19.1%	14.0%	11.2%	7.8%	8.5%	97.9%	97.3%	95.7%	96.3%	99.7%
Iron	100.0%	58.3%	58.3%	58.3%	40.9%	46.1%	25.3%	31.4%	34.9%	35.6%	35.2%	36.4%	31.7%
Crude_F1	58.3%	100.0%	99.6%	99.7%	66.1%	63.3%	29.0%	44.0%	20.1%	20.9%	24.4%	25.6%	19.6%
Brent_F1	58.3%	99.6%	100.0%	99.9%	70.4%	68.4%	34.4%	49.9%	20.1%	21.1%	23.0%	24.4%	18.8%
Heating_F1	58.3%	99.7%	99.9%	100.0%	70.5%	66.8%	32.4%	47.6%	20.4%	21.3%	23.4%	24.7%	19.2%
Natural_gas_F1	40.9%	66.1%	70.4%	70.5%	100.0%	75.3%	57.4%	66.0%	19.3%	20.4%	11.1%	13.2%	13.2%
Natural_Gas_F2	46.1%	63.3%	68.4%	66.8%	75.3%	100.0%	83.3%	91.7%	15.1%	16.3%	10.9%	12.3%	10.6%
Coal_F1	25.3%	29.0%	34.4%	32.4%	57.4%	83.3%	100.0%	96.8%	10.6%	11.6%	6.4%	7.1%	7.4%

Coal_F2	31.4%	44.0%	49.9%	47.6%	66.0%	91.7%	96.8%	100.0%	11.5%	12.5%	7.0%	7.9%	8.0%
Wheat_F1	34.9%	20.1%	20.1%	20.4%	19.3%	15.1%	10.6%	11.5%	100.0%	99.8%	89.7%	91.1%	96.5%
Wheat_F2	35.6%	20.9%	21.1%	21.3%	20.4%	16.3%	11.6%	12.5%	99.8%	100.0%	89.3%	90.9%	95.7%
Soybeans_F1	35.2%	24.4%	23.0%	23.4%	11.1%	10.9%	6.4%	7.0%	89.7%	89.3%	100.0%	99.8%	96.8%
Soybeans_F2	36.4%	25.6%	24.4%	24.7%	13.2%	12.3%	7.1%	7.9%	91.1%	90.9%	99.8%	100.0%	97.3%
Corn_F1	31.7%	19.6%	18.8%	19.2%	13.2%	10.6%	7.4%	8.0%	96.5%	95.7%	96.8%	97.3%	100.0%
Corn_F2	32.0%	19.9%	19.3%	19.7%	14.6%	11.6%	7.9%	8.6%	98.0%	97.4%	95.9%	96.6%	99.7%
Iron_F1	32.8%	70.5%	75.0%	72.6%	71.7%	82.2%	72.7%	83.6%	17.8%	19.3%	14.1%	15.8%	13.4%
Iron_F2	8.4%	56.9%	56.8%	56.3%	46.6%	32.3%	25.6%	30.5%	13.1%	14.2%	16.2%	17.2%	13.4%
Copper	49.6%	94.6%	95.4%	95.8%	75.5%	61.2%	32.8%	46.1%	27.3%	28.5%	28.2%	30.1%	25.4%
Copper_F3	49.8%	94.5%	95.3%	95.8%	75.8%	61.3%	32.9%	46.2%	27.6%	28.8%	28.4%	30.2%	25.5%
Sugar	21.4%	39.5%	35.6%	38.5%	18.5%	1.7%	4.3%	1.3%	13.5%	12.1%	14.5%	14.5%	16.6%
Sugar_F1	17.9%	31.3%	26.7%	29.3%	8.3%	0.3%	11.6%	5.1%	12.2%	10.6%	16.8%	16.3%	17.8%
Sugar_F2	19.5%	32.2%	27.7%	30.3%	9.0%	0.5%	11.0%	4.9%	13.9%	12.2%	18.3%	17.8%	19.5%
Rice	9.5%	18.9%	22.9%	22.5%	57.2%	34.0%	43.9%	43.6%	13.4%	14.9%	2.1%	3.1%	5.2%
Rice_F1	9.5%	19.3%	23.4%	23.0%	58.1%	34.8%	44.6%	44.3%	13.1%	14.6%	2.1%	3.1%	5.0%
Rice_F2	8.7%	18.1%	22.1%	21.7%	55.6%	32.7%	42.8%	42.4%	13.2%	14.7%	2.0%	3.0%	5.1%
Barley	8.0%	24.4%	21.7%	23.3%	21.5%	7.2%	1.0%	1.4%	3.5%	3.7%	3.1%	3.5%	2.6%
Barley_F1	2.0%	4.2%	4.7%	4.7%	3.3%	1.6%	3.9%	3.4%	9.8%	10.3%	4.8%	4.9%	6.8%
Barley_F2	1.5%	25.6%	27.3%	28.1%	43.0%	19.1%	19.1%	21.8%	0.5%	0.6%	0.7%	0.5%	0.6%
Canola	17.4%	6.1%	5.3%	5.6%	7.6%	6.6%	9.2%	8.7%	70.2%	68.4%	85.6%	84.0%	82.6%
Canola_F1	21.3%	8.1%	7.2%	7.5%	7.7%	7.0%	8.1%	7.6%	76.5%	75.1%	90.2%	89.0%	87.4%
Canola_F2	22.4%	9.9%	8.9%	9.2%	7.3%	6.8%	7.1%	6.7%	78.5%	77.2%	92.6%	91.5%	89.4%
BDI	11.7%	6.8%	6.1%	6.1%	11.1%	8.6%	5.6%	5.2%	8.1%	7.6%	2.2%	2.4%	4.3%
BLPG1	11.9%	0.6%	1.6%	1.1%	11.7%	31.7%	45.5%	39.0%	2.9%	3.4%	0.9%	0.8%	1.3%
TD3	2.8%	7.9%	8.3%	9.2%	35.5%	14.0%	7.8%	6.6%	8.7%	8.6%	6.2%	6.4%	6.8%
TC2_37	9.8%	11.6%	12.2%	12.1%	31.9%	17.7%	17.3%	16.7%	18.5%	18.9%	12.2%	12.5%	13.7%

Table 0.3 Spectral Coherence Daily Reduced (periodicity @ 36 months), cont.

	Corn_F2	Iron_F1	Iron_F2	Copper	Copper_F3	Sugar	Sugar_F1	Sugar_F2	Rice	Rice_F1	Rice_F2	Barley	Barley_F1
BCI_TCE	4.0%	6.0%	27.7%	6.4%	6.1%	3.9%	4.7%	4.1%	0.1%	0.1%	0.2%	40.7%	32.7%
BPI_TCE	5.1%	4.2%	17.8%	3.3%	3.1%	7.4%	10.8%	9.9%	5.3%	5.2%	4.8%	32.0%	31.4%
BPI_TCE	3.4%	9.3%	31.3%	3.7%	3.6%	3.3%	2.5%	2.3%	3.9%	3.7%	3.8%	19.8%	15.6%
TC2$	14.3%	14.4%	22.3%	12.8%	12.7%	10.2%	9.1%	8.2%	6.1%	6.4%	5.6%	55.7%	2.5%
TD3$	8.2%	7.6%	15.5%	12.7%	12.8%	15.8%	10.6%	10.2%	12.4%	13.1%	11.9%	35.6%	2.2%
BHSI	15.0%	26.0%	25.0%	16.6%	16.4%	2.6%	1.7%	1.4%	9.5%	9.8%	8.8%	44.1%	2.8%
BDTI	7.3%	8.6%	16.0%	7.2%	7.2%	4.8%	2.8%	2.8%	8.7%	9.0%	8.2%	18.9%	0.5%
BCTI	1.5%	4.1%	24.9%	2.8%	2.8%	2.6%	2.4%	2.1%	6.3%	6.1%	6.0%	18.9%	33.9%
4TC_C+1MON	10.4%	17.5%	48.2%	19.9%	19.9%	13.3%	9.6%	9.8%	20.8%	21.0%	21.7%	8.0%	56.3%
4TC_C+2MON	7.8%	21.6%	58.5%	24.3%	24.2%	14.9%	10.5%	10.6%	23.5%	23.8%	24.4%	13.3%	58.8%
4TC_P+1MON	8.4%	24.3%	59.8%	25.8%	25.7%	12.1%	7.6%	7.8%	26.9%	27.2%	27.9%	12.9%	59.4%
4TC_P+2MON	8.4%	25.4%	60.8%	27.3%	27.2%	13.3%	7.8%	8.0%	30.3%	30.6%	31.4%	14.7%	61.9%
5TC_S+1MON	8.3%	23.8%	63.0%	25.7%	25.6%	11.8%	7.7%	7.8%	26.7%	27.1%	27.6%	16.4%	59.4%
5TC_S+2MON	7.1%	23.4%	63.8%	26.5%	26.4%	15.0%	9.9%	10.1%	27.9%	28.2%	28.9%	17.6%	61.0%
TC2$+1_M	1.4%	4.0%	21.4%	7.3%	7.2%	42.0%	57.4%	55.2%	21.5%	21.5%	21.4%	51.1%	2.2%
TC2$+2_M	0.2%	4.8%	14.5%	4.3%	4.2%	40.0%	55.3%	52.8%	24.3%	24.3%	24.3%	53.2%	4.2%
TD3$+1_M	11.2%	11.3%	17.4%	15.1%	15.3%	16.2%	9.5%	9.2%	25.4%	26.3%	25.2%	18.1%	5.9%
TD3$+2_M	14.6%	23.2%	20.3%	22.2%	22.4%	10.3%	5.0%	4.8%	33.9%	34.9%	33.4%	14.7%	5.6%
Crude	20.3%	69.5%	56.9%	94.6%	94.5%	40.6%	32.4%	33.4%	18.4%	18.9%	17.7%	24.8%	4.3%
Brent	16.0%	79.6%	61.3%	96.6%	96.6%	34.9%	24.0%	24.9%	32.2%	32.8%	31.3%	20.9%	8.1%
Heating_oil	9.8%	18.1%	25.8%	40.3%	40.6%	51.0%	35.6%	36.2%	32.4%	33.2%	31.9%	32.6%	5.6%
Natural_Gas	8.5%	36.3%	34.8%	40.7%	40.9%	19.0%	8.7%	9.7%	53.1%	53.7%	52.1%	10.9%	6.3%
Coal	9.1%	83.0%	28.6%	48.7%	48.8%	1.1%	4.2%	4.0%	46.2%	46.8%	44.9%	0.9%	4.3%
Wheat	97.6%	14.9%	8.4%	21.3%	21.5%	11.0%	11.2%	12.8%	7.3%	7.1%	7.1%	5.3%	6.0%
Soybeans	96.2%	15.5%	15.7%	27.9%	28.1%	11.5%	13.1%	14.5%	3.0%	2.9%	2.9%	4.0%	4.3%
Corn	100.0%	14.4%	13.8%	25.7%	25.9%	15.1%	15.5%	17.2%	7.1%	7.0%	7.0%	2.3%	8.2%
Iron	32.0%	32.8%	8.4%	49.6%	49.8%	21.4%	17.9%	19.5%	9.5%	9.5%	8.7%	8.0%	2.0%
Crude_F1	19.9%	70.5%	56.9%	94.6%	94.5%	39.5%	31.3%	32.2%	18.9%	19.3%	18.1%	24.4%	4.2%
Brent_F1	19.3%	75.0%	56.8%	95.4%	95.3%	35.6%	26.7%	27.7%	22.9%	23.4%	22.1%	21.7%	4.7%
Heating_F1	19.7%	72.6%	56.3%	95.8%	95.8%	38.5%	29.3%	30.3%	22.5%	23.0%	21.7%	23.3%	4.7%
Natural_gas_F1	14.6%	71.7%	46.6%	75.5%	75.8%	18.5%	8.3%	9.0%	57.2%	58.1%	55.6%	21.5%	3.3%
Natural_Gas_F2	11.6%	82.2%	32.3%	61.2%	61.3%	1.7%	0.3%	0.5%	34.0%	34.8%	32.7%	7.2%	1.6%
Coal_F1	7.9%	72.7%	25.6%	32.8%	32.9%	4.3%	11.6%	11.0%	43.9%	44.6%	42.8%	1.0%	3.9%

Coal_F2	8.6%	83.6%	30.5%	46.1%	46.2%	1.3%	5.1%	4.9%	43.6%	44.3%	42.4%	1.4%	3.4%
Wheat_F1	98.0%	17.8%	13.1%	27.3%	27.6%	13.5%	12.2%	13.9%	13.4%	13.1%	13.2%	3.5%	9.8%
Wheat_F2	97.4%	19.3%	14.2%	28.5%	28.8%	12.1%	10.6%	12.2%	14.9%	14.6%	14.7%	3.7%	10.3%
Soybeans_F1	95.9%	14.1%	16.2%	28.2%	28.4%	14.5%	16.8%	18.3%	2.1%	2.1%	2.0%	3.1%	4.8%
Soybeans_F2	96.6%	15.8%	17.2%	30.1%	30.2%	14.5%	16.3%	17.8%	3.1%	3.1%	3.0%	3.5%	4.9%
Corn_F1	99.7%	13.4%	13.4%	25.4%	25.5%	16.6%	17.8%	19.5%	5.2%	5.0%	5.1%	2.6%	6.8%
Corn_F2	100.0%	14.8%	14.1%	26.3%	26.5%	15.3%	15.7%	17.4%	7.1%	7.0%	7.0%	2.5%	8.0%
Iron_F1	14.8%	100.0%	63.6%	74.4%	74.4%	6.3%	2.2%	2.7%	42.6%	43.1%	41.6%	6.0%	11.9%
Iron_F2	14.1%	63.6%	100.0%	67.3%	66.9%	25.9%	20.3%	20.3%	25.5%	26.0%	25.5%	23.3%	31.0%
Copper	26.3%	74.4%	67.3%	100.0%	100.0%	42.4%	31.0%	32.2%	34.0%	34.5%	33.2%	22.5%	11.4%
Copper_F3	26.5%	74.4%	66.9%	100.0%	100.0%	42.4%	31.0%	32.2%	34.4%	34.9%	33.6%	22.2%	11.4%
Sugar	15.3%	6.3%	25.9%	42.4%	42.4%	100.0%	95.8%	96.3%	3.4%	3.5%	3.4%	39.5%	5.4%
Sugar_F1	15.7%	2.2%	20.3%	31.0%	31.0%	95.8%	100.0%	99.9%	0.0%	0.0%	0.0%	42.3%	2.0%
Sugar_F2	17.4%	2.7%	20.3%	32.2%	32.2%	96.3%	99.9%	100.0%	0.0%	0.0%	0.0%	40.5%	2.2%
Rice	7.1%	42.6%	25.5%	34.0%	34.4%	3.4%	0.0%	0.0%	100.0%	100.0%	100.0%	1.2%	25.8%
Rice_F1	7.0%	43.1%	26.0%	34.5%	34.9%	3.5%	0.0%	0.0%	100.0%	100.0%	99.9%	1.1%	25.9%
Rice_F2	7.0%	41.6%	25.5%	33.2%	33.6%	3.4%	0.0%	0.0%	100.0%	99.9%	100.0%	1.5%	27.5%
Barley	2.5%	6.0%	23.3%	22.5%	22.2%	39.5%	42.3%	40.5%	1.2%	1.1%	1.5%	100.0%	14.1%
Barley_F1	8.0%	11.9%	31.0%	11.4%	11.4%	5.4%	2.0%	2.2%	25.8%	25.9%	27.5%	14.1%	100.0%
Barley_F2	0.4%	33.5%	50.9%	38.6%	38.4%	20.7%	9.9%	10.0%	49.1%	49.8%	49.9%	26.6%	52.6%
Canola	79.6%	4.5%	2.2%	6.8%	6.8%	6.5%	11.6%	12.4%	5.4%	5.7%	5.4%	6.8%	0.0%
Canola_F1	85.0%	5.2%	3.3%	9.2%	9.2%	6.4%	10.7%	11.6%	2.9%	3.1%	2.8%	6.6%	0.2%
Canola_F2	87.1%	5.8%	5.1%	11.3%	11.4%	7.3%	11.5%	12.5%	2.1%	2.3%	2.1%	5.9%	0.5%
BDI	4.8%	5.1%	23.8%	5.6%	5.4%	3.9%	4.9%	4.3%	0.5%	0.4%	0.5%	38.8%	31.4%
BLPG1	1.4%	12.6%	4.5%	0.5%	0.5%	29.2%	40.7%	38.8%	17.2%	17.1%	16.4%	38.1%	9.1%
TD3	7.1%	6.6%	14.4%	11.5%	11.6%	16.4%	10.8%	10.6%	12.5%	13.1%	12.0%	30.2%	1.5%
TC2_37	14.4%	17.7%	24.3%	13.9%	13.8%	7.2%	6.4%	5.6%	6.4%	6.6%	5.9%	53.9%	2.6%

Table 0.3 Spectral Coherence Daily Reduced (periodicity @ 36 months), cont.

	Barley_F2	Canola	Canola_F1	Canola_F2	BDI	BLPG1	TD3	TC2_37
BCI_TCE	33.7%	5.4%	5.7%	4.2%	98.8%	36.9%	32.9%	37.7%
BPI_TCE	16.2%	2.6%	3.0%	2.5%	87.7%	48.2%	32.7%	25.2%
BPI_TCE	11.8%	3.4%	3.5%	3.1%	39.9%	17.2%	8.0%	12.4%
TC2$	19.4%	18.4%	19.5%	17.9%	31.4%	23.8%	31.1%	99.2%
TD3$	25.1%	13.8%	14.0%	12.8%	33.6%	16.1%	98.7%	33.8%
BHSI	20.8%	20.7%	21.0%	18.8%	34.7%	13.9%	25.4%	96.8%
BDTI	11.0%	7.7%	7.9%	6.8%	59.8%	18.0%	75.9%	42.4%
BCTI	16.1%	0.7%	0.8%	0.5%	49.3%	36.0%	9.1%	7.8%
4TC_C+1MON	42.0%	1.7%	2.0%	2.8%	23.8%	3.4%	2.5%	3.3%
4TC_C+2MON	51.4%	0.3%	0.6%	1.2%	24.6%	6.0%	3.7%	7.5%
4TC_P+1MON	52.9%	0.3%	0.6%	1.3%	22.9%	4.1%	4.1%	7.2%
4TC_P+2MON	55.9%	0.1%	0.4%	1.0%	23.9%	4.1%	4.7%	7.4%
5TC_S+1MON	55.6%	0.3%	0.6%	1.3%	23.9%	6.7%	7.3%	9.9%
5TC_S+2MON	59.8%	0.1%	0.2%	0.6%	26.1%	7.4%	8.0%	10.8%
TC2$+1_M	1.6%	6.0%	4.1%	4.3%	20.3%	66.6%	12.9%	32.9%
TC2$+2_M	0.7%	2.3%	1.1%	1.1%	20.7%	69.4%	13.8%	34.3%
TD3$+1_M	25.4%	15.3%	15.8%	15.4%	7.4%	8.7%	80.6%	24.8%
TD3$+2_M	23.6%	16.8%	17.5%	17.2%	8.6%	12.2%	73.7%	28.0%
Crude	25.6%	6.3%	8.3%	10.2%	6.8%	0.5%	7.9%	11.4%
Brent	38.0%	3.7%	4.8%	5.9%	6.1%	1.9%	11.6%	14.5%
Heating_oil	40.5%	8.9%	8.5%	8.1%	6.4%	3.2%	74.0%	21.6%
Natural_Gas	38.7%	1.7%	1.4%	1.0%	19.8%	7.6%	43.9%	17.2%
Coal	20.1%	6.6%	6.0%	5.5%	4.1%	43.1%	7.0%	13.9%
Wheat	1.8%	79.0%	84.5%	85.6%	9.7%	2.9%	10.8%	24.2%
Soybeans	1.0%	84.8%	89.9%	92.2%	3.3%	1.0%	7.6%	14.5%
Corn	0.3%	79.2%	84.7%	86.8%	4.7%	1.5%	6.8%	14.0%
Iron	1.5%	17.4%	21.3%	22.4%	11.7%	11.9%	2.8%	9.8%
Crude_F1	25.6%	6.1%	8.1%	9.9%	6.8%	0.6%	7.9%	11.6%
Brent_F1	27.3%	5.3%	7.2%	8.9%	6.1%	1.6%	8.3%	12.2%
Heating_F1	28.1%	5.6%	7.5%	9.2%	6.1%	1.1%	9.2%	12.1%
Natural_gas_F1	43.0%	7.6%	7.7%	7.3%	11.1%	11.7%	35.5%	31.9%
Natural_Gas_F2	19.1%	6.6%	7.0%	6.8%	8.6%	31.7%	14.0%	17.7%
Coal_F1	19.1%	9.2%	8.1%	7.1%	5.6%	45.5%	7.8%	17.3%

Coal_F2	21.8%	8.7%	7.6%	6.7%	5.2%	39.0%	6.6%	16.7%
Wheat_F1	0.5%	70.2%	76.5%	78.5%	8.1%	2.9%	8.7%	18.5%
Wheat_F2	0.6%	68.4%	75.1%	77.2%	7.6%	3.4%	8.6%	18.9%
Soybeans_F1	0.7%	85.6%	90.2%	92.6%	2.2%	0.9%	6.2%	12.2%
Soybeans_F2	0.5%	84.0%	89.0%	91.5%	2.4%	0.8%	6.4%	12.5%
Corn_F1	0.6%	82.6%	87.4%	89.4%	4.3%	1.3%	6.8%	13.7%
Corn_F2	0.4%	79.6%	85.0%	87.1%	4.8%	1.4%	7.1%	14.4%
Iron_F1	33.5%	4.5%	5.2%	5.8%	5.1%	12.6%	6.6%	17.7%
Iron_F2	50.9%	2.2%	3.3%	5.1%	23.8%	4.5%	14.4%	24.3%
Copper	38.6%	6.8%	9.2%	11.3%	5.6%	0.5%	11.5%	13.9%
Copper_F3	38.4%	6.8%	9.2%	11.4%	5.4%	0.5%	11.6%	13.8%
Sugar	20.7%	6.5%	6.4%	7.3%	3.9%	29.2%	16.4%	7.2%
Sugar_F1	9.9%	11.6%	10.7%	11.5%	4.9%	40.7%	10.8%	6.4%
Sugar_F2	10.0%	12.4%	11.6%	12.5%	4.3%	38.8%	10.6%	5.6%
Rice	49.1%	5.4%	2.9%	2.1%	0.5%	17.2%	12.5%	6.4%
Rice_F1	49.8%	5.7%	3.1%	2.3%	0.4%	17.1%	13.1%	6.6%
Rice_F2	49.9%	5.4%	2.8%	2.1%	0.5%	16.4%	12.0%	5.9%
Barley	26.6%	6.8%	6.6%	5.9%	38.8%	38.1%	30.2%	53.9%
Barley_F1	52.6%	0.0%	0.2%	0.5%	31.4%	9.1%	1.5%	2.6%
Barley_F2	100.0%	15.9%	12.8%	9.9%	29.4%	4.0%	23.0%	19.4%
Canola	15.9%	100.0%	99.3%	98.5%	5.3%	1.1%	12.1%	18.2%
Canola_F1	12.8%	99.3%	100.0%	99.7%	5.7%	0.5%	12.1%	19.2%
Canola_F2	9.9%	98.5%	99.7%	100.0%	4.2%	0.5%	11.0%	17.5%
BDI	29.4%	5.3%	5.7%	4.2%	100.0%	36.8%	35.1%	34.7%
BLPG1	4.0%	1.1%	0.5%	0.5%	36.8%	100.0%	13.5%	21.8%
TD3	23.0%	12.1%	12.1%	11.0%	35.1%	13.5%	100.0%	29.3%
TC2_37	19.4%	18.2%	19.2%	17.5%	34.7%	21.8%	29.3%	100.0%

Table 0.4 Reference Variable: Baltic Dry Index (BDI)

		Monthly Dataset		Weekly Dataset		Daily Dataset	
#	Variable	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.
1	BCI_TCE	0.8	0.0	0.5	0.0	0.6	0.0
2	BPI_TCE	0.0	0.0	0.8	0.0	-1.5	0.0
3	BSI_TCE	-1.0	0.0	-1.8	0.0	-11.1	0.0
4	TC2$	-8.0	3.1	-15.4	3.1	-4.5	3.1
5	TD3$	-16.0	3.1	-4.4	3.1	-3.6	0.0
6	BHSI	-5.2	3.1	-12.8	3.1	-4.7	3.1
7	BDTI	-13.5	3.1	3.6	0.0	0.2	0.0
8	BCTI	-2.3	0.0	-2.2	0.0	-14.2	0.0
9	4TC_C+1MON	0.6	0.0	2.8	0.0	7.9	0.0
10	4TC_C+2MON	0.8	0.0	3.2	0.0	9.6	0.0
11	4TC_P+1MON	1.2	0.0	4.6	0.0	9.4	0.0
12	4TC_P+2MON	1.5	0.0	5.2	0.0	9.4	0.0
13	5TC_S+1MON	0.9	0.0	5.8	0.0	11.1	0.0
14	5TC_S+2MON	1.6	0.0	5.5	0.0	10.4	0.0
15	TC2$+1_M	-10.0	3.1	-12.7	3.1	-2.0	3.1
16	TC2$+2_M	-11.9	3.1	-12.1	3.1	-2.4	3.1
17	TD3$+1_M	-16.0	3.1	-6.2	3.1	-3.7	0.0
18	TD3$+2_M	-16.0	3.1	-5.3	3.1	-3.4	0.0
19	Crude	16.6	0.0	-1.4	0.0	-12.9	0.0
20	Brent	16.3	0.0	-0.5	0.0	-13.4	0.0
21	Heating_oil	16.3	0.0	-7.8	0.0	-5.1	0.0
22	Natural_Gas	-2.9	0.0	-4.2	0.0	-2.7	0.0
23	Coal	9.9	0.0	2.4	0.0	-6.9	0.0
24	Wheat	-0.7	3.1	-11.8	3.1	-3.7	3.1
25	Soybeans	-4.0	0.0	11.7	3.1	-2.9	3.1
26	Corn	3.7	3.1	17.9	3.1	-4.7	3.1
27	Iron	2.1	0.0	9.8	0.0	-2.1	0.0
28	CME_Crude_F1	16.8	0.0	-1.6	0.0	-12.9	0.0
29	ICE_Brent_F1	16.4	0.0	-0.6	0.0	-12.6	0.0
30	CME_Heating_F1	16.9	0.0	-0.6	0.0	-12.5	0.0
31	CME_Natural_gas_F1	-2.7	0.0	-3.0	0.0	-7.4	0.0
32	ICE_Natural_Gas_F2	6.3	0.0	-0.2	0.0	-6.9	0.0
33	ICE_Coal_F1	12.6	0.0	7.0	0.0	-7.7	0.0
34	ICE_Coal_F2	10.6	0.0	6.1	0.0	-8.7	0.0
35	CME_Wheat_F1	0.5	3.1	-9.9	3.1	-4.0	3.1
36	CME_Wheat_F2	0.4	3.1	-9.5	3.1	-3.9	3.1
37	CME_Soybeans_F1	4.1	3.1	10.8	3.1	-4.1	3.1
38	CME_Soybeans_F2	3.9	3.1	11.3	3.1	-3.4	3.1
39	CME_Corn_F1	2.6	3.1	-17.1	3.1	-4.4	3.1
40	CME_Corn_F2	2.3	3.1	-17.3	3.1	-4.4	3.1
41	CME_Iron_F1	11.1	0.0	11.4	0.0	-13.9	0.0
42	CME_Iron_F2	13.0	0.0	-6.6	0.0	17.0	0.0
43	Copper	14.7	0.0	-4.6	0.0	-14.0	0.0
44	Copper_F3	14.7	0.0	-4.5	0.0	-14.0	0.0
45	Sugar	-15.7	0.0	-3.8	0.0	-17.2	0.0
46	Sugar_F1	-15.8	0.0	-3.8	0.0	-16.9	0.0
47	Sugar_F2	-14.7	0.0	-3.9	0.0	-17.0	0.0
48	Rice	6.1	3.1	-3.7	3.1	5.3	0.0
49	Rice_F1	7.1	3.1	-4.2	3.1	5.1	0.0
50	Rice_F2	6.3	3.1	-4.5	3.1	6.5	0.0
51	Barley	4.9	3.1	12.5	3.1	11.6	3.1
52	Barley_F1	-0.3	0.0	16.0	0.0	16.2	0.0
53	Barley_F2	0.3	0.0	-12.9	0.0	-16.1	0.0
54	Canola	-3.8	3.1	13.9	3.1	-2.3	3.1
55	Canola_F1	-0.9	3.1	12.2	3.1	-2.4	3.1
56	Canola_F2	-0.9	3.1	13.9	3.1	-2.5	3.1
57	BDI	0.0	0.0	0.0	0.0	0.0	0.0
58	BLPG1	-16.2	3.1	-11.7	3.1	-0.9	3.1
59	TD3	-16.0	3.1	-4.1	3.1	-2.9	0.0
60	TC2_37	-7.9	3.1	-14.7	3.1	-4.5	3.1
61	Urea	14.4	0.0	-14.3	3.1	-	-
62	DAP	1.4	3.1	-3.7	3.1	-	-
63	Ammonia	-15.0	3.1	-10.5	3.1	-	-
64	Scrap VLCC	6.9	0.0	-	-	-	-
65	Scrap Cape/Pana	4.3	0.0	-	-	-	-

Note: The details of the parameters are denoted in **Table 3.1**

Table 0.5 Reference Variable: Middle East to Far East VLCC freight rates (TD3 route)

		Monthly Dataset		Weekly Dataset		Daily Dataset	
#	Variable	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.
1	BCI_TCE	-14.8	3.1	-3.4	3.1	4.5	0.0
2	BPI_TCE	14.6	3.1	3.4	3.1	1.8	0.0
3	BSI_TCE	15.4	3.1	3.6	3.1	-5.6	0.0
4	TC2$	-8.5	0.0	-2.0	0.0	11.2	0.0
5	TD3$	0.0	0.0	0.0	0.0	0.0	0.0
6	BHSI	-9.6	0.0	-2.2	0.0	11.0	0.0
7	BDTI	-3.7	0.0	-0.9	0.0	2.4	0.0
8	BCTI	16.7	3.1	3.9	3.1	-10.0	0.0
9	4TC_C+1MON	-17.2	3.1	-4.0	3.1	-6.9	0.0
10	4TC_C+2MON	17.0	3.1	4.0	3.1	-10.5	0.0
11	4TC_P+1MON	11.3	3.1	2.6	3.1	-10.6	0.0
12	4TC_P+2MON	7.3	3.1	1.7	3.1	-10.8	0.0
13	5TC_S+1MON	11.1	3.1	2.6	3.1	-11.6	0.0
14	5TC_S+2MON	8.6	3.1	2.0	3.1	-12.5	0.0
15	TC2$+1_M	-6.4	0.0	-1.5	0.0	7.6	0.0
16	TC2$+2_M	-4.2	0.0	-1.0	0.0	7.7	0.0
17	TD3$+1_M	-0.6	0.0	-0.1	0.0	-1.0	0.0
18	TD3$+2_M	-0.7	0.0	-0.2	0.0	-1.1	0.0
19	Crude	0.3	3.1	0.1	3.1	4.1	3.1
20	Brent	0.1	3.1	0.0	3.1	4.2	3.1
21	Heating_oil	0.2	3.1	0.1	3.1	-1.5	0.0
22	Natural_Gas	-17.7	3.1	-4.1	3.1	0.3	0.0
23	Coal	4.2	3.1	1.0	3.1	0.6	3.1
24	Wheat	-17.4	3.1	-4.0	0.0	-8.1	3.1
25	Soybeans	-12.1	3.1	-2.8	3.1	-7.5	3.1
26	Corn	-17.0	3.1	-4.0	3.1	-7.8	3.1
27	Iron	1.8	3.1	0.4	3.1	-4.7	3.1
28	CME_Crude_F1	0.1	3.1	0.0	3.1	4.2	3.1
29	ICE_Brent_F1	-0.1	3.1	0.0	3.1	3.9	3.1
30	CME_Heating_F1	0.1	3.1	0.0	3.1	3.7	3.1
31	CME_Natural_gas_F1	-17.8	3.1	-4.1	3.1	1.8	3.1
32	ICE_Natural_Gas_F2	6.7	3.1	1.6	3.1	0.6	3.1
33	ICE_Coal_F1	3.8	3.1	0.9	3.1	-0.4	0.0
34	ICE_Coal_F2	4.8	3.1	1.1	3.1	1.3	3.1
35	CME_Wheat_F1	-17.2	3.1	-4.0	0.0	-7.0	3.1
36	CME_Wheat_F2	-17.0	3.1	-4.0	0.0	-7.1	3.1
37	CME_Soybeans_F1	-12.1	3.1	-2.8	3.1	-8.2	3.1
38	CME_Soybeans_F2	-12.4	3.1	-2.9	3.1	-7.6	3.1
39	CME_Corn_F1	-16.8	3.1	-3.9	3.1	-7.6	3.1
40	CME_Corn_F2	-16.1	3.1	-3.8	3.1	-7.5	3.1
41	CME_Iron_F1	-6.4	3.1	-1.5	3.1	5.5	3.1
42	CME_Iron_F2	-6.5	3.1	-1.5	3.1	9.9	3.1
43	Copper	-1.4	3.1	-0.3	3.1	3.8	3.1
44	Copper_F3	-1.3	3.1	-0.3	3.1	3.7	3.1
45	Sugar	-7.1	3.1	-1.6	3.1	4.9	3.1
46	Sugar_F1	-7.1	3.1	-1.7	3.1	5.6	3.1
47	Sugar_F2	-7.3	3.1	-1.7	3.1	5.4	3.1
48	Rice	10.4	0.0	2.4	0.0	2.2	3.1
49	Rice_F1	9.7	0.0	2.3	0.0	2.2	3.1
50	Rice_F2	10.0	0.0	2.3	0.0	2.3	3.1
51	Barley	-17.1	3.1	-4.0	3.1	3.4	3.1
52	Barley_F1	-9.3	3.1	-2.2	3.1	-11.2	0.0
53	Barley_F2	-10.8	3.1	-2.5	3.1	-5.9	0.0
54	Canola	-2.0	0.0	-0.5	3.1	-9.0	3.1
55	Canola_F1	0.8	0.0	0.2	3.1	-9.0	3.1
56	Canola_F2	0.3	0.0	0.1	3.1	-8.9	3.1
57	BDI	15.3	3.1	3.5	3.1	3.6	0.0
58	BLPG1	-3.1	0.0	-0.7	0.0	-6.6	3.1
59	TD3	-0.3	0.0	-0.1	0.0	0.2	0.0
60	TC2_37	-9.0	0.0	-2.1	0.0	11.1	0.0
61	Urea	0.6	0.0	0.1	0.0	-	-
62	DAP	-12.5	0.0	-2.9	0.0	-	-
63	Ammonia	9.9	3.1	2.3	0.0	-	-
64	Scrap VLCC	-3.2	3.1	-	-	-	-
65	Scrap Cape/Pana	-8.2	3.1	-	-	-	-

Note: The details of the parameters are denoted in **Table 3.1**

Table 0.6 Reference Variable: North West Europe to US Atlantic Coast (TC2 route)

		Monthly Dataset		Weekly Dataset		Daily Dataset	
#	Variable	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.
1	BCI_TCE	-17.9	0.0	-4.2	3.1	3.6	3.1
2	BPI_TCE	5.1	3.1	1.2	3.1	8.0	3.1
3	BSI_TCE	6.0	3.1	1.4	3.1	14.8	3.1
4	TC2$	0.2	0.0	0.1	0.0	-0.1	0.0
5	TD3$	9.0	0.0	2.1	0.0	-11.1	0.0
6	BHSI	-0.2	0.0	-0.1	0.0	0.2	0.0
7	BDTI	4.8	0.0	1.1	0.0	-4.5	0.0
8	BCTI	6.9	3.1	1.6	3.1	-17.3	3.1
9	4TC_C+1MON	14.5	3.1	3.4	3.1	-8.6	3.1
10	4TC_C+2MON	11.6	3.1	2.7	3.1	-10.2	3.1
11	4TC_P+1MON	0.8	3.1	0.2	3.1	-10.9	3.1
12	4TC_P+2MON	-4.9	3.1	-1.1	3.1	-11.0	3.1
13	5TC_S+1MON	3.0	3.1	0.7	3.1	-11.3	3.1
14	5TC_S+2MON	-0.3	3.1	-0.1	3.1	-10.5	3.1
15	TC2$+1_M	1.8	0.0	0.4	0.0	-2.2	0.0
16	TC2$+2_M	3.3	0.0	0.8	0.0	-2.3	0.0
17	TD3$+1_M	8.0	0.0	1.9	0.0	-13.0	0.0
18	TD3$+2_M	8.2	0.0	1.9	0.0	-13.2	0.0
19	Crude	-8.2	3.1	-1.9	3.1	15.2	3.1
20	Brent	-7.4	3.1	-1.7	3.1	15.5	3.1
21	Heating_oil	-7.1	3.1	-1.6	3.1	13.4	3.1
22	Natural_Gas	8.8	3.1	2.1	3.1	8.7	3.1
23	Coal	-3.0	3.1	-0.7	0.0	-12.0	0.0
24	Wheat	-5.6	0.0	-1.3	3.1	2.7	3.1
25	Soybeans	8.4	3.1	1.9	3.1	4.1	3.1
26	Corn	-4.5	0.0	-1.0	3.1	3.3	3.1
27	Iron	-5.3	3.1	-1.2	3.1	5.8	3.1
28	CME_Crude_F1	-8.3	3.1	-1.9	3.1	15.2	3.1
29	ICE_Brent_F1	-7.8	3.1	-1.8	3.1	15.0	3.1
30	CME_Heating_F1	-7.3	3.1	-1.7	3.1	14.9	3.1
31	CME_Natural_gas_F1	8.4	3.1	1.9	3.1	13.6	3.1
32	ICE_Natural_Gas_F2	0.5	0.0	0.1	0.0	-11.9	0.0
33	ICE_Coal_F1	-0.7	3.1	-0.2	0.0	-12.3	0.0
34	ICE_Coal_F2	-1.3	3.1	-0.3	0.0	-13.1	0.0
35	CME_Wheat_F1	-5.8	0.0	-1.3	3.1	3.3	3.1
36	CME_Wheat_F2	-5.8	0.0	-1.4	3.1	3.4	3.1
37	CME_Soybeans_F1	8.3	3.1	1.9	3.1	3.7	3.1
38	CME_Soybeans_F2	7.9	3.1	1.8	3.1	4.1	3.1
39	CME_Corn_F1	-5.4	0.0	-1.2	3.1	3.4	3.1
40	CME_Corn_F2	-5.4	0.0	-1.3	3.1	3.4	3.1
41	CME_Iron_F1	-14.6	3.1	-3.4	3.1	15.8	3.1
42	CME_Iron_F2	-14.9	3.1	-3.5	3.1	-16.2	3.1
43	Copper	-9.1	3.1	-2.1	3.1	15.1	3.1
44	Copper_F3	-9.0	3.1	-2.1	3.1	15.1	3.1
45	Sugar	-17.0	3.1	-3.9	3.1	-17.2	3.1
46	Sugar_F1	-17.0	3.1	-4.0	3.1	-16.4	3.1
47	Sugar_F2	-17.1	3.1	-4.0	3.1	-16.5	3.1
48	Rice	8.2	3.1	1.9	3.1	12.8	3.1
49	Rice_F1	9.2	3.1	2.1	3.1	12.8	3.1
50	Rice_F2	8.5	3.1	2.0	3.1	12.8	3.1
51	Barley	5.4	3.1	1.3	3.1	16.4	3.1
52	Barley_F1	-17.2	3.1	-4.0	0.0	-4.7	3.1
53	Barley_F2	17.8	3.1	4.1	0.0	17.9	3.1
54	Canola	-1.1	0.0	-0.3	3.1	-2.7	0.0
55	Canola_F1	3.3	3.1	0.8	3.1	-2.8	0.0
56	Canola_F2	-2.6	0.0	-0.6	3.1	3.0	3.1
57	BDI	5.9	3.1	1.4	3.1	4.5	3.1
58	BLPG1	2.6	0.0	0.6	0.0	-4.3	0.0
59	TD3	8.6	0.0	2.0	0.0	-10.2	0.0
60	TC2_37	0.0	0.0	0.0	0.0	0.0	0.0
61	Urea	9.7	0.0	2.3	0.0	-	-
62	DAP	-1.6	0.0	-0.4	3.1	-	-
63	Ammonia	0.4	0.0	0.1	0.0	-	-
64	Scrap VLCC	-12.2	3.1	-	-	-	-
65	Scrap Cape/Pana	-14.8	3.1	-	-	-	-

Note: The details of the parameters are denoted in **Table 3.1**

Table 0.7 Reference Variable: Panamax T/C Futures second-near month

		Monthly Dataset		Weekly Dataset		Daily Dataset	
#	Variable	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.
1	BCI_TCE	0.7	0.0	-4.5	0.0	-9.0	0.0
2	BPI_TCE	-2.0	0.0	-4.8	0.0	-11.3	0.0
3	BSI_TCE	-4.7	0.0	-7.8	0.0	13.3	0.0
4	TC2$	6.2	3.1	-2.3	3.1	11.7	3.1
5	TD3$	-6.1	3.1	9.8	3.1	10.8	0.0
6	BHSI	2.4	3.1	-0.3	3.1	9.9	3.1
7	BDTI	5.7	0.0	-5.0	0.0	13.3	3.1
8	BCTI	-7.8	0.0	-9.6	0.0	12.4	0.0
9	4TC_C+1MON	0.4	0.0	-1.3	0.0	-0.2	0.0
10	4TC_C+2MON	0.2	0.0	-0.7	0.0	0.0	0.0
11	4TC_P+1MON	-0.1	0.0	-0.4	0.0	-0.1	0.0
12	4TC_P+2MON	0.0	0.0	0.0	0.0	0.0	0.0
13	5TC_S+1MON	-0.7	0.0	0.5	0.0	0.6	0.0
14	5TC_S+2MON	-0.6	0.0	0.4	0.0	0.0	0.0
15	TC2$+1_M	-4.0	3.1	-4.7	3.1	-17.8	3.1
16	TC2$+2_M	-7.6	3.1	-4.2	3.1	-15.6	3.1
17	TD3$+1_M	-11.9	3.1	1.6	3.1	5.9	0.0
18	TD3$+2_M	-12.1	3.1	2.2	3.1	5.4	0.0
19	Crude	9.5	0.0	-4.3	0.0	6.8	0.0
20	Brent	9.1	0.0	-2.1	0.0	6.3	0.0
21	Heating_oil	8.9	0.0	-12.8	0.0	6.8	0.0
22	Natural_Gas	-8.6	0.0	-11.3	0.0	13.7	0.0
23	Coal	4.3	0.0	4.5	0.0	8.3	0.0
24	Wheat	-1.7	3.1	-7.0	3.1	-6.9	3.1
25	Soybeans	3.0	3.1	-14.0	3.1	-6.8	3.1
26	Corn	7.0	3.1	-10.7	3.1	-6.4	3.1
27	Iron	0.5	0.0	2.4	0.0	-16.2	0.0
28	CME_Crude_F1	9.9	0.0	-4.6	0.0	6.8	0.0
29	ICE_Brent_F1	9.3	0.0	-2.1	0.0	6.8	0.0
30	CME_Heating_F1	11.6	0.0	-2.5	0.0	6.9	0.0
31	CME_Natural_gas_F1	-8.9	0.0	-11.8	0.0	8.6	0.0
32	ICE_Natural_Gas_F2	-0.3	0.0	-8.0	0.0	9.2	0.0
33	ICE_Coal_F1	9.6	0.0	6.3	0.0	9.2	0.0
34	ICE_Coal_F2	5.2	0.0	5.7	0.0	8.6	0.0
35	CME_Wheat_F1	0.1	3.1	-6.1	3.1	-6.4	3.1
36	CME_Wheat_F2	-0.1	3.1	-6.5	3.1	-6.7	3.1
37	CME_Soybeans_F1	3.5	3.1	-13.5	3.1	-6.5	3.1
38	CME_Soybeans_F2	3.6	3.1	-12.9	3.1	-6.8	3.1
39	CME_Corn_F1	3.8	3.1	-10.7	3.1	-6.3	3.1
40	CME_Corn_F2	2.6	3.1	-10.5	3.1	-6.4	3.1
41	CME_Iron_F1	7.6	0.0	2.2	0.0	5.4	0.0
42	CME_Iron_F2	8.3	0.0	0.8	0.0	3.1	0.0
43	Copper	10.9	0.0	-10.0	0.0	6.5	0.0
44	Copper_F3	11.0	0.0	-9.5	0.0	6.5	0.0
45	Sugar	6.0	0.0	-8.9	0.0	4.1	0.0
46	Sugar_F1	6.5	0.0	-9.1	0.0	3.6	0.0
47	Sugar_F2	5.8	0.0	-8.7	0.0	3.6	0.0
48	Rice	-6.7	0.0	0.5	0.0	6.5	0.0
49	Rice_F1	-7.8	0.0	-0.7	3.1	6.6	0.0
50	Rice_F2	-6.9	0.0	-0.8	3.1	6.5	0.0
51	Barley	7.9	3.1	-17.1	3.1	-12.6	3.1
52	Barley_F1	4.8	0.0	7.8	0.0	7.7	0.0
53	Barley_F2	5.8	0.0	-17.4	0.0	8.5	0.0
54	Canola	-0.7	3.1	-16.7	3.1	-8.9	3.1
55	Canola_F1	0.0	3.1	-17.3	3.1	-8.1	3.1
56	Canola_F2	-0.2	3.1	-16.3	3.1	-8.3	3.1
57	BDI	-1.5	0.0	-5.2	0.0	-9.4	0.0
58	BLPG1	12.4	3.1	-8.1	3.1	10.6	3.1
59	TD3	-7.5	3.1	8.9	3.1	10.9	0.0
60	TC2_37	8.1	3.1	-1.4	3.1	11.0	3.1
61	Urea	6.8	0.0	-6.0	3.1	-	-
62	DAP	6.6	3.1	-10.0	0.0	-	-
63	Ammonia	-7.8	0.0	4.9	3.1	-	-
64	Scrap VLCC	3.5	0.0	-	-	-	-
65	Scrap Cape/Pana	3.2	0.0	-	-	-	-

Note: The details of the parameters are denoted in **Table 3.1**

Table 0.8 Reference variable: Crude Oil

		Monthly Dataset		Weekly Dataset		Daily Dataset	
#	Variable	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.	No. of Factors - 4	Cycl.
1	BCI_TCE	15.1	3.1	2.9	0.0	14.1	0.0
2	BPI_TCE	-16.4	0.0	-0.7	0.0	10.7	0.0
3	BSI_TCE	-17.6	0.0	-0.6	0.0	6.3	0.0
4	TC2$	8.1	3.1	-10.3	0.0	-15.2	3.1
5	TD3$	0.4	3.1	-6.0	3.1	-4.1	3.1
6	BHSI	9.1	3.1	11.3	3.1	-15.4	3.1
7	BDTI	-2.3	0.0	-3.8	3.1	-9.5	3.1
8	BCTI	17.5	0.0	-0.1	0.0	9.8	0.0
9	4TC_C+1MON	-15.1	0.0	4.3	0.0	-7.4	0.0
10	4TC_C+2MON	-13.3	0.0	3.8	0.0	-7.2	0.0
11	4TC_P+1MON	-12.7	0.0	4.2	0.0	-7.5	0.0
12	4TC_P+2MON	-9.5	0.0	4.3	0.0	-6.8	0.0
13	5TC_S+1MON	-14.0	0.0	4.0	0.0	-7.1	0.0
14	5TC_S+2MON	-10.9	0.0	2.9	0.0	-7.0	0.0
15	TC2$+1_M	5.9	3.1	-12.0	3.1	-15.6	3.1
16	TC2$+2_M	4.2	3.1	-7.3	3.1	-15.5	3.1
17	TD3$+1_M	0.5	3.1	-6.8	3.1	-1.0	3.1
18	TD3$+2_M	-0.2	3.1	-6.5	3.1	-0.1	0.0
19	Crude	0.0	0.0	0.0	0.0	0.0	0.0
20	Brent	-0.7	0.0	0.2	0.0	-0.1	0.0
21	Heating_oil	-0.8	0.0	-5.8	0.0	2.2	0.0
22	Natural_Gas	16.1	0.0	-4.7	0.0	5.4	0.0
23	Coal	-4.5	0.0	2.5	0.0	-0.5	0.0
24	Wheat	11.7	3.1	-5.2	3.1	-4.3	3.1
25	Soybeans	-14.3	0.0	-2.8	0.0	2.2	0.0
26	Corn	-12.9	0.0	-3.0	3.1	-3.2	3.1
27	Iron	-6.9	0.0	2.2	0.0	2.1	0.0
28	CME_Crude_F1	0.1	0.0	0.0	0.0	0.0	0.0
29	ICE_Brent_F1	-0.5	0.0	0.3	0.0	0.0	0.0
30	CME_Heating_F1	-0.4	0.0	0.0	0.0	0.0	0.0
31	CME_Natural_gas_F1	16.8	0.0	-1.7	0.0	1.1	0.0
32	ICE_Natural_Gas_F2	-7.9	0.0	2.8	0.0	-0.1	0.0
33	ICE_Coal_F1	-4.5	0.0	3.7	0.0	-0.6	0.0
34	ICE_Coal_F2	-4.9	0.0	3.8	0.0	-0.7	0.0
35	CME_Wheat_F1	12.9	3.1	-6.3	3.1	-3.7	3.1
36	CME_Wheat_F2	12.8	3.1	-6.0	3.1	3.6	0.0
37	CME_Soybeans_F1	-14.7	0.0	-3.5	0.0	2.1	0.0
38	CME_Soybeans_F2	-14.8	0.0	-2.2	0.0	2.1	0.0
39	CME_Corn_F1	-13.4	0.0	4.4	0.0	3.1	0.0
40	CME_Corn_F2	-13.0	0.0	-4.1	3.1	3.2	0.0
41	CME_Iron_F1	2.4	0.0	-2.9	0.0	-1.2	0.0
42	CME_Iron_F2	2.8	0.0	-3.0	0.0	-2.5	0.0
43	Copper	0.3	0.0	-1.5	0.0	0.2	0.0
44	Copper_F3	0.2	0.0	-1.4	0.0	0.2	0.0
45	Sugar	4.7	0.0	-1.8	0.0	1.2	0.0
46	Sugar_F1	5.2	0.0	-1.6	0.0	1.2	0.0
47	Sugar_F2	4.8	0.0	-1.9	0.0	1.2	0.0
48	Rice	-15.9	0.0	2.7	0.0	2.1	0.0
49	Rice_F1	-16.4	0.0	-3.1	3.1	2.1	0.0
50	Rice_F2	-16.1	0.0	-3.6	3.1	2.1	0.0
51	Barley	-14.6	0.0	-5.7	0.0	-0.9	3.1
52	Barley_F1	4.5	0.0	-8.3	0.0	3.8	0.0
53	Barley_F2	3.1	0.0	-6.6	0.0	1.5	0.0
54	Canola	11.8	3.1	10.6	3.1	-4.2	3.1
55	Canola_F1	13.1	3.1	-9.5	0.0	3.8	0.0
56	Canola_F2	12.3	3.1	-6.3	0.0	3.4	0.0
57	BDI	-16.6	0.0	1.4	0.0	12.9	0.0
58	BLPG1	5.9	3.1	-7.7	3.1	2.8	3.1
59	TD3	0.3	3.1	-6.0	3.1	-5.1	3.1
60	TC2_37	8.2	3.1	10.2	3.1	-15.2	3.1
61	Urea	0.3	0.0	15.9	3.1	-	-
62	DAP	12.5	3.1	10.9	3.1	-	-
63	Ammonia	-5.8	0.0	16.7	3.1	-	-
64	Scrap VLCC	-2.4	0.0	-	-	-	-
65	Scrap Cape/Pana	-1.7	0.0	-	-	-	-

Note: The details of the parameters are denoted in **Table 3.1**

Table 0.9 Reference Variable: Corn

		Monthly Dataset		Weekly Dataset		Daily Dataset	
#	**Variable**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**	**No. of Factors - 4**	**Cycl.**
1	BCI_TCE	**-8.7**	**3.1**	**-13.7**	**3.1**	**3.5**	**3.1**
2	BPI_TCE	**-1.1**	**3.1**	**14.6**	**3.1**	**9.2**	**3.1**
3	BSI_TCE	**2.1**	**3.1**	**14.2**	**3.1**	**11.6**	**3.1**
4	TC2$	**3.5**	**0.0**	**-5.2**	**0.0**	**-3.2**	**3.1**
5	TD3$	**16.5**	**0.0**	**17.9**	**3.1**	**7.8**	**3.1**
6	BHSI	**3.9**	**0.0**	**1.8**	**3.1**	**-3.4**	**3.1**
7	BDTI	**-14.1**	**3.1**	**12.8**	**3.1**	**3.0**	**3.1**
8	BCTI	**3.5**	**3.1**	**17.4**	**3.1**	**17.8**	**3.1**
9	4TC_C+1MON	**-7.1**	**3.1**	**12.6**	**3.1**	**5.7**	**3.1**
10	4TC_C+2MON	**-6.7**	**3.1**	**10.1**	**3.1**	**6.0**	**3.1**
11	4TC_P+1MON	**-5.0**	**3.1**	**11.8**	**3.1**	**6.5**	**3.1**
12	4TC_P+2MON	**-7.0**	**3.1**	**10.7**	**3.1**	**6.4**	**3.1**
13	5TC_S+1MON	**-0.9**	**3.1**	**9.9**	**3.1**	**5.9**	**3.1**
14	5TC_S+2MON	**-2.6**	**3.1**	**9.2**	**3.1**	**5.7**	**3.1**
15	TC2$+1_M	**5.5**	**0.0**	**-6.7**	**0.0**	**-14.8**	**3.1**
16	TC2$+2_M	**6.7**	**0.0**	**-7.9**	**0.0**	**-7.2**	**3.1**
17	TD3$+1_M	**16.5**	**0.0**	**11.7**	**3.1**	**8.3**	**3.1**
18	TD3$+2_M	**15.8**	**0.0**	**14.0**	**3.1**	**8.6**	**3.1**
19	Crude	**12.9**	**0.0**	**3.0**	**3.1**	**3.2**	**3.1**
20	Brent	**10.0**	**0.0**	**-4.0**	**0.0**	**4.1**	**3.1**
21	Heating_oil	**9.7**	**0.0**	**-12.9**	**0.0**	**4.8**	**3.1**
22	Natural_Gas	**2.5**	**0.0**	**9.9**	**0.0**	**0.1**	**3.1**
23	Coal	**-8.3**	**3.1**	**-3.9**	**0.0**	**7.2**	**3.1**
24	Wheat	**1.2**	**0.0**	**0.8**	**0.0**	**0.2**	**0.0**
25	Soybeans	**-0.7**	**0.0**	**-1.2**	**0.0**	**-0.4**	**0.0**
26	Corn	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
27	Iron	**-0.9**	**3.1**	**6.1**	**3.1**	**0.4**	**3.1**
28	CME_Crude_F1	**13.0**	**0.0**	**2.8**	**3.1**	**3.3**	**3.1**
29	ICE_Brent_F1	**10.8**	**0.0**	**-3.5**	**0.0**	**3.5**	**3.1**
30	CME_Heating_F1	**11.2**	**0.0**	**-4.0**	**0.0**	**3.3**	**3.1**
31	CME_Natural_gas_F1	**2.9**	**0.0**	**-10.9**	**3.1**	**4.8**	**3.1**
32	ICE_Natural_Gas_F2	**-2.3**	**3.1**	**-6.5**	**3.1**	**6.7**	**3.1**
33	ICE_Coal_F1	**-2.4**	**3.1**	**-5.2**	**0.0**	**8.4**	**3.1**
34	ICE_Coal_F2	**-5.0**	**3.1**	**-4.4**	**0.0**	**8.3**	**3.1**
35	CME_Wheat_F1	**0.4**	**0.0**	**0.6**	**0.0**	**0.0**	**0.0**
36	CME_Wheat_F2	**0.4**	**0.0**	**0.7**	**0.0**	**0.0**	**0.0**
37	CME_Soybeans_F1	**-0.9**	**0.0**	**-1.3**	**0.0**	**-0.3**	**0.0**
38	CME_Soybeans_F2	**-1.0**	**0.0**	**-1.0**	**0.0**	**-0.3**	**0.0**
39	CME_Corn_F1	**-0.1**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**
40	CME_Corn_F2	**0.1**	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**
41	CME_Iron_F1	**-10.3**	**3.1**	**-10.4**	**0.0**	**6.4**	**3.1**
42	CME_Iron_F2	**-12.3**	**3.1**	**-10.0**	**0.0**	**5.4**	**3.1**
43	Copper	**11.0**	**0.0**	**-2.1**	**0.0**	**-2.8**	**0.0**
44	Copper_F3	**11.1**	**0.0**	**-2.1**	**0.0**	**-2.8**	**0.0**
45	Sugar	**17.3**	**3.1**	**3.8**	**0.0**	**1.0**	**3.1**
46	Sugar_F1	**16.9**	**3.1**	**4.2**	**0.0**	**-0.5**	**0.0**
47	Sugar_F2	**17.1**	**3.1**	**3.7**	**0.0**	**-0.5**	**0.0**
48	Rice	**-2.7**	**0.0**	**-0.2**	**0.0**	**-2.5**	**0.0**
49	Rice_F1	**-3.1**	**0.0**	**0.0**	**0.0**	**-2.6**	**0.0**
50	Rice_F2	**-2.8**	**0.0**	**0.1**	**0.0**	**-2.4**	**0.0**
51	Barley	**-1.2**	**0.0**	**-0.1**	**0.0**	**-9.4**	**0.0**
52	Barley_F1	**3.1**	**0.0**	**-10.0**	**0.0**	**-1.6**	**3.1**
53	Barley_F2	**4.1**	**0.0**	**-12.7**	**0.0**	**11.3**	**3.1**
54	Canola	**-0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
55	Canola_F1	**-0.4**	**0.0**	**-0.3**	**0.0**	**0.0**	**0.0**
56	Canola_F2	**-0.3**	**0.0**	**-0.7**	**0.0**	**0.0**	**0.0**
57	BDI	**-3.7**	**3.1**	**-17.9**	**3.1**	**4.7**	**3.1**
58	BLPG1	**-0.6**	**0.0**	**-1.9**	**0.0**	**-8.4**	**0.0**
59	TD3	**-16.6**	**3.1**	**-17.4**	**3.1**	**7.3**	**3.1**
60	TC2_37	**4.0**	**0.0**	**4.7**	**3.1**	**-3.3**	**3.1**
61	Urea	**-16.8**	**3.1**	**-10.7**	**0.0**	-	-
62	DAP	**-2.3**	**0.0**	**16.4**	**3.1**	-	-
63	Ammonia	**8.6**	**0.0**	**-13.1**	**3.1**	-	-
64	Scrap VLCC	**-10.8**	**3.1**	-	-	-	-
65	Scrap Cape/Pana	**-13.3**	**3.1**	-	-	-	-

Note: The details of the parameters are denoted in **Table 3.1**

Table 0.10 Commonality of Variables

#	Variable	Commonality Monthly	Commonality Weekly	Commonality Daily
1	BCI_TCE	0.39	0.53	0.74
2	BPI_TCE	0.78	0.65	0.66
3	BSI_TCE	0.81	0.80	0.86
4	TC2$	0.73	0.72	0.72
5	TD3$	0.81	0.80	0.91
6	BHSI	0.77	0.62	0.71
7	BDTI	0.30	0.36	0.32
8	BCTI	0.77	0.71	0.83
9	4TC_C+1MON	0.69	0.61	0.66
10	4TC_C+2MON	0.59	0.62	0.65
11	4TC_P+1MON	0.89	0.82	0.72
12	4TC_P+2MON	0.83	0.79	0.73
13	5TC_S+1MON	0.83	0.73	0.60
14	5TC_S+2MON	0.82	0.76	0.61
15	TC2$+1_M	0.69	0.65	0.27
16	TC2$+2_M	0.65	0.55	0.27
17	TD3$+1_M	0.83	0.70	0.34
18	TD3$+2_M	0.76	0.56	0.31
19	Crude	0.87	0.85	0.82
20	Brent	0.96	0.87	0.62
21	Heating_oil	0.94	0.77	0.04
22	Natural_Gas	0.44	0.19	0.05
23	Coal	0.88	0.53	0.33
24	Wheat	0.66	0.64	0.41
25	Soybeans	0.82	0.70	0.54
26	Corn	0.81	0.73	0.61
27	Iron	0.54	0.14	0.03
28	CME_Crude_F1	0.88	0.85	0.86
29	ICE_Brent_F1	0.96	0.89	0.84
30	CME_Heating_F1	0.97	0.84	0.76
31	CME_Natural_gas_F1	0.51	0.23	0.05
32	ICE_Natural_Gas_F2	0.54	0.34	0.08
33	ICE_Coal_F1	0.79	0.47	0.22
34	ICE_Coal_F2	0.88	0.59	0.34
35	CME_Wheat_F1	0.73	0.72	0.59
36	CME_Wheat_F2	0.72	0.72	0.59
37	CME_Soybeans_F1	0.84	0.72	0.60
38	CME_Soybeans_F2	0.81	0.77	0.72
39	CME_Corn_F1	0.89	0.73	0.63
40	CME_Corn_F2	0.88	0.73	0.66
41	CME_Iron_F1	0.63	0.29	0.03
42	CME_Iron_F2	0.72	0.26	0.05
43	Copper	0.67	0.38	0.31
44	Copper_F3	0.68	0.39	0.31
45	Sugar	0.78	0.61	0.56
46	Sugar_F1	0.76	0.57	0.76
47	Sugar_F2	0.78	0.61	0.78
48	Rice	0.86	0.68	0.86
49	Rice_F1	0.86	0.71	0.82
50	Rice_F2	0.86	0.72	0.84
51	Barley	0.31	0.16	0.01
52	Barley_F1	0.58	0.13	0.03
53	Barley_F2	0.46	0.15	0.03
54	Canola	0.54	0.53	0.49
55	Canola_F1	0.60	0.56	0.56
56	Canola_F2	0.61	0.59	0.61
57	BDI	0.83	0.83	0.88
58	BLPG1	0.26	0.04	0.03
59	TD3	0.73	0.81	0.88
60	TC2_37	0.77	0.77	0.79
61	Urea	0.42	0.14	-
62	DAP	0.02	0.06	-

63	Ammonia	0.34	0.03	-
64	Scrap VLCC	0.73	-	-
65	Scrap Cape/Pana	0.74	-	-

Table 0.11 Names and Sources of Variables

#	Variable	Name	Source
1	BCI_TCE	Baltic Capesize Index Time Charter Equivalent	Baltic Exchange
2	BPI_TCE	Baltic Panamax Index Time Charter Equivalent	Baltic Exchange
3	BSI_TCE	Baltic Supramax Index Time Charter Equivalent	Baltic Exchange
4	TC2$	Continent to US Atlantic coast freight rate - Time Charter Equivalent	Baltic Exchange
5	TD3$	Middle East Gulf to Japan VLCC freight rate - Time Charter Equivalent	Baltic Exchange
6	BHSI	Baltic Exchange Handysize Index	Baltic Exchange
7	BDTI	Baltic Exchange Dirty Tanker Index	Baltic Exchange
8	BCTI	Baltic Exchange Clean Tanker Index	Baltic Exchange
9	4TC_C+1MON	Baltic Exchange Forward Assessment for Capesize - Near Month Contract	Baltic Exchange
10	4TC_C+2MON	Baltic Exchange Forward Assessment for Capesize - Second Near Month Contract	Baltic Exchange
11	4TC_P+1MON	Baltic Exchange Forward Assessment for Panamax - Near Month Contract	Baltic Exchange
12	4TC_P+2MON	Baltic Exchange Forward Assessment for Panamax - Second Near Month Contract	Baltic Exchange
13	5TC_S+1MON	Baltic Exchange Forward Assessment for Supramax - Near Month Contract	Baltic Exchange
14	5TC_S+2MON	Baltic Exchange Forward Assessment for Supramax - Second Near Month Contract	Baltic Exchange
15	TC2$+1_M	Baltic Exchange Forward Assessment for Clean $/mt (TC2) - Near Month Contract	Baltic Exchange
16	TC2$+2_M	Baltic Exchange Forward Assessment for Clean $/mt (TC2) - Second Near Month Contract	Baltic Exchange
17	TD3$+1_M	Baltic Exchange Forward Assessment for Dirty $/mt (TD3) - Near Month Contract	Baltic Exchange
18	TD3$+2_M	Baltic Exchange Forward Assessment for Dirty $/mt (TD3) - Second Near Month Contract	Baltic Exchange
19	Crude	WTI Crude Oil Spot Price	US Energy Information Administration
20	Brent	Brent Oil Spot Price	US Energy Information Administration
21	Heating_oil	Heating Oil Spot Price	US Energy Information Administration
22	Natural_Gas	Natural Gas Spot Price	US Energy Information Administration
23	Coal	Coal Spot Price	API 2 index
24	Wheat	Wheat Spot Price	US Department of Agriculture
25	Soybeans	Soybeans Spot Price	US Department of Agriculture
26	Corn	Corn Spot Price	US Department of Agriculture
27	Iron	Iron Ore Spot Price	Bloomberg composite Fe 62% price
28	CME_Crude_F1	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
29	ICE_Brent_F1	Crude Oil Futures - Near Month Contract	Intercontinental Exchange
30	CME_Heating_F1	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
31	ICE_Natural_Gas_F1	Crude Oil Futures - Near Month Contract	Intercontinental Exchange
32	ICE_Natural_Gas_F2	Crude Oil Futures - Near Month Contract	Intercontinental Exchange
33	ICE_Coal_F1	Crude Oil Futures - Near Month Contract	Intercontinental Exchange
34	ICE_Coal_F2	Crude Oil Futures - Near Month Contract	Intercontinental Exchange

35	CME_Wheat_F1	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
36	CME_Wheat_F2	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
37	CME_Soybeans_F1	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
38	CME_Soybeans_F2	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
39	CME_Corn_F1	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
40	CME_Corn_F2	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
41	CME_Iron_F1	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
42	CME_Iron_F2	Crude Oil Futures - Near Month Contract	Chicago Mercantile Exchange
43	Copper	Copper Spot Price	London Metal Exchange
44	Copper_F3	Copper Futures - Third Near Month Contract	London Metal Exchange
45	Sugar	Sugar Spot Price	International Sugar Organization(ISO)
46	Sugar_F1	Sugar Futures - Near Month Contract	Intercontinental Exchange
47	Sugar_F2	Sugar Futures - Second Near Month Contract	Intercontinental Exchange
48	Rice	Rice Spot Price	JP Morgan CBOT RR Index
49	Rice_F1	Rice Futures - Near Month Contract	Chicago Mercantile Exchange
50	Rice_F2	Rice Futures - Second Near Month Contract	Chicago Mercantile Exchange
51	Barley	Barley Spot Price	US Energy Information Administration
52	Barley_F1	Barley Futures - Near Month Contract	National Commodity and Derivatives Exchange
53	Barley_F2	Barley Futures - Second Near Month Contract	National Commodity and Derivatives Exchange
54	Canola	Canola Spot Price	DataStream
55	Canola_F1	Canola Futures - Near Month Contract	Intercontinental Exchange
56	Canola_F2	Canola Futures - Second Near Month Contract	Intercontinental Exchange
57	BDI	Baltic Exchange Dry Index	Baltic Exchange
58	BLPG1	Baltic Exchange Liquid Petroleum Gas Index	Baltic Exchange
59	TD3	Middle East Gulf to Japan VLCC freight rate - Worldscale	Baltic Exchange
60	TC2_37	Continent to US Atlantic coast freight rate - Worldscale	Baltic Exchange
61	Urea	Urea Fertilizer Spot Price	US Gulf NOLA Urea
62	DAP	Diammonium Phosphate Fertilizer Spot Price	US Gulf NOLA DAP
63	Ammonia	Ammonia Fertilizer Spot Price	US Gulf NOLA Ammonia
64	Scrap VLCC	India VLCC Scrap Spot Price	Clarksons
65	Scrap Cape/Pana	India dry Scrap Spot Price	Clarksons