Analyzing intraday volatility spillovers between Petroleum and stock sectors

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Abstract

This study analyses intraday volatility spillovers between petroleum and sector indices of five petroleum exporting and nine petroleum importing countries applying the connectedness approach. Ten sector indices are manually built utilising 5-minute data of 1,689 stocks listed over the period from July 31, 2020 to April 30, 2021. The empirical results reveal that the total volatility connectedness mostly remains high during the period when the peak phases of turbulences in markets caused by the global health crisis passed. The evidence of significant volatility interdependencies between petroleum and sector indices, which exhibit a dynamic nature and responsiveness to market events, is documented. The intensity and course of transmissions differ across sectors of petroleum exporters and importers. Furthermore, the pairwise investigation suggests that petroleum is the large net-contributor of volatility to sectors of Norway and the United Kingdom, but the major net-recipient of volatility from sectors of Canada and the United States. The low volatility interlinkages with petroleum are observed for sectors of Australia, China, Mexico and South Korea.

Keywords: Stock sectors, Petroleum exporters, Petroleum importers, Volatility spillover

JEL Classification: G14, G15, Q43

1. Introduction

Comprehension of the dynamic linkages between petroleum and stock markets remains one of the foremost matters for industry professionals and academics around the world. Given a nearly round-the-clock operation of the petroleum market and an extensive geography of global petroleum trade flows, the spread of information and investors' sentiment across markets has been accelerated with the financialization of commodity markets and technological advancements. The interaction of petroleum price volatility with stock market volatility, which tends to intensify during turmoil periods, is a phenomenon that has been well documented in the finance literature (Malik and Ewing, 2009; Arouri et al., 2011; Awartani and Maghyereh, 2013; Boldanov et al., 2016; Maghyereh et al., 2016; among others). Recently, financial markets have experienced unprecedented levels of turbulence caused by the global health crisis, which is characterised as an origin of systematic risk (Sharif et al., 2020; Hung and Vo, 2021). In particular, the empirical evidence indicates that during the pandemic, global trade was severely affected (Vidya and Prabheesh, 2020), volatilities surged in stock markets (Baek et al. 2020; Haroon and Rizvi, 2020) and petroleum markets, driven by demand and supply side factors, where prices of major grades, such as Brent and WTI, displayed one of the significant declines in their modern history (Bourghelle et al., 2021; Le et al., 2021; Yu et al., 2022). Furthermore, the connectedness of petroleum prices, which generally capture expectations regarding global economic growth, with stock markets considerably soared in the peak stages of the pandemic (Cui et al., 2021; Zhang et al., 2021; Bouri et al., 2021). Although the negative effects of the global health crisis have started fading away over time (Topcu and Gulal, 2020), investors still face challenges with cross market asset allocations amid the increased risks of contagion. In this context, the sectoral investigation of the time-varying volatility connectedness structure among petroleum and stock markets of petroleum exporting and importing countries during the post pandemic period is of great importance for market participants in identifying diversification opportunities and managing risks efficiently.

The strand of literature devoted to the analysis of return and volatility spillovers between petroleum prices and stock markets through the application of connectedness approaches proposed by Diebold and Yilmaz (2009, 2012, 2014) and Barunik and Krehlik (2018) has been increasing. The large portion of these studies concentrates on the aggregate market indices. For instance, Awartani and Maghyereh (2013) employing weekly data examine return and volatility transmissions between petroleum and seven stock markets in the GCC region over the period from 2004 to 2012. Their findings indicate that the magnitude of observed spillovers, both return and volatility, which intensifies during the financial crisis, is larger from the petroleum market to stock markers than in the opposite course. Al-Yahyaee et al. (2019) investigate return and volatility linkages between the energy, precious metals commodity markets and the GCC stock markets. Utilising daily data for the period from September 2005 to October 2016, the authors found that among energy commodities, WTI grade of crude petroleum is the net transmitter in terms of volatility and returns. In addition, the results show that the total connectedness between commodities and stock markets strengthens at times of the financial crisis and geopolitical events.

Other works consider a mixture of developed and emerging markets. Zhang (2017) uses monthly data to assess the connectedness between petroleum and six stock markets. The author detects that petroleum prices receive more shocks from stock markets than they transmit in the reverse direction. Gomez-Gonzalez et al. (2020) study the nexus between Brent grade of petroleum and seventeen aggregate stock market indices of petroleum dependent countries. The authors employ monthly data for the period from August 1999 to March 2018. They also provide evidence indicating that the magnitude of shocks transmitted from stock markets to petroleum prices is larger. The overall dynamic connectedness considerably increases during the financial uncertainty. Tiwari et al. (2021) investigate return and volatility connectedness between two grades of petroleum, Brent and WTI, and twelve stock market indices over the period from January 2000 to March 2017. The authors document that both grades are the net-receivers of return and volatility spillovers. In addition, the major global events are found to influence dynamic interactions. On the other hand, Maghyereh et al. (2016) utilising higher frequency data examine the implied volatility connectedness between petroleum and eleven major stock market indices for the period of 2008 to 2015. Their results demonstrate that the connectedness is greatly ruled by the contribution of petroleum implied volatility to all stock markets and not contrariwise. The outputs associated with alternative volatility measures confirm this finding. Furthermore, the authors observe that the pairwise volatility connectedness of petroleum is stronger with developed stock markets. Mensi et al. (2021d) analyse volatility spillovers between two strategic commodities, petroleum and gold, and stock markets of seven developed and five emerging economies. The authors employ daily data covering the period from January 2000 to February 2018. The findings show that the contribution of volatility transmissions from the short-term horizon to the total connectedness between the studied markets is higher. The directions of short-, medium- and long-term spillovers run from the stock markets to petroleum market, except for Russia, China and Japan in the case of latter two horizons.

Some studies provide evidence in the context of different sectors. Ahmad (2017) examines the daily directional volatility interactions among petroleum prices, technology and clean energy indices for the period from May 2005 to April 2015. The author shows that petroleum is a net recipient of volatility emanating from clean energy and technology stocks. Furthermore, the increased volatility interdependencies between the considered assets are observed during turmoil periods in markets. Employing daily data over the period from January 2005 to May 2020, Mensi et al. (2021a) investigate asymmetric return transmissions between petroleum, gold and ten Chinese sector indices. Their results indicate that sectors as *Industrials* and *Consumer Discretionary* are the main net-transmitters of spillovers, whereas both commodities are the net-receivers in the system. In addition, the authors report predominance of negative return transmissions over positive return transmissions, particularly during crisis periods. Maitra et al. (2021) observe sharp increases in the daily volatility connectedness between prices of petroleum and stocks of international logistics firms during the global financial crisis, Eurozone debt crisis and slowdown in the global economic activity. Mensi et al. (2022b) focus on twenty-two global European sector indices in their study of asymmetric return connectedness for the period from September 2010 to December 2020. They also provide evidence of asymmetries in return transmissions. The petroleum market is the net-receiver of return spillovers in the system, where contribution of the *Energy* sector is larger compared to all other sectors. The dynamic positive and negative return connectedness indices are strongly affected by the recent global health crisis. Costola and Lorusso (2022) analyse the volatility connectedness among six sector indices of Russia and energy commodities using the weekly frequency of data for the period 2005-2020. Their results reveal that petroleum weakly influences sectors in Russia, but instead the intensity of volatility spillovers is larger from sectors to petroleum. Specifically, the *Metals & Mining* and *Oil & Gas* sectors appear to exhibit high shock contributions to petroleum and other sectors. The total time-varying volatility connectedness between studied variables is strong, on average equalling to 70%, and spikes during the pandemic.

A group of works consider the impact of the global health crisis. Hung and Vo (2021), Bouri et al. (2021), and Benlagha and El Omari (2022) provide evidence of the significantly strengthened return and volatility connectedness among various asset classes, inclusive of crude petroleum and stocks, during the pandemic. Jebabli et al. (2022) show that volatility transmissions between energy and MSCI World, Emerging and Europe stock market indices detected throughout the global health crisis surpass those reported over the global financial crisis. The authors observe that energy markets are the net-receivers of volatility from global stock markets during the financial instability, whereas the patterns are different at the time of the pandemic. Zhang et al. (2021) document the increased degree of risk spillovers from ten stock markets to energy markets after the outbreak of COVID-19. Mensi et al. (2021c) found that Brent crude petroleum, regardless of frequency bands, is the net-recipient of risks transmitting from the studied stock markets in Asia, Europe and the US. In addition, their results indicate that the effects of the global health crisis on the total volatility spillover index are more marked than those of other major events. Cui et al. (2021) and Zhang and Hamori (2021) report that spillover effects between petroleum and a wide range of stock markets mostly occur over the long-term horizons, and the dynamic total connectedness reaches unprecedented levels during the recent pandemic. Mensi et al. (2021b) investigate the interrelationship between petroleum prices and twelve stock markets in the MENA region for the period from January 2003 to October 2005. Their findings demonstrate that the magnitude of time-varying spillovers is greater for petroleum exporters than for petroleum importers, particularly over the petroleum price crash and global health crisis periods.

Given the high speed of information transmission among markets, several works make a use of intraday data ranging from 5 to 15 minutes in their analyses. Xu et al. (2019) examine volatility interdependencies between WTI futures prices and stock markets of China and the US, represented by the SSE Composite and S&P 500 indices, for the period 2007-2016. The volatility connectedness between petroleum and the US stock markets is detected to be stronger in comparison to the Chinese stock market. The time-varying volatility spillovers reveal that during the financial crisis, petroleum and the Chinese stock market are the net-receivers, while the stock market of the US is the net-transmitter. Furthermore, the authors' results point to the dominance of bad volatility transmissions throughout most of the period. Suleman et al. (2021) study the asymmetric volatility spillovers between commodity markets and the DJIM index over the period from January 2010 to November 2020. The authors report that commodities, such as silver and Brent crude petroleum, are the net-receivers of shocks in the system during the pandemic. The DJIM index is the largest contributor of volatility to commodity markets. The dynamic negative volatility transmissions are observed to be relatively larger as opposed to their positive counterparts. Farid et al. (2021) assess volatility linkages between major commodities and equities utilising intraday data on the US ETFs for the period from January

2019 to May 2020. Their findings exhibit that the equity market acts as the major volatility transmitter over the investigation period. The global health crisis led to an upward trend in the time-varying total volatility connectedness. Heinlein et al. (2021) and Mensi et al. (2022a) document significant upsurges in correlations between petroleum and stock markets during the global health crisis.

The empirical literature focusing on the post pandemic period is rather limited. To this end, the present study seeks to provide new insights with regard to the volatility connectedness between petroleum prices and stock sectors of petroleum exporting and importing countries during a period when the peak phases of the crisis had passed, but uncertainty among investors still persisted. The examination of this matter at a sectoral level is essential given that dynamic volatility interactions may vary across sectors of petroleum exporters and importers because of the dissimilar degrees of petroleum dependency. In addition, since the importance of sectors within countries is unbalanced, some of them may function as major drivers of volatility transmissions. Thus, identification of heterogeneities inherent in each sector provides valuable information for the management of investment portfolios and risks. In contrast to preceding works, the current research considers a large sample of net petroleum exporting and importing economies with developed and emerging markets. The unique equal-weighted approach for the manual construction of sector indices proposed by Mateus et al. (2017) is adopted in the study, which possesses several advantages. First, it helps to overcome constraints related to the absence of sector indices representing largest stocks with ample intraday liquidity in most of the selected countries. Second, as construction methodologies and regulatory processes are market specific, it permits the execution of the uniform technique across different markets. The study strives to achieve the following two main objectives: (i) to investigate intraday volatility transmissions, in both static and dynamic frameworks, between Brent crude petroleum futures prices and manually built ten stock sector indices, namely *Basic Materials*, *Consumer Cyclicals*, *Consumer Non-Cyclicals*, *Energy*, *Financials*, *Healthcare*, *Industrials*, *Real Estate*, *Technology* and *Utilities*, of five net petroleum exporting (Brazil, Canada, Mexico, Norway and Russia) and nine net petroleum importing (Australia, China, the Eurozone, India, Japan, South Africa, South Korea, the United Kingdom and United States) countries; and (ii) to analyse net pairwise volatility linkages among assets by constructing spillover networks. The high frequency data allows to monitor information incorporated in intraday fluctuations of prices (Farid et al., 2021), and hence, leads to a better detection of short-term patterns in cross-market volatility spillovers (Mensi et al. (2022a), which may be wholly absorbed by markets at longer time periods (Mateus et al., 2017). Taking this into account, the study utilises data at 5-minute intervals from July 31, 2020 to April 30, 2021. To quantify intraday volatilities of assets, the volatility estimator of Garman and Klass (1980) is applied. Empirically, the connectedness approach introduced by Diebold and Yilmaz (2012), which measures magnitude and dynamics of volatility interdependencies among multiple variables in the system, is employed.

The current work adds to the scant literature on the intraday volatility connectedness among petroleum and stock sectors on three major fronts. First, unlike the previous studies, it focuses on the after-crisis comparative assessment of dynamic volatility spillovers between petroleum and sectors of an extensive assortment of net petroleum exporting and importing economies with different levels of market development. Second, it manually constructs sector indices adopting a novel technique introduced by Mateus et al. (2017) and using high frequency data of 1,689 listed stocks, which leads to a more precise investigation of the volatility interaction mechanisms. Third, it demonstrates that sector indices of net petroleum exporters and importers experience diverse intraday sensitivities to the petroleum price volatility, which are commonly supressed by low frequency data and aggregate market indices, and thus, emphasises the importance of comprehending the heterogeneity of spillover effects for defining intermarket asset allocations strategies and implementing risk mitigation regulations.

The conducted investigation produces noteworthy empirical results. The presence of significant bidirectional volatility transmissions between petroleum and sectors of petroleum exporters and importers is observed. The intensity of volatility interdependencies differs across countries and sectors. The total volatility connectedness remains sizable, surpassing 50% for most markets, during the post global health crisis period. Sectors of Norway, Russia, South Africa, South Korea, the Eurozone and United Kingdom are the net-receivers of volatility spilling from the petroleum market. On the other hand, sectors of Brazil, Canada, Mexico, Australia, China, India, Japan and the United States act as the net-contributors of volatility to the petroleum market. The pairwise analysis allowed to identify sectors that drive volatility in each country. Furthermore, the volatility spillovers, which exhibit a time-varying nature, are generally sensitive to short-term market events. For Mexico, Australia, China and South Korea, the relatively low volatility interactions between petroleum and sectors are documented. The findings are robust to different lag orders and forecast horizons.

The remainder of the present work is structured as follows. Section 2 presents sample selection procedures, data sources, construction techniques of sector indices and empirical model. Sector 3 discusses static and dynamic empirical results. Section 4 concludes the study.

2. Data and methodology

2.1. Sample selection and data sources

The study applies several methods to determine the sample of countries, sectors and stocks for the analysis of intraday volatility interdependencies between stock sector indices of petroleum exporting and importing countries and prices of petroleum. The countries are categorised into groups of exporters and importers employing the annual figures on crude petroleum production and consumption supplied by the British Petroleum Statistical Review of World Energy.[1] The first group of countries produce more crude petroleum than they consume, while in the second group of countries the level of petroleum production does not surpass petroleum consumption. The procedure of compiling the list of petroleum exporters and importers is dictated by several conditions. First, the aggregate market indices constituting the largest stocks are considered to prevent issues associated with intraday liquidity of stock prices, particularly in emerging markets. Second, the quarterly components of the aggregate market indices are retrieved form the Datastream database and subsequently utilised to pick sectors following the Thomson Reuters Business Classification standards,[2] which should comprise at least five stocks in every quarter. Third, aggregate market indices should have no less than three sectors with the number of stocks exceeding or equalling five. The set eligibility requirements allow to making sectoral level comparisons within a single as well as multiple markets. The final sample covers five net petroleum exporting economies, such as Brazil, Canada, Mexico, Norway and Russia, and nine net petroleum importing economies, such as Australia, China, Eurozone, India, Japan, South Africa, South Korea, the United Kingdom, and the United States. One should note that the Eurozone comprises six member countries, namely Belgium, France, Germany, Italy, Netherlands and Spain, which are located in the Central European Time zone and have the same stock market trading hours. To capture as many sectors in the European region as possible, markets meeting the above-mentioned criteria were grouped. The aggregate market indices considered in the process of identifying sectors and individual stocks include: BOVESPA, S&P/TSX 60, S&P/BMV IPC, OSEBX, MOEX, S&P/ASX 50, CSI 300, BEL 20, CAC 40, DAX 30, FTSE MIB, AEX, IBEX 35, NIFTY 50, NIKKEI 225, FTSE/JSE TOP 40, KOSPI 50, FTSE 100 and S&P 500.

[1] BP Statistical Review of World Energy 2020.

[2] Given that the chosen stock market indices do not use the same industry classification schemes, the Thomson Reuters Business Classification is adopted with the objective of standardisation.

Table 1: Total number of unique stocks listed between July 31, 2020 to April 30, 2021 in ten sectors of petroleum exporters and importers.

Country/Index		Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	Healthcare	Industrials	Real Estate	Technology	Utilities	Total
Panel A: Petroleum Exporters												
Brazil/BOVESPA	Unique stocks	8	7	9	6	13	-	10	7	-	12	72
	#Obs. per sector	16,058	16,058	16,058	16,058	16,058	-	16,058	16,058	-	16,058	
Canada/S&P TSX 60	Unique stocks	10	5	6	9	10	-	5	-	8	-	53
	#Obs. per sector	14,382	14,382	14,382	14,382	14,382	-	14,382	-	14,382	-	
Mexico/S&P BMV IPC	Unique stocks	5	6	9	-	7	-	-	-	-	-	27
	#Obs. per sector	14,029	14,029	14,029	-	14,029	-	-	-	-	-	
Norway/OSEBX	Unique stocks	-	5	6	13	6	-	-	-	-	-	30
	#Obs. per sector	-	16,592	16,592	16,592	16,592	-	-	-	-	-	
Russia/MOEX	Unique stocks	10	-	-	9	6	-	-	-	6	5	36
	#Obs. per sector	19,552	-	-	19,552	19,552	-	-	-	19,552	19,552	
Panel B: Petroleum Importers												
Australia/S&P ASX 50	Unique stocks	9	-	-	-	10	-	6	7	-	-	32
	#Obs. per sector	10,572	-	-	-	10,572	-	10,572	10,572	-	-	
China/CSI 300	Unique stocks	31	29	24	11	66	29	59	14	53	9	325
	#Obs. per sector	8,687	8,687	8,687	8,687	8,687	8,687	8,687	8,687	8,687	8,687	
Eurozone/MULTIPLE INDICES	Unique stocks	18	22	12	9	34	15	26	8	26	14	184
	#Obs. per sector	19,292	19,292	19,292	19,292	19,292	19,292	19,292	19,292	19,292	19,292	
India/NIFTY 50	Unique stocks	8	7	-	5	11	-	-	-	6	-	37
	#Obs. per sector	13,826	13,826	-	13,826	13,826	-	-	-	13,826	-	
Japan/NIKKEI 225	Unique stocks	31	35	24	-	22	11	60	5	30	5	223
	#Obs. per sector	9,990	9,990	9,990	-	9,990	9,990	9,990	9,990	9,990	9,990	
South Africa/FTSE JSE TOP 40	Unique stocks	11	-	5	-	12	-	-	-	-	-	28
	#Obs. per sector	17,424	-	17,424	-	17,424	-	-	-	-	-	
South Korea/KOSPI 50	Unique stocks	5	8	5	-	7	-	6	-	11	-	42
	#Obs. per sector	12,841	12,841	12,841	-	12,841	-	12,841	-	12,841	-	
United Kingdom/FTSE 100	Unique stocks	13	19	13	5	20	-	12	-	8	-	90
	#Obs. per sector	19,284	19,284	19,284	19,284	19,284	-	19,284	-	19,284	-	
United States/S&P 500	Unique stocks	26	80	39	27	62	61	73	31	83	28	510
	#Obs. per sector	13,950	13,950	13,950	13,950	13,950	13,950	13,950	13,950	13,950	13,950	
Total		**185**	**223**	**152**	**94**	**286**	**116**	**257**	**72**	**231**	**73**	**1689**

Notes: The Eurozone comprises six member countries that use the euro as their official currency, located in the Central European Time zone and have the same trading hours, such as Belgium (BEL 20), France (CAC 40), Germany (DAX 30), Italy (FTSE MIB), Netherlands (AEX) and Spain (IBEX 35). The TRBC standards are followed.

Table 1 exhibits sectors and stocks selected for each petroleum exporting and importing market. There were in total 1,689 unique stocks listed in ten sectors, namely *Basic Materials*, *Consumer Cyclicals*, *Consumer Non-Cyclicals*, *Energy*, *Financials*, *Healthcare*, *Industrials*, *Real Estate*, *Technology* and *Utilities* during the study period. The *Consumer Cyclicals*, *Financials*, *Industrials* and *Technology* sectors stand out with the highest number of stocks in the full sample. It can be distinctly observed that shares of sectors in the composition of aggregate market indices of petroleum exporters and importers are dissimilar, thereby supporting rationality of the sectoral examination in order to obtain a comprehensive picture. The prices of the first nearest futures contracts for Brent grade of crude petroleum, which is among the major benchmarks, traded on the Intercontinental Exchange are used a proxy for the petroleum market.[3] The study utilises the 5-minute frequency of data to compute intraday volatilities of sector indices and petroleum. It has been documented that the selected frequency is optimal for sampling considering microstructure noise and estimation precision (Sevi, 2014; Liu et al., 2015; Xu et al., 2019; among others). In addition, the intraday data permits to tackle challenges associated with the sample size in the post global health crisis period. The 5-minute opening, high, low and closing prices of the ICE Brent crude petroleum futures contracts and individual stocks are extracted from the Refinitiv Eikon database. Given that crude petroleum sorts are traded in US dollars, stock prices, expressed in national currencies, were converted to US dollars using intraday exchange rates. The sample spans the period from July 31, 2020 to April 30, 2021. As indicated in Table 1, sectors in Russia, the Eurozone and United Kingdom, after the data cleaning processes explained in the next subsection, have the greater number of observations, and hence, more trading hours and days.

2.2. Data cleaning procedures

Prior to the manual construction of stock sector indices for petroleum exporting and importing countries and estimation of the empirical model, the study undertakes several actions to resolve constraints related to non-synchronous trading hours and non-matching observations. The critical role of trading details' synchronisation is emphasised by studies of Schotman and Zalewska (2006), Mateus et al. (2017) and Kuang (2022). Therefore, overlapping trading hours are considered to accurately analyse dynamics of volatility transmissions.

[3] The advantages of Brent over the other marker sort as WTI are discussed in the study of Batten et al. (2021).

Table 2: Trading hours of the stock markets and ICE Brent crude petroleum futures in local times (Standard Time).

Market	Opening Time	Closing Time	Break	Trading Hours
Petroleum Exporters				
Brazil/Sao Paulo	10:00	17:55	-	7 hrs 55 min
Canada/Toronto	09:30	16:00	-	6 hrs 30 min
Mexico/Mexico City	08:30	15:00	-	6 hrs 30 min
Norway/Oslo	09:00	16:20	-	7 hrs 20 min
Russia/Moscow	10:00	18:40	-	8 hrs 40 min
Petroleum Importers				
Australia/Sydney	10:00	16:00	-	6 hrs
China/Shanghai	09:30	15:00	11:30 - 13:00	4 hrs
Eurozone	09:00	17:30	-	8 hrs 30 min
India/Mumbai	09:15	15:30	-	6 hrs 15 min
Japan/Tokyo	09:00	15:00	11:30 - 12:30	5 hrs
South Africa/Johannesburg	09:00	17:00	-	8 hrs
South Korea/Busan	09:00	15:30	-	6 hrs 30 min
UK/London	08:00	16:30	-	8 hrs 30 min
US/New York	09:30	16:00	-	6 hrs 30 min
ICE Brent Crude Futures				
New York	20:00	18:00*	-	22 hrs
London	01:00	23:00	-	22 hrs
Singapore	09:00	07:00*	-	22 hrs

Notes: * denotes closing times on the next day. Due to DST, the stock market in Brazil (Sao Paulo) is open 6 hours 55 minutes from 10:00 to 16:55, and trading hours of the ICE Brent crude petroleum futures in local time of Singapore run from 08:00 to 06:00 next day. After-hours trading on the Russian stock exchange from 19:00 to 23:50 is not considered.

Table 2 presents local opening, closing and break times for petroleum and studied stock markets. The ICE Brent crude petroleum futures are traded for 22 hours on the Intercontinental Exchange, with trading hours quoted in local times of Singapore, London and New York. Thus, in order to ease the synchronisation process, trading hours of petroleum in each of three locations are employed for corresponding stock markets from nearby regions. More precisely, Singapore trading hours for Asian and Oceanian stock markets, London trading hours for European and African stock markets, and New York trading hours for North and South American stock markets. Table 3 displays trading times of stock markets under local times of the ICE Brent crude petroleum futures during both Standard Time (ST) and Daylight Saving Time (DST).[4] It can be seen that opening and closing times of majority stock markets are always within trading hours of the ICE Brent crude petroleum futures, irrespective of the

[4] Fig. D1 in Appendix depicts timelines of trading hours of stock markets and petroleum produced based on the information provided in Table 3.

region, thereby pointing to the possibility of analysing overlapping values. However, there are some exceptions. First, the ICE Brent crude petroleum futures are traded from 09:00 to 07:00 and 08:00 to 06:00 next day in local time of Singapore when ST and DST are observed, respectively. Second, as a consequence, opening times of trading sessions in stock markets of Australia, Japan and South Korea do not align with those of the petroleum market only during ST. The difference between opening times is one hour for Japan and South Korea, and two hours for Australia, because of ST in the petroleum market trading location falling under DST in the country. Given the noncontinuous trading with relatively low volume and count during the last two hours of preceding sessions in the petroleum market, instead of utilising lagged values, 5-minute stock prices related to the first one and two hours of trading sessions are excluded. It is worth mentioning that in Mexico (Mexico City) the transition to ST starts earlier and to DST later than in the Unites States (New York), which leads to a two-hour difference in trading times between petroleum and stock markets during several weeks in autumn and spring. In addition, trading sessions on the Brazilian stock market last 6 hours and 55 minutes during DST.

After conversion of petroleum futures trading hours to local times of each market, taking into account time differences due to ST and DST, and exclusion of non-overlapping values, the process of matching observations across petroleum and stock markets is still encumbered with difficulties for the following reasons: national holidays, temporary changes in trading hours and lunch breaks. Hence, 5-minute series require some additional adjustments. Specifically, if stock prices are not available on a specific day and/or time, corresponding petroleum prices are removed, and vice versa. These steps are also followed when grouping stocks from the Eurozone markets. Furthermore, infrequent anomalies in stock prices are replaced by previous minute figures.

Table 3: Stock markets' trading hours in local times of the ICE Brent crude petroleum futures contracts.

Market	Trading Times (ST)	Break	Trading Times (DST)	Break
Location - Singapore				
ICE Brent Crude	09:00 - 07:00*		08:00 - 06:00*	
Australia/Sydney	07:00 - 13:00	-	08:00 - 14:00	-
China/Shanghai	09:30 - 15:00	11:30 - 13:00	09:30 - 15:00	11:30 - 13:00
India/Mumbai	11:45 - 18:00	-	11:45 - 18:00	-
Japan/Tokyo	08:00 - 14:00	10:30 - 11:30	08:00 - 14:00	10:30 - 11:30
South Korea/Busan	08:00 - 14:30	-	08:00 - 14:30	-
Location - London				
ICE Brent Crude	01:00 - 23:00		01:00 - 23:00	
Eurozone	08:00 - 16:30	-	08:00 - 16:30	-
Norway/Oslo	08:00 - 15:20	-	08:00 - 15:20	-
Russia/Moscow	07:00 - 15:40	-	08:00 - 16:40	-
South Africa/Johannesburg	07:00 - 15:00	-	08:00 - 16:00	-
UK/London	08:00 - 16:30	-	08:00 - 16:30	-
Location - New York				
ICE Brent Crude	20:00 - 18:00*		20:00 - 18:00*	
Brazil/Sao Paulo	08:00 - 15:55	-	09:00 - 15:55	-
Canada/Toronto	09:30 - 16:00	-	09:30 - 16:00	-
Mexico/Mexico City	09:30 - 16:00	-	10:30 - 17:00	-
US/New York	09:30 - 16:00	-	09:30 - 16:00	-

Notes: * denotes closing times on the next day. The ICE Brent crude petroleum futures trading times in Singapore, London and New York are used for stock markets located in Asia and Oceania, Europe and Africa, North and Latin America regions, respectively. The converted trading time of the stock market in Mexico (Mexico City) during DST only lasts a few weeks in spring and autumn due to minor differences in time transition periods. ST observed in the petroleum market trading location falls under DST in Australia (Sydney), which runs from October to April, and vice versa.

2.3. Estimation of volatility, construction of sector indices and preliminary analysis

Given the importance of the industry level investigation of volatility interactions, but at the same time the unavailability of sector indices for this purpose, the present work adopts the unique approach of Mateus et al. (2017) to manually construct sector indices for petroleum exporting and importing countries. First, the analytic scale-invariant estimator of Garman and Klass (1980), which requires opening, high, low and closing values, is employed to quantify volatilities of studied assets. The estimator copes with high frequency data well (Mateus et al., 2017), and has been reported to perform better than other range-based estimators of volatility (Molnar, 2012; Arneric et al. 2019). In addition, the previous literature focusing on the volatility connectedness between different assets have widely applied this estimator (Diebold and Yilmaz, 2009; Awartani and Maghyereh, 2013; Ahmad, 2017; Costola and Lorusso; 2022; among others). The variance of the *i*th stock in the petroleum exporting and importing country (or petroleum) at time *t* is computed based on the analytic scale-invariant estimator of Garman and Klass, expressed as:

$$\sigma^2_{GK,i,t} = 0.511\left[log\left(\frac{h_{i,t}}{l_{i,t}}\right)^2\right] - 0.019\left[log\left(\frac{c_{i,t}}{o_{i,t}}\right)log\left(\frac{h_{i,t}l_{i,t}}{o^2_{i,t}}\right) - 2log\left(\frac{h_{i,t}}{o_{i,t}}\right)log\left(\frac{l_{i,t}}{o_{i,t}}\right)\right] - 0.383\left[log\left(\frac{c_{i,t}}{o_{i,t}}\right)^2\right] \quad (1)$$

where, open, high, low and close prices of the *i*th stock in the petroleum exporting and importing country (or Brent crude petroleum futures contracts) at the *t*th 5-minute interval of time are represented by $o_{i,t}$, $h_{i,t}$, $l_{i,t}$ and $c_{i,t}$, respectively.

Second, calculated variances of stocks and petroleum are utilised to obtain annualised volatility figures at time *t*, given as:

$$\sigma_{AV,i,t} = \sqrt{\sigma^2_{GK,i,t}nm} \quad (2)$$

where, *n* signifies the number of trading days in a year, totalling to 252, and *m* refers to the amount of trading minutes in each stock market, which remains the same irrespective of early closures on certain days prior to national holidays. For instance, the session of 6 hours 30 minutes on the Mexican stock market equals to 78 trading minutes given the 5-minute interval. In the case of petroleum, since only overlapping values are considered, *m* is based on the number of trading minutes in the corresponding stock market.

Third, $\sigma_{AV,i,t}$ values associated with individual stocks at time *t* are merged to produce annualised volatilities for each sector of petroleum exporting and importing country during the same time *t*. To this end, following Mateus et al. (2017), the study makes a use of the Markowitz's (1952) modern portfolio theory in order to derive the variance of the *i*th sector index (portfolio) as:

$$\sigma^2_{IDX,i,t} = \sum_i \omega^2_{i,t}\,\sigma^2_{i,t} + \sum_i \sum_{j\neq i} \omega_{i,t}\,\omega_{j,t}\sigma_{i,t}\sigma_{j,t}\rho_{ij,t} \quad (3)$$

where, $\rho_{ij,t}$ refers to the correlation coefficient between stocks, $\omega_{i,t}$ and $\sigma_{i,t}$ denote the weight and annualised volatility of the *i*th stock, respectively. Hence, the square root of $\sigma^2_{IDX,i,t}$

represents the *i*th sector index (portfolio) volatility at time *t*. The equal weights are assigned to all stocks within the *i*th sector index (portfolio). The correlation coefficients among constituents of the *i*th sector index (portfolio) are calculated employing initial seven days of 5-minute data and remain constant. Given that correlations tend to exhibit a dynamic nature, this could be regarded as a limitation. However, it should be emphasised that the *i*th sector index (portfolio) is rebalanced every quarter when there are joining or leaving stocks by updating correlation coefficients and weights.

Tables 4 and 5 report the selective descriptive statistics of 5-minute volatilities for Brent crude petroleum futures and manually built sector indices of petroleum exporting and importing countries. On average, the highest intraday volatilities are observed for Brent crude petroleum, and sector indices of Brazil and South Korea. Conversely, sector indices of Canada and Japan display the lowest average intraday volatilities among petroleum exporters and importers, respectively. The series have positive skewness and kurtosis above the value of three in all cases, pointing to presence of heavy tails. The Augmented Dickey-Fuller unit root test, where the selection of lags is based on the Schwarz Bayesian Criterion, indicates that all the series are stationary at the significance level of 1%, and hence, they can be utilised in the further analyses.[5]

[5] The series are also found to be stationary when the number of lags is chosen using the Akaike Information Criterion.

Table 4: Descriptive statistics of 5-minute volatilities for Brent crude petroleum futures and sector indices of petroleum exporters and importers.

Panel A: Petroleum Exporters		**Brent**	**Basic Materials**	**Consumer Cyclicals**	**Consumer Non-Cyclicals**	**Energy**	**Financials**	**Healthcare**	**Industrials**	**Real Estate**	**Technology**	**Utilities**
Brazil	Mean (%)	19.6018	23.7872	28.2779	20.0024	26.5576	21.2053	-	24.7987	28.2512	-	20.3628
	Skewness	2.0883	3.2876	2.0733	2.6049	2.4715	2.1016	-	1.9515	1.8830	-	1.9478
	Kurtosis	14.3837	36.0788	10.2298	21.0322	15.9251	11.7521	-	9.4443	9.8550	-	9.3797
	ADF	-23.3964**	-30.5527**	-26.2223**	-27.5089**	-24.0580**	-27.5104**	-	-27.9904**	-26.9576**		-28.9456**
Canada	Mean (%)	17.3247	12.3452	9.4323	6.4289	13.8432	7.9157	-	7.8684	-	6.8676	-
	Skewness	2.1800	3.4790	4.4346	5.2470	4.0122	4.0761	-	4.9979	-	3.6829	-
	Kurtosis	15.4637	23.3293	37.9780	55.6131	37.2769	39.7731	-	60.7412	-	25.0882	-
	ADF	-23.3565**	-26.5092**	-28.3755**	-29.3589**	-26.8916**	-26.1867**	-	-26.9367**	-	-26.7398**	-
Mexico	Mean (%)	16.9527	13.8228	12.3476	9.7039	-	11.1657	-	-	-	-	-
	Skewness	2.2674	2.5430	2.7507	5.7708	-	2.4947	-	-	-	-	-
	Kurtosis	16.7970	16.4728	22.8865	75.2461	-	14.5917	-	-	-	-	-
	ADF	-23.4658**	-29.1281**	-30.1418**	-27.3388**	-	-29.3468**	-	-	-	-	-
Norway	Mean (%)	17.9359	-	14.1896	8.4961	12.7881	8.6063	-	-	-	-	-
	Skewness	2.0865	-	4.4082	4.1357	3.7475	3.5243	-	-	-	-	-
	Kurtosis	13.0097	-	39.0219	33.7504	25.4929	25.8542	-	-	-	-	-
	ADF	-18.3685**	-	-25.9139**	-29.3857**	-23.9862**	-25.3006**	-	-	-	-	-
Russia	Mean (%)	19.8771	11.0222	-	-	12.7550	12.3663	-	-	-	12.4858	10.1720
	Skewness	2.2310	4.2594	-	-	2.6560	3.7176	-	-	-	3.4451	2.7011
	Kurtosis	15.3438	43.5822	-	-	17.4783	32.1206	-	-	-	26.7949	16.3410
	ADF	-20.2244**	-22.4754**	-	-	-20.1779**	-21.2198**	-	-	-	-21.8855**	-23.8875**

Panel B: Petroleum Importers		Brent	Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	Healthcare	Industrials	Real Estate	Technology	Utilities
Australia	Mean (%)	7.3701	8.8886	-	-	-	9.8165	-	12.2706	14.9172	-	-
	Skewness	3.2623	2.8480	-	-	-	3.2478	-	2.5051	2.3196	-	-
	Kurtosis	31.4766	17.0467	-	-	-	22.4584	-	15.1219	17.8481	-	-
	ADF	-22.1934**	-28.4391**	-	-	-	-26.1198**	-	-24.7665**	-28.2701**	-	-
China	Mean (%)	6.8695	18.6706	15.0175	16.9834	18.2098	16.6382	17.2409	13.0995	16.6930	16.0918	15.6978
	Skewness	2.9988	2.3833	2.4282	2.7409	2.6382	2.1113	2.5267	2.5250	2.7839	2.4516	2.8317
	Kurtosis	36.1343	11.6666	11.7545	14.1901	14.7535	10.1977	12.4962	12.3841	15.8305	12.1586	17.4453
	ADF	-17.4887**	-21.3016**	-24.3606**	-24.6330**	-22.2036**	-22.0367**	-25.7876**	-24.1440**	-23.5068**	-23.7215**	-21.4089**
Eurozone	Mean (%)	20.4550	8.9304	10.6480	7.5139	14.5089	13.5180	9.6266	10.6215	9.3199	9.6586	8.7822
	Skewness	2.2929	3.4792	3.4942	3.8309	3.2180	3.3969	3.5047	3.8511	3.8509	3.4431	3.5904
	Kurtosis	16.2913	23.8056	24.2808	30.2405	22.4796	24.6062	21.7145	28.4399	26.6814	22.9086	24.9505
	ADF	-18.9488**	-26.6880**	-21.7664**	-22.4394**	-22.4538**	-21.2754**	-27.2468**	-28.5774**	-25.9758**	-25.4004**	-31.0217**
India	Mean (%)	11.0302	15.2444	16.3303	-	16.1923	16.9703	-	-	-	15.9796	-
	Skewness	1.6579	2.8394	3.0281	-	3.1490	2.9600	-	-	-	3.8141	-
	Kurtosis	8.8777	17.7388	18.8818	-	22.9529	19.6882	-	-	-	36.0191	-
	ADF	-20.4124**	-23.5274**	-24.2869**	-	-24.6221**	-21.4097**	-	-	-	-24.9217**	-
Japan	Mean (%)	6.7287	7.7787	8.7454	6.4120	-	8.5653	7.7437	7.2591	13.1187	7.2962	11.3512
	Skewness	3.2327	4.1678	4.0257	4.0770	-	3.9392	4.9182	3.9811	3.8539	3.4265	2.9666
	Kurtosis	31.3899	32.7759	30.5247	31.8980	-	30.4525	51.7787	30.1770	29.4665	22.3050	18.3139
	ADF	-21.5270**	-33.7860**	-33.6265**	-34.2901**	-	-25.8505**	-27.4749**	-33.1256**	-27.8463**	-24.6818**	-31.2253**
South Africa	Mean (%)	18.4333	19.3158	-	12.5175	-	17.1109	-	-	-	-	-
	Skewness	2.1652	2.7995	-	4.8934	-	3.2312	-	-	-	-	-
	Kurtosis	13.2956	16.6168	-	47.4547	-	20.2883	-	-	-	-	-
	ADF	-20.0930**	-19.5209**	-	-23.7363**	-	-21.0154**	-	-	-	-	-
South Korea	Mean (%)	7.9235	17.6431	18.5066	16.8777	-	17.5686	-	19.4114	-	14.2827	-
	Skewness	3.0644	2.7547	3.1821	2.6429	-	3.4498	-	2.6920	-	2.3751	-
	Kurtosis	28.3527	17.8930	24.0700	18.0664	-	27.8101	-	19.6249	-	13.8951	-
	ADF	-19.8652**	-23.5026**	-22.2325**	-22.2215**	-	-22.4185**	-	-18.5227**	-	-20.2051**	-
United Kingdom	Mean (%)	20.4669	11.0528	11.8134	9.0807	18.7755	11.9138	-	12.6128	-	9.6749	-
	Skewness	2.2927	6.3035	5.6993	6.4654	4.3306	6.1483	-	6.5093	-	7.4200	-
	Kurtosis	16.2738	109.5095	61.1197	96.4938	44.7456	87.9338	-	89.0848	-	153.0436	-
	ADF	-18.9608**	-25.6224**	-32.5340**	-28.5832**	-24.2550**	-27.6839**	-	-23.8279**	-	-34.5482**	-
United States	Mean (%)	17.3717	10.4767	13.4766	7.6251	26.4237	15.1900	9.7238	9.8617	12.0406	10.2664	11.1553
	Skewness	2.2006	3.2726	3.4097	3.2173	3.0936	3.2715	3.5415	3.1878	4.4781	2.8762	3.3951
	Kurtosis	15.6137	21.4642	27.1465	21.8998	20.5868	21.4918	26.7762	20.3493	46.5684	16.7753	26.0108
	ADF	-23.5388**	-25.1422**	-25.0765**	-24.7865**	-24.4384**	-24.6917**	-24.3925**	-24.0452**	-24.8091**	-23.2736**	-24.3508**

Notes: ADF refers to the Augmented Dickey-Fuller unit root test. ** indicates the significance level at 1%.

2.4. Empirical model

The current study makes a use of the framework introduced by Diebold and Yilmaz (2012), which grounds on the generalised VAR model, to measure intraday static and time-varying bilateral volatility spillovers between petroleum and self-constructed stock sectors indices of petroleum exporters and importers. Awartani and Maghyereh (2013) emphasise a number of advantages that the approach possesses: (i) in contrast to the earlier version (Diebold and Yilmaz, 2009), which depends on the Cholesky factorisation, the generated variance decompositions are unresponsive to variables' sequence; (ii) it enables to quantify the intensity of gross and net bidirectional transmissions of volatility among numerous asset classes in the system; and lastly (iii) it facilitates the analysis of fluctuations in volatility spillovers over time through the rolling window. The efficient performance of this approach in examining intraday volatility interdependencies among different markets has been documented in recent works (Xu et al., 2019; Farid et al., 2021; Suleman et al., 2021).

Consider first the covariance stationary VAR process with the *p*-lag length and *N*-variables that is expressed in the following form:

$$V_t = \sum_{i=1}^{p} \Phi_i V_{t-i} + \varepsilon_t \tag{4}$$

where, V_t refers to the $N \times 1$ vector of volatility series for petroleum and stock sector indices at time *t*, Φ_i signifies the $N \times N$ matrix of autoregressive parameters, $\varepsilon_t \sim (0,\Sigma)$ denotes the vector of i.i.d. error terms. The moving average representation of the fourth equation is expressed as follows:

$$V_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i} \tag{5}$$

where, A_i refers to the $N \times N$ matrices of parameters that conform the recursion of the form $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p}$, with A_0 representing the $N \times N$ identity matrix and A_i equalling zero for $i < 0$. The parameters' transformation in the above representation of the VAR process permits the identification of variance decompositions. Diebold and Yilmaz (2012) employ the generalised VAR framework of Koop et al. (1996) and Pesaran and Shin (1998) in order to eliminate the dependence of variance decompositions on the variables' ordering.

The variance decompositions contribute to the evaluation of both own and cross variance shares, or transmissions, where the first are explained as the portions of the H-step-ahead error variances in predicting the variables V_i, which are because of shocks to the same variables V_i, for $i = 1,2,3, \dots, N$, and the latter are interpreted as the portions of the H-step-ahead error variances in predicting the variables V_i, which are because of shocks to the other variables V_j, for $i, j = 1,2,3, \dots, N$, so that $i \neq j$. The H-step-ahead generalised forecast error variance decompositions, signified by $\theta_{ij}^{g}(H)$, for $H = 1,2,3, \dots, N$, are given as:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)^2} \tag{6}$$

where, Σ denotes the variance matrix for the vector of error term ε, σ_{jj} refers to the error terms' standard deviation for the *j*th equation and e_i represents the selection vector, where the *i*th element equals to one and the remainders equal to zero. Since the shocks are not restricted to be orthogonal, the elements' sum in each row does not necessarily add up to unity, that is $\sum_{j=1}^{N} \theta_{ij}^{g}(H) \neq 1$. The further normalisation of the third equation is specified as:

$$\tilde{\theta}_{ij}^{g}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \tag{7}$$

where, one should note that $\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H) = N$. The generalised variance decomposition contributions are utilised to build the total volatility spillover index as follows:

$$S^{g}(H) = \frac{\sum_{i,j=1, i\neq j}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{i,j=1, i\neq j}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \times 100 \tag{8}$$

The constructed index estimates the average contribution to the total forecast error variance of volatility transmissions among petroleum and stock sectors. Furthermore, the approach of Diebold and Yilmaz (2012) allows to measure the direction of volatility spillovers between the studied assets. Thus, the directional volatility transmission received by the variable *i*, that is, the *i*th stock sector index (or petroleum), from all variables *j*, that is, *j*th stock sector indices and petroleum (or stock sector indices), referred to as "From Others", and the directional volatility transmission from the variable *i*, that is, the *i*th stock sector index (or petroleum), to all variables *j*, that is, *j*th stock sector indices and petroleum (or stock sector indices), referred to as "To Others", are computed as:

$$S_{i\leftarrow *}^{g}(H)=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N}\tilde{\theta}_{ij}^{g}(H)}\times 100=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ij}^{g}(H)}{N}\times 100 \qquad (9)$$

and

$$S_{i\rightarrow *}^{g}(H)=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N}\tilde{\theta}_{ji}^{g}(H)}\times 100=\frac{\sum_{j=1,j\neq i}^{N}\tilde{\theta}_{ji}^{g}(H)}{N}\times 100 \qquad (10)$$

The net directional volatility transmission, which is the difference between gross figures of "To Others" and "From Others", is measured as:

$$S_{i}^{g}(H)=S_{i\rightarrow *}^{g}(H)-S_{i\leftarrow *}^{g}(H) \qquad (11)$$

Lastly, the net pairwise volatility transmission is derived as:

$$S_{ij}^{g}(H)=\left(\frac{\tilde{\theta}_{ji}^{g}(H)}{\sum_{i,k=1}^{N}\tilde{\theta}_{ik}^{g}(H)}-\frac{\tilde{\theta}_{ij}^{g}(H)}{\sum_{j,k=1}^{N}\tilde{\theta}_{jk}^{g}(H)}\right)\times 100=\left(\frac{\tilde{\theta}_{ji}^{g}(H)-\tilde{\theta}_{ij}^{g}(H)}{N}\right)\times 100 \qquad (12)$$

The twelfth equation simply quantifies the difference, for instance, between the gross volatility spilling from petroleum to the *i*th stock sector index and those transmitting from the *i*th stock sector index to petroleum.

3. Empirical results

This section summarises empirical findings obtained from estimating the Diebold and Yilmaz (2012) framework. First, the static volatility interdependencies are reported. Second, the constructed spillover networks indicating net volatility transmitters and receivers are presented. Third, the dynamic nature of total, net directional and pairwise volatility transmissions are discussed.

3.1. Static volatility transmissions

Tables 5 (panels A to E) and 6 (panels A to I) report the total static volatility spillovers between petroleum and sector indices of petroleum exporting and importing countries. The bolded diagonal elements of the table provide information on own contributions of petroleum and stock sector indices. The off-diagonal values, which are of special interest, exhibit pairwise directional volatility spillovers between the studied variables. More specifically, the row marked "To Others", which sums the off-diagonal column figures, shows the total directional volatility spillover from the *i*th stock sector index (or petroleum) to *j*th stock sector indices and petroleum (or all stock sector indices). Similarly, the column marked "From Others", which sums the off-diagonal row figures, indicates the total directional volatility spillover received by the *i*th stock sector index (or petroleum) from *j*th stock sector indices and petroleum (or all stock sector indices). The row marked "Net", which is the difference between "To Others" and "From Others", displays the total net directional volatility spillover, where positive and negative figures point to net-transmitters and net-receivers, respectively. Lastly, the total volatility spillover in the entire system is signified by "TSI" at the bottom right corner of the table.

The average figures of total volatility spillover indices (TSI) are fairly high, exceeding 50% in most cases, with the exception Mexico, Norway, Russia, Australia and South Africa where moderate values are obtained, which points to the strong connectedness between volatilities of petroleum and sector indices of petroleum exporting and importing countries during the post global health crisis period. The own contributions of petroleum and stock sector indices, although not the primary focus of this study, are relatively large. In both groups of countries, the sector indices of Mexico, Australia and South Africa are more influenced by their own shocks to volatilities. Moving to the off-diagonal elements of the tables associated with petroleum exporting countries, one can observe from the row "To Others" that Brent crude petroleum transmits a greater portion of volatility to sector indices of Norway (20.1%) and Russia (15.1%). The spillovers of volatility from Brent crude petroleum to sector indices of Canada, Brazil and Mexico are lower in magnitude, amounting to 9.4%, 7.6% and 4.9%, respectively. As expected, the *Energy* sectors of Canada, Norway and Russia are the major recipients of petroleum volatility. In the case of Brazil and Mexico, the most affect sectors are *Basic Materials* and *Consumer Non-Cyclicals*. Conversely, the column "From Others" shows that the sectors of Canada, Brazil and Mexico exhibit larger effects on the volatility of Brent crude petroleum, equalling to 61.4%, 27.7% and 14.6%, respectively, whereas contributions from sectors of Norway (3.6%) and Russia (4.8%) are smaller. In particular, the *Financials* sector of Canada (10.14%), *Industrials* sector of Brazil (4.96%), *Basic Materials* sectors of Mexico (4.64%) and Russia (1.46%), and *Energy* sector of Norway (1.21%) are the main transmitters of volatility to petroleum in each system. Thus, the differences between "To Others" and "From Others" values indicate that Brent crude petroleum is the net-recipient of volatility from sectors of Brazil, Canada and Mexico, but acts as the net-transmitter of volatility to sectors of Norway and Russia over the post pandemic period. This outcome highlights the significance of information originating from sectors of the first three exporters for the petroleum market, which could be attributed to the facts that Canada and Mexico cut petroleum production by a smaller amount than other large OPEC and non-OPEC producers, while Brazil retained an increase in petroleum production during 2020.[6] In addition, the high dependency on petroleum revenues of the latter two exporters provide a plausible elucidation for the greater exposure of sectors to petroleum risk.[7] Generally, the obtain results for petroleum exporters are partially in line with the studies of Maghyereh et al. (2016), Gomez-Gonzalez et al. (2020), Zhang et al. (2021), Cui et al. (2021) and Mensi et al. (2021d) that focus on aggregate market indices, utilise different data frequencies and analysis periods.

Turning to the off-diagonal figures of the tables related to petroleum importing countries, the row "To Others" shows that Brent crude petroleum accounts for variations of 24.9%, 23% and 22.5% in volatilities of sectors belonging to the Eurozone, South Africa and the United Kingdom, respectively. The sectors indices of the remaining countries receive a smaller portion of volatility from Brent crude petroleum, ranging between 1.6% for Australia and 14.2% for India. In individual systems, petroleum mostly impacts the *Basic Materials* sectors of Australia (0.75%), South Korea (2.41%) and South Africa (9.14%), *Energy* sectors of the Eurozone

[6] In 2020, petroleum production dropped by approximately 4.5% in Canada and 0.5% in Mexico, but rose by 4.9% in Brazil according to the BP Statistical Review of World Energy 2022.
[7] For details see: World Bank, https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS

(2.93%) and United Kingdom (4.6%), *Technology* sectors of Japan (0.95%) and India (3.3%), *Energy* and *Industrials* sectors of the United States (1.12% and 1.13%, respectively), and *Utilities* sector of China (0.32%). As indicated in the column "From Others", the volatility spillovers in the reverse direction are stronger from sectors of Japan (22.4%), India (40%) and the United States (70.2%) to Brent crude petroleum, but less intense in other cases, not exceeding 10%. Specifically, the major volatility contributors towards petroleum in each market are the *Energy* sectors of China (0.46%), the United Kingdom (2.21%) and Eurozone (2.66%), *Consumer Non-Cyclicals* sectors of South Africa (3.49%) and the United States (7.7%), *Financials* and *Industrials* sectors of Japan (both 2.74%), *Basic Materials* sector of Australia (1.62%), *Consumer Cyclicals* sector of India (11.01%), and *Financials* sector of South Korea (2.18%). The row "Net" displays that Brent crude petroleum possesses the net position in terms of transmitting volatility to sectors of South Africa, South Korea, the Eurozone and United Kingdom, implying that sectors' sensitivities in these importing countries to petroleum uncertainty persisted during the post global health crisis period. However, petroleum is the net-receiver of volatility spilling from sectors of Australia, China, India, Japan and the United States, emphasising their important roles as major petroleum consumers. The documented findings are consistent, although moderately, with those of Cui et al. (2021), Benlagha and El Omari (2022), Zhang and Hamori (2021), and Zhang et al. (2021) that consider effects of the pandemic. It is worth noting that between two top petroleum importers, the magnitude of volatility spillovers from petroleum to sectors is low for China and from sectors to petroleum is high for the United States. The Chinese stock market appears to be relatively resilient to the petroleum market disturbances, which is also the case prior (Xu et al., 2019) and during the pandemic (Heinlein et al., 2021). The figures associated with the United States stock market are not surprising given that the country is a major petroleum producer at the same time.

Among sector indices of petroleum exporters, the highest total contributions of volatility to each system are detected from the *Utilities* sector of Brazil, *Financials* sectors of Canada and Mexico, *Energy* sectors of Norway and Russia, while in the case of petroleum importers, from *Consumer Cyclicals* sectors of India, South Korea and the United Kingdom, *Industrials* sectors of China, Japan and the Eurozone, *Basic Materials* sectors of Australia and South Africa, and *Healthcare* sector of the United States. Unsurprisingly, these sectors are also found to be the biggest net-transmitters of volatility, with the exception Japan and South Korea, where the *Financials* sectors are the main net-contributors. Interestingly, in the group of petroleum exporters, the *Basic Materials* sectors of Brazil, Canada and Mexico, *Consumer Cyclicals* sector of Norway, and *Utilities* sector of Russia are the major net-receivers of volatility. For petroleum importers, they are the *Energy* sectors of India, the United Kingdom and United States, *Utilities* sectors of China and Japan, *Industrials* sector of Australia, *Real Estate* sector of the Eurozone, *Financials* sector of South Africa, and *Basic Materials* sector of South Korea.

Table 5: Static volatility spillovers between Brent crude petroleum and sector indices of petroleum exporting countries.

Panel A: Brazil	**Brent**	**Basic Materials**	**Consumer Cyclicals**	**Consumer Non-Cyclicals**	**Energy**	**Financials**	**Industrials**	**Real Estate**	**Utilities**	**From Others**
Brent	**72.31**	2.64	2.7	3.36	2.33	3.55	4.96	4.13	4.02	27.7
Basic Materials	0.76	**23.95**	8.94	12.87	11.17	10.86	10.28	9.58	11.59	76.1
Consumer Cyclicals	0.59	7.75	**22.67**	12.16	9.36	11.42	12.13	11.95	11.97	77.3
Consumer Non-Cyclicals	0.6	8.57	9.87	**26.69**	10	11.2	10.44	10.25	12.36	73.3
Energy	0.69	8.9	8.84	11.47	**25.1**	12.6	10.86	9.7	11.83	74.9
Financials	0.58	7.8	9.65	11.45	10.95	**23.17**	12.51	11.06	12.83	76.8
Industrials	0.63	7.52	10.57	11.6	9.45	13	**22.64**	11.94	12.64	77.4
Real Estate	0.52	6.62	11.2	11.06	8.73	11.92	12.21	**25.44**	12.31	74.6
Utilities	0.57	6.63	8.87	11.17	9.2	12.62	11.47	10.61	**28.86**	71.1
To Others	4.9	56.4	70.6	85.1	71.2	87.2	84.9	79.2	89.6	629.2
Including Own	77.2	80.4	93.3	111.8	96.3	110.3	107.5	104.7	118.4	TSI=69.90%
Net	-22.8	-19.7	-6.7	11.8	-3.7	10.4	7.5	4.6	18.5	

Panel B: Canada	**Brent**	**Basic Materials**	**Consumer Cyclicals**	**Consumer Non-Cyclicals**	**Energy**	**Financials**	**Industrials**	**Technology**	**From Others**
Brent	**38.62**	7.9	7.92	8.3	9.67	10.14	7.8	9.65	61.4
Basic Materials	1.39	**19.34**	12.71	13.22	12.29	14.93	11.96	14.16	80.7
Consumer Cyclicals	1.26	11.71	**21.18**	12.71	12.22	14.68	12.18	14.05	78.8
Consumer Non-Cyclicals	1.3	11.43	12.19	**23.65**	11.75	14.33	11.83	13.52	76.3
Energy	1.56	11.82	12.77	12.65	**20**	15.53	12.12	13.54	80
Financials	1.23	11.64	12.95	13.02	12.87	**21.7**	12.47	14.12	78.3
Industrials	1.33	10.86	12.38	12.51	11.59	14.14	**23.28**	13.91	76.7
Technology	1.3	11.4	12.58	13.23	11.42	14.71	12.73	**22.63**	77.4
To Others	9.4	76.7	83.5	85.6	81.8	98.5	81.1	93	609.6
Including Own	48	96.1	104.7	109.3	101.8	120.2	104.4	115.6	TSI=76.20%
Net	-52	-4	4.7	9.3	1.8	20.2	4.4	15.6	

Panel C: Mexico	Brent	Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Financials	From Others
Brent	**85.39**	4.64	3.04	3.2	3.73	14.6
Basic Materials	1.79	**71.38**	6.44	10.98	9.41	28.6
Consumer Cyclicals	1.79	5.73	**78.24**	6.69	7.55	21.8
Consumer Non-Cyclicals	2.53	8.68	5.46	**75.58**	7.76	24.4
Financials	1.52	4.97	4.57	6.25	**82.68**	17.3
To Others	7.6	24	19.5	27.1	28.4	106.7
Including Own	93	95.4	97.8	102.7	111.1	TSI=21.30%
Net	-7	-4.6	-2.3	2.7	11.1	

Panel D: Norway	Brent	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	From Others
Brent	**96.39**	1.11	0.69	1.21	0.61	3.6
Consumer Cyclicals	3.17	**51.28**	13.78	18.27	13.5	48.7
Consumer Non-Cyclicals	4.93	11.64	**45.38**	22.29	15.77	54.6
Energy	6.85	12.92	17.8	**45.3**	17.12	54.7
Financials	5.16	11.2	15.77	21.21	**46.66**	53.3
To Others	20.1	36.9	48	63	47	215
Including Own	116.5	88.2	93.4	108.3	93.7	TSI=43.00%
Net	16.5	-11.8	-6.6	8.3	-6.3	

Panel E: Russia	Brent	Basic Materials	Energy	Financials	Technology	Utilities	From Others
Brent	**95.24**	1.46	1.27	0.97	0.3	0.77	4.8
Basic Materials	2.19	**43.52**	16.08	14.32	11.75	12.13	56.5
Energy	4.35	15.01	**42.82**	14.64	11.27	11.91	57.2
Financials	1.77	15.67	16.5	**42.59**	12.36	11.12	57.4
Technology	3.59	12.05	12.28	11.47	**51.61**	9.01	48.4
Utilities	3.18	13.06	13.17	11.07	9.99	**49.53**	50.5
To Others	15.1	57.2	59.3	52.5	45.7	44.9	274.7
Including Own	110.3	100.8	102.1	95.1	97.3	94.5	TSI=45.80%
Net	10.3	0.7	2.1	-4.9	-2.7	-5.6	

Notes: The results are derived utilising the VAR process of the *p*-order and the H-step-ahead generalised forecast error variance decompositions. The number of lags determined by the Schwarz Bayesian Criterion and the length of predictive horizons associated with each market are reported in Appendix (Table D1). TSI denotes the total volatility spillover index. All figures are expressed in percentage.

Table 6: Static volatility spillovers between Brent crude petroleum and sector indices of petroleum importing countries.

Panel A: Australia	**Brent**	**Basic Materials**	**Financials**	**Industrials**	**Real Estate**	**From Others**
Brent	**97.27**	1.62	0.6	0.16	0.36	2.7
Basic Materials	0.75	**52.72**	18.81	14.38	13.34	47.3
Financials	0.41	21.96	**47.11**	16.29	14.23	52.9
Industrials	0.32	19.21	20	**47.42**	13.05	52.6
Real Estate	0.14	14.93	15.28	11.78	**57.87**	42.1
To Others	1.6	57.7	54.7	42.6	41	197.6
Including Own	98.9	110.4	101.8	90	98.8	TSI=39.50%
Net	-1.1	10.4	1.8	-10	-1.1	

Panel B: China	**Brent**	**Basic Materials**	**Consumer Cyclicals**	**Consumer Non-Cyclicals**	**Energy**	**Financials**	**Healthcare**	**Industrials**	**Real Estate**	**Technology**	**Utilities**	**From Others**
Brent	**96.91**	0.35	0.26	0.26	0.46	0.31	0.34	0.31	0.28	0.27	0.27	3.1
Basic Materials	0.22	**15.07**	10.37	10.62	10.48	8.22	9.26	11.34	8.51	10.22	5.69	84.9
Consumer Cyclicals	0.23	10.24	**14.05**	10.46	8.87	8.2	10.46	11.65	9.41	11.28	5.14	86
Consumer Non-Cyclicals	0.24	10.73	10.7	**13.84**	8.86	8.02	10.63	11.5	8.82	10.8	5.86	86.2
Energy	0.25	11.63	10.06	9.89	**17.42**	7.92	8.77	10.74	8.38	9.85	5.09	82.6
Financials	0.19	9.56	9.85	9.3	8.19	**16.94**	9.29	11.5	9.8	10.19	5.2	83.1
Healthcare	0.17	9.73	11.02	10.98	8.11	8.09	**13.96**	11.68	9.37	11.36	5.53	86
Industrials	0.21	10.37	10.84	10.36	8.72	8.86	10.18	**13.66**	9.57	11.32	5.92	86.3
Real Estate	0.13	9.18	10.37	9.49	8.1	9.01	9.63	11.3	**17.39**	10.28	5.12	82.6
Technology	0.19	9.9	11.29	10.48	8.58	8.26	10.72	12.08	9.38	**13.77**	5.36	86.2
Utilities	0.32	8.67	8.28	8.73	7.04	6.97	8.1	10.08	7.48	8.53	**25.8**	74.2
To Others	2.2	90.4	93	90.6	77.4	73.9	87.4	102.2	81	94.1	49.2	841.2
Including Own	99.1	105.4	107.1	104.4	94.8	90.8	101.4	115.8	98.4	107.9	75	TSI=76.50%
Net	-0.9	5.5	7	4.4	-5.2	-9.2	1.4	15.9	-1.6	7.9	-25	

Panel C: Eurozone	Brent	Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	Healthcare	Industrials	Real Estate	Technology	Utilities	From Others
Brent	**92.05**	0.92	0.97	0.46	2.66	0.97	0.26	0.52	0.3	0.5	0.39	8
Basic Materials	2.57	**13.73**	10.34	10.11	8.41	8.93	9.13	10.52	7.02	10.3	8.94	86.3
Consumer Cyclicals	2.86	10.33	**14.19**	10.49	7.82	9.55	8.58	10.8	7	9.75	8.63	85.8
Consumer Non-Cyclicals	2.43	10.18	10.61	**14.74**	7.5	8.7	9.02	10.62	7.02	9.97	9.2	85.3
Energy	2.93	10.13	9.65	9.29	**14.71**	9.85	8.28	10.41	6.62	9.64	8.49	85.3
Financials	2.68	10.04	10.84	10.04	8.76	**13.66**	7.92	11.09	7.44	9.3	8.22	86.3
Healthcare	2.27	10.08	9.74	10.23	7.42	7.93	**15.21**	10.16	7.41	10.53	9.02	84.8
Industrials	2.56	10.22	10.64	10.29	8.13	9.69	8.72	**13.15**	7.48	10.07	9.05	86.8
Real Estate	2.12	9.21	9.46	9.42	7.15	8.61	8.5	10.15	**17.97**	9.06	8.33	82
Technology	2.45	10.36	10.05	10.24	7.9	8.35	9.67	10.63	7.15	**14.01**	9.19	86
Utilities	2.03	9.98	9.84	10.19	7.69	8.13	9.13	10.54	7.2	10.21	**15.05**	84.9
To Others	24.9	91.5	92.2	90.7	73.4	80.7	79.2	95.5	64.6	89.3	79.5	861.5
Including Own	116.9	105.2	106.4	105.5	88.2	94.4	94.4	108.6	82.6	103.3	94.5	TSI=78.30%
Net	16.9	5.2	6.4	5.4	-11.9	-5.6	-5.6	8.7	-17.4	3.3	-5.4	

Panel D: India	Brent	Basic Materials	Consumer Cyclicals	Energy	Financials	Technology	From Others
Brent	**60.02**	10.39	11.01	7.1	4.72	6.75	40
Basic Materials	3.12	**34.02**	18.91	13.8	16.28	13.88	66
Consumer Cyclicals	2.27	18.87	**34.05**	13.85	17.13	13.82	65.9
Energy	2.54	17.28	17.15	**34.47**	15.25	13.3	65.5
Financials	2.95	17.54	18.52	13.49	**33.9**	13.6	66.1
Technology	3.3	16.99	16.76	12.85	14.99	**35.11**	64.9
To Others	14.2	81.1	82.4	61.1	68.4	61.3	368.4
Including Own	74.2	115.1	116.4	95.6	102.3	96.5	TSI=61.40%
Net	-25.8	15.1	16.5	-4.4	2.3	-3.6	

Panel E: Japan	**Brent**	**Basic Materials**	**Consumer Cyclicals**	**Consumer Non-Cyclicals**	**Financials**	**Healthcare**	**Industrials**	**Real Estate**	**Technology**	**Utilities**	**From Others**
Brent	**77.55**	2.48	2.53	2.72	2.74	2.71	2.74	2.1	2.6	1.82	22.4
Basic Materials	0.66	**13.92**	11.88	11.67	11.78	10.47	12.14	9.3	10.87	7.31	86.1
Consumer Cyclicals	0.69	11.62	**13.88**	11.63	11.83	10.54	11.97	9.56	11.04	7.22	86.1
Consumer Non-Cyclicals	0.79	11.56	11.85	**13.56**	11.71	10.8	11.99	9.44	11	7.3	86.4
Financials	0.65	11.33	11.47	11.28	**15.64**	10.36	11.63	9.57	10.72	7.36	84.4
Healthcare	0.79	11	11.33	11.47	11.39	**14.9**	11.55	9.33	10.9	7.33	85.1
Industrials	0.68	11.74	11.86	11.7	11.93	10.66	**13.23**	9.47	11.26	7.47	86.8
Real Estate	0.72	10.84	11.3	10.96	11.43	10.4	11.34	**15.93**	10.16	6.93	84.1
Technology	0.95	10.99	11.41	11.28	11.5	10.53	11.65	8.91	**15.05**	7.74	85
Utilities	0.65	10.17	10.25	10.34	10.72	9.79	10.69	8.37	10.39	**18.65**	81.3
To Others	6.6	91.7	93.9	93.1	95	86.3	95.7	76.1	88.9	60.5	787.7
Including Own	84.1	105.6	107.8	106.6	110.7	101.2	108.9	92	104	79.1	TSI=78.80%
Net	-15.8	5.6	7.8	6.7	10.6	1.2	8.9	-8	3.9	-20.8	

Panel F: South Africa	**Brent**	**Basic Materials**	**Consumer Non-Cyclicals**	**Financials**	**From Others**
Brent	**92.62**	1.55	3.49	2.35	7.4
Basic Materials	9.14	**58.5**	14.54	17.81	41.5
Consumer Non-Cyclicals	5.56	23.66	**48.41**	22.37	51.6
Financials	8.29	27.16	20.56	**43.99**	56
To Others	23	52.4	38.6	42.5	156.5
Including Own	115.6	110.9	87	86.5	TSI=39.10%
Net	15.6	10.9	-13	-13.5	

Panel G: South Korea	**Brent**	**Basic Materials**	**Consumer Cyclicals**	**Consumer Non-Cyclicals**	**Financials**	**Industrials**	**Technology**	**From Others**
Brent	**91.93**	1.4	1.49	1.04	2.18	0.73	1.23	8.1
Basic Materials	2.41	**36.72**	14.2	11.09	14.19	9.41	11.97	63.3
Consumer Cyclicals	1.51	11.45	**39.27**	11.08	12.76	10.94	12.98	60.7
Consumer Non-Cyclicals	1.25	9.79	12.55	**43.92**	13.26	8.36	10.87	56.1
Financials	1.8	11.1	12.35	10.8	**43.55**	9.51	10.89	56.5
Industrials	1.07	8.9	12.58	9.14	11.64	**42.56**	14.12	57.4
Technology	1.82	9.87	13.38	10.59	12.03	13	**39.3**	60.7
To Others	9.9	52.5	66.6	53.7	66.1	52	62.1	362.7
Including Own	101.8	89.2	105.8	97.7	109.6	94.5	101.4	TSI=51.80%
Net	1.8	-10.8	5.9	-2.4	9.6	-5.4	1.4	

Panel H: United Kingdom	Brent	Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	Industrials	Technology	From Others
Brent	**96.27**	0.29	0.26	0.28	2.21	0.28	0.18	0.22	3.7
Basic Materials	2.62	**28.63**	12.61	12.05	10.97	12.51	9.37	11.23	71.4
Consumer Cyclicals	3.06	11.35	**25.94**	14.52	8.95	13.83	11.39	10.95	74.1
Consumer Non-Cyclicals	3.13	11.15	14.87	**26.22**	8.97	13.66	10.93	11.05	73.8
Energy	4.6	12.49	11.59	11.14	**29.46**	12.14	9.2	9.39	70.5
Financials	3.12	11.61	14.55	13.72	10	**25.94**	10.29	10.76	74.1
Industrials	3.31	10.01	13.84	12.61	8.6	12.4	**29.48**	9.75	70.5
Technology	2.64	12.01	13.17	12.87	8.85	12.39	9.53	**28.54**	71.5
To Others	22.5	68.9	80.9	77.2	58.6	77.2	60.9	63.4	509.5
Including Own	118.7	97.5	106.9	103.4	88	103.2	90.4	91.9	TSI=63.70%
Net	18.8	-2.5	6.8	3.4	-11.9	3.1	-9.6	-8.1	

Panel I: United States	Brent	Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	Healthcare	Industrials	Real Estate	Technology	Utilities	From Others
Brent	**29.82**	7.18	6.7	7.7	6.12	7.5	7.55	6.76	5.96	7.44	7.27	70.2
Basic Materials	1.08	**11.79**	9.46	10.67	6.88	9.89	11.1	10.76	8.86	10.15	9.37	88.2
Consumer Cyclicals	0.98	9.36	**11.12**	10.54	7.26	9.89	11.42	10.45	9.27	10.24	9.48	88.9
Consumer Non-Cyclicals	1.1	9.5	9.34	**12.8**	6.44	9.48	11.3	10.46	9.2	10.3	10.1	87.2
Energy	1.12	9.09	9.81	9.81	**11.45**	10.09	11.08	10.12	8.84	9.57	9.02	88.5
Financials	0.99	9.59	9.64	10.32	7.27	**12.12**	11.24	10.55	9.11	9.85	9.3	87.9
Healthcare	1.07	9.18	9.56	10.71	6.79	9.75	**13.9**	10.17	9.12	10.12	9.64	86.1
Industrials	1.13	9.69	9.6	10.44	6.88	9.84	11.06	**12.45**	8.88	10.88	9.15	87.5
Real Estate	1	9.05	9.59	10.72	6.78	9.61	11.08	9.87	**12.98**	9.29	10.06	87
Technology	1.08	9.3	9.49	10.53	6.55	9.39	11.12	11.19	8.5	**13.37**	9.46	86.6
Utilities	0.97	9.11	8.98	10.97	6.36	9.36	10.95	9.87	9.46	9.85	**14.12**	85.9
To Others	10.5	91	92.2	102.4	67.3	94.8	107.9	100.2	87.2	97.7	92.8	944.1
Including Own	40.3	102.8	103.3	115.2	78.8	106.9	121.8	112.6	100.2	111.1	107	TSI=85.80%
Net	-59.7	2.8	3.3	15.2	-21.2	6.9	21.8	12.7	0.2	11.1	6.9	

Notes: The results are derived utilising the VAR process of the *p*-order and the H-step-ahead generalised forecast error variance decompositions. The number of lags determined by the Schwarz Bayesian Criterion and the length of predictive horizons associated with each market are reported in Appendix (Table D1). TSI denotes the total volatility spillover index. All figures are expressed in percentage.

3.2. Net pairwise volatility transmission networks

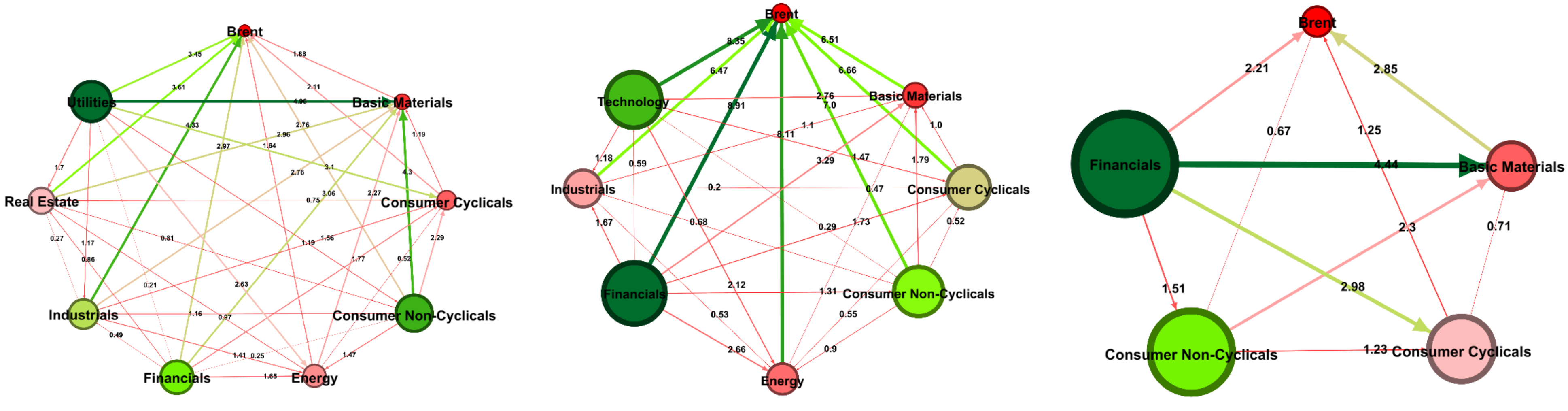
The network analysis of pairwise volatility spillovers between petroleum and sectors, while summarises findings from the previous subsection, allows to clearly identify net-transmitters and net-recipients. Fig. 1 (panels A to E) and Fig. 2 (panels A to I) portray the net pairwise volatility connectedness among Brent crude petroleum and sectors of petroleum exporting and importing countries over the full study period. The node's diameter signifies the intensity of a net volatility transmission (reception) to (from) other variables. The node's colour indicates a variable's position within the network, that is, green and red colours refer to a strong net-transmitter and net-receiver of volatility, respectively. The edge's size and colour exhibit the magnitude of a pairwise directional volatility transmission.

A close inspection of the network diagrams suggests that Brent crude petroleum retains its role as the net-contributor (net-receiver) of volatility to (from) each sector in both petroleum exporting and importing countries. However, some exceptions should be underscored. First, the *Financial* sector is the sole source of net volatility spillover to petroleum in South Korea. Second, the *Utilities* sector of China and the *Industrials* sector of Australia are the only net-recipients of volatility from petroleum within their systems. On average, the strong volatility linkages between petroleum and sectors in terms of net magnitudes are observed for Canada and the United States, while weak for Australia, South Korea and China.

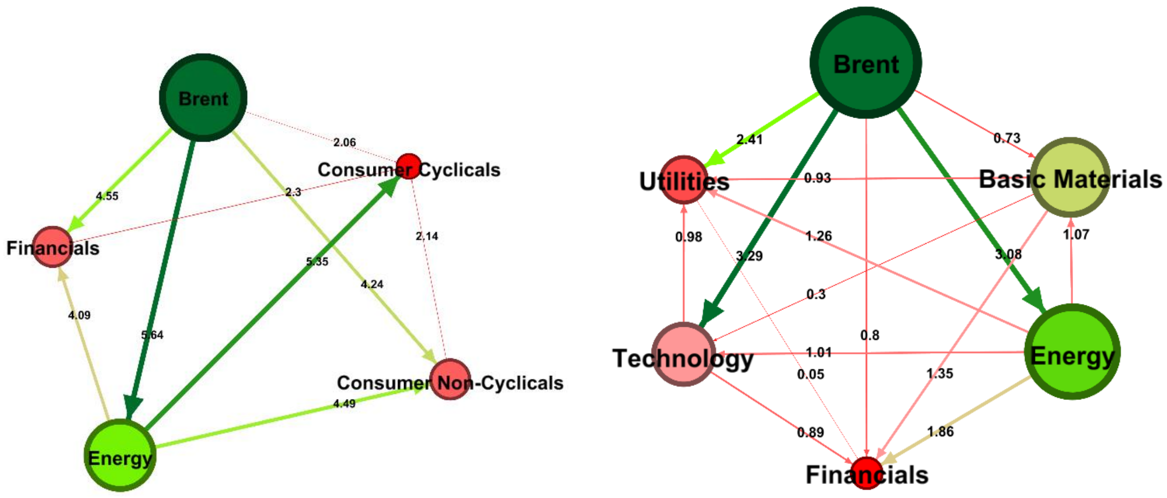
Comparing outputs among sectors of petroleum exporters, it can be seen that the largest net-receivers of volatility are the *Basic Materials* and *Consumer Cyclicals* sectors in Brazil, *Basic Materials* and *Energy* sectors in Canada, *Basic Materials* and *Consumer Cyclicals* sectors in Mexico, *Consumer Cyclicals* and *Consumer Non-Cyclicals* sectors in Norway, *Financials* and *Utilities* sectors in Russia. On the other hand, the strongest net-transmitters of volatility are the *Utilities* and *Consumer Non-Cyclicals* sectors in Brazil, *Financials* and *Technology* sectors in Canada, *Financials* and *Consumer Non-Cyclicals* sectors in Mexico, *Energy* sector in Norway, *Basic Materials* and *Energy* sectors in Russia. In the case of petroleum importers, the major net-recipients of volatility are the *Industrials* and *Real Estate* sectors in Australia, *Utilities* and *Financials* sectors in China, *Real Estate* and *Energy* sectors in the Eurozone, *Energy* and *Technology* sectors in India, *Utilities* and *Real Estate* sectors in Japan, *Consumer Non-Cyclicals* and *Financials* sectors in South Africa, *Basic Materials* and *Industrials* sectors in South Korea, *Energy* and *Industrials* sectors in the United Kingdom, *Energy* and *Real Estate* sectors in the United States. Contrarily, the principal net-contributors of volatility are the *Basic*

Materials and *Financials* sectors in Australia, *Industrials* and *Consumer Cyclicals* sectors in China and the Eurozone, *Consumer Cyclicals* and *Basic Materials* sectors in India, *Financials* and *Industrials* sectors in Japan, *Basic Materials* sector in South Africa, *Financials* and *Consumer Cyclicals* sectors in South Korea, *Consumer Cyclicals* and *Consumer Non-Cyclicals* sectors in the United Kingdom, *Healthcare* and *Industrials* sectors in the United States. Overall, the empirical findings reveal sectors that serve as main drivers of volatility spillovers in markets of petroleum exporters and importers during the post global health crisis period.

Fig. 1. Net pairwise volatility transmission networks for petroleum exporters.

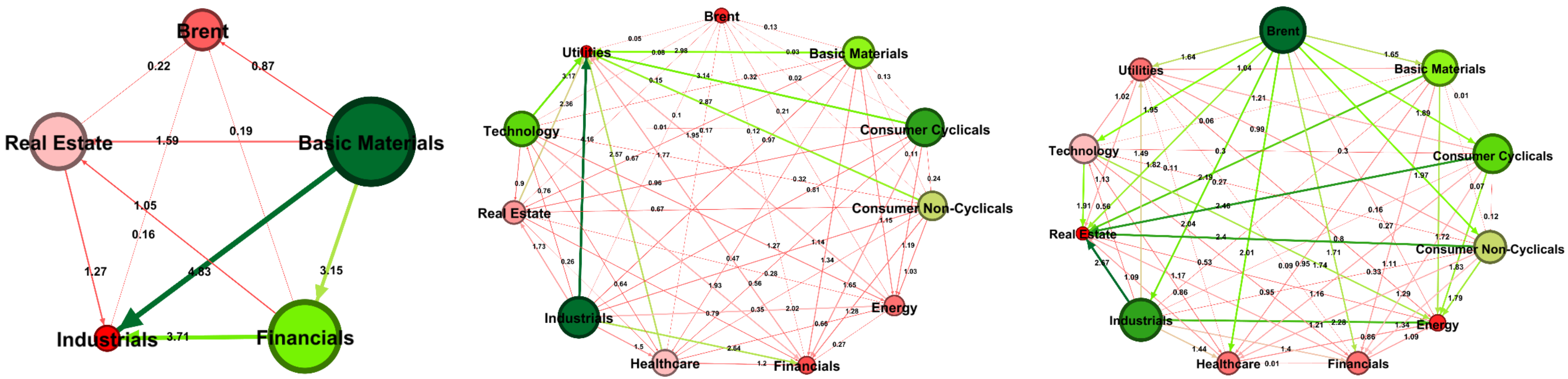


Panel A: Brazil **Panel B: Canada** **Panel C: Mexico**

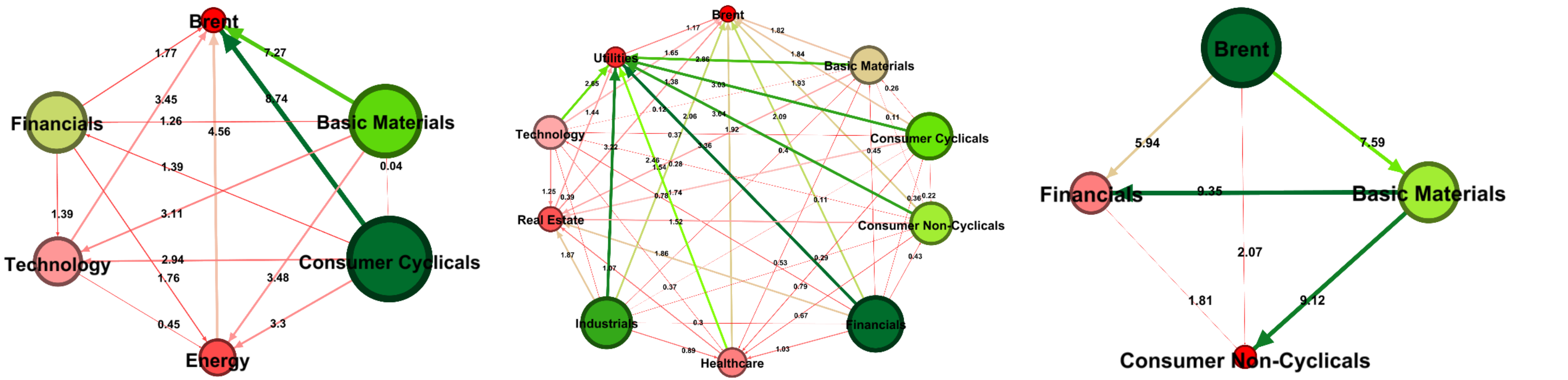


Panel D: Norway **Panel E: Russia**

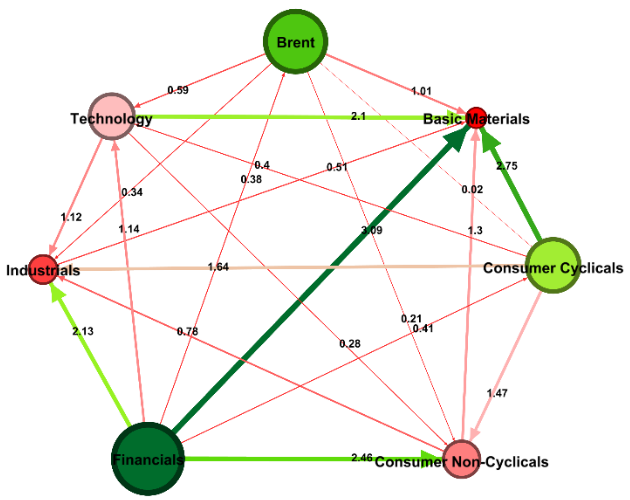
Fig. 2. Net pairwise volatility transmission networks for petroleum importers.



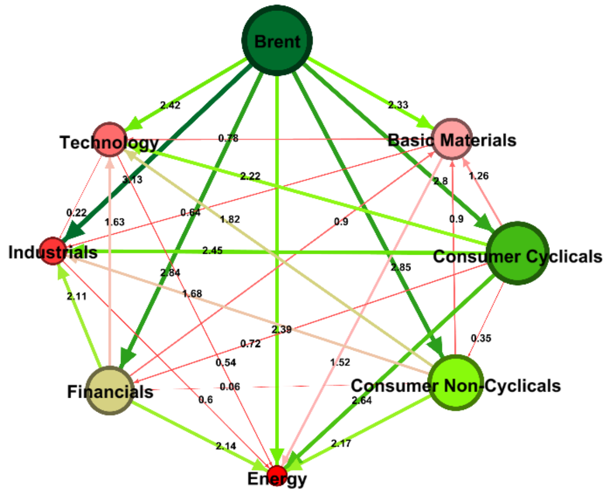
Panel A: Australia **Panel B: China** **Panel C: Eurozone**



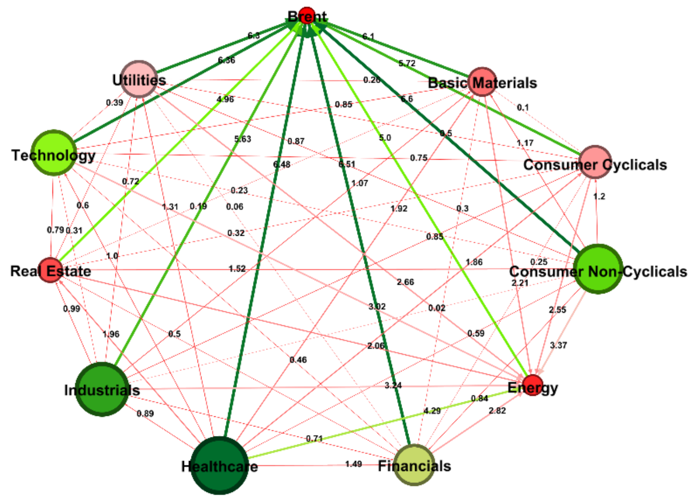
Panel D: India



Panel E: Japan



Panel F: South Africa



Panel G: South Korea

Panel H: United Kingdom

Panel I: United States

3.3. Dynamic volatility transmissions

The volatility interactions tend to exhibit a dynamic nature, which is concealed by static figures, although their significance should not be undervalued. Thus, in order to gain a better understanding of how total and net pairwise volatility spillovers evolve during a period when the peak stages of market turbulences were over, the study utilises a rolling window of one month.[8] Fig. 3 and Fig. 4 illustrate the time-varying total volatility transmissions between petroleum and sectors of petroleum exporting and importing countries, respectively. In general, moderate and strong volatility interdependencies persist throughout most of the sample period. Specifically, among petroleum exporters and importers, the highest values are detected for Canada and the United States, while the indices of Mexico, Australia and South Africa oscillate at relatively low ranges.

It is evident that all total volatility spillover indices experience considerable swings. Despite the dissimilar patterns in plots across petroleum exporters and importers, few notable common trends can be observed over certain sub-periods. First, the intensity of volatility spillovers mostly declines by the mid-December 2020. The positive expectations on the restoration of pre pandemic economic activity and growth in global petroleum demand associated with the deployment of vaccination provide a reasonable elucidation for this descending movement, the commencement of which varies among markets. The effects appear to be long-lasting for Australia and Japan in contrast to other markets. Second, the total volatility spillover indices upsurge, albeit with different magnitudes, between February and April 2021. The obtained result could be attributed to the volatile time in the petroleum market due to the short-term concerns on global petroleum demand amid the unsatisfactory rollout of vaccination, Texas power crisis, obstruction in the Suez Canal and agreement on the extension of petroleum production cuts by OPEC+. In the case of China, the additional potential cause of the hike in the volatility connectedness towards the end of February 2021 is the announcement of an equity trading tax increase in Hong Kong.[9] To sum up, the spikes (or slumps) in the total volatility spillover indices are associated with amplifications (or attenuations) in the levels of volatility of sectors and petroleum. Hence, the documented evidence suggests that volatility interlinkages between petroleum and sectors of petroleum exporters and importers strengthen at times of

[8] Table D1 in Appendix reports the number of 5-minute observations in one month related to each market that are employed for the rolling window analysis.
[9] For details see: Reuters, https://www.reuters.com/article/us-hkex-results-idUSKBN2AO0LX

uncertainty in markets, and aligns with findings of Awartani and Maghyereh (2013), Xu et al. (2019), and Benlagha and El Omari (2022).

Fig. 5 (panels A to E) and Fig. 6 (panels A to I)[10] display the dynamic total net volatility spillovers among petroleum and sectors of petroleum exporting and importing countries, respectively. The positive (negative) areas of plots indicate that a variable is a net-transmitter (net-receiver) of volatility to (from) all other variables. It can be seen that the intensity of net volatility transmissions varies over time. Starting with exporters, Brent crude petroleum is the net-contributor of volatility to all sectors of Norway and Russia, although its position changes to the net-receiver towards the end of March 2020, with the magnitude of spillovers reaching low levels. In the case of Brazil and Canada, the transmission of volatility is dominated from all sectors to petroleum throughout the entire period, thereby pointing to its role as the net-recipient of volatility. For sectors of Mexico, Brent crude petroleum acts as the net-transmitter of volatility, switching to the weak net-receiver of volatility in October 2020, December 2020 and March 2021. The *Financials* and *Technology* sectors of Canada and *Energy* sector of Norway remain the key net-contributors of volatility to others in their systems, whereas the *Consumer Cyclicals* sector of Norway is the only net-receiver of volatility from others during the study period. The figures associated with the remaining sectors fluctuate in both positive and negative zones.

Turning to importers, Brent crude petroleum is the strong net-recipient of volatility from all sectors of Japan and the United States, but contributes a small portion of volatility to sectors of China and India. For Australia, it acts as the net-receiver of volatility approximately from November 2020 until mid-April 2021, and the rest of the time as the net-transmitter of volatility. Despite the static values indicating the net-contributor role of Brent crude petroleum in the Eurozone, South Korea, South Africa and the United Kingdom, volatility spillovers from sectors prevail during some periods, which are evident to a lesser extent in the latter two markets. The sectoral comparison of time-varying figures reveals that the *Consumer Cyclicals*, *Consumer Non-Cyclicals*, *Industrials* and *Technology* sectors of China, *Industrials* sector of the Eurozone, *Consumer Cyclicals* sectors of India, *Consumer Cyclicals*, *Financials* and *Industrials* sectors of Japan, *Consumer Non-Cyclicals*, *Healthcare, Industrials* and *Technology* sectors of the United States retain their positions as the important net-contributors of volatility to others in each system irrespective of the sample period. Conversely, the main net-receivers

[10] EFMA conference paper submissions only allow a Maximum File Size of 10 MB. Therefore, due to this limitation, Figures 5 and 6 are only available upon request.

of volatility from others are the *Financials* and *Utilities* sectors of China, *Energy* sector of the Eurozone, *Real Estate* and *Utilities* sectors of Japan, *Financials* sector of South Africa, and *Energy* sector of the United States. In the case of all other sectors, the net volatility spillovers oscillate in positive and negative regions.

Fig. 7 (panels A to E) and Fig. 8 (panels A to I) [11]depict the time-varying net pairwise volatility transmissions between petroleum and sectors of petroleum exporting and importing countries, respectively. The net pairwise figures are computed as the difference between the gross volatility transmitting from Brent crude petroleum to each sector and those spilling from each sector in the reverse direction. At first sight, it can be observed that the role of petroleum as the net-contributor or net-recipient of volatility changes at different points in time. As expected, the major events discussed earlier in this sub-section affect the intensity and sign of net-pairwise volatility spillovers. Among petroleum exporting countries, Brent crude petroleum is the strong net-receiver of volatility from each sector of Canada and Brazil throughout the whole period of analysis, but it transforms into the net-contributor of volatility to sectors of the latter mostly in December 2020. For Mexico, although net pairwise volatility transmissions swing in positive and negative domains, the predominance of negative values is reported. Brent crude petroleum is the net-transmitter of volatility to the *Energy* sector of Norway and *Technology* sector of Russia, whereas it receives volatility from the remaining sectors of both markets at the start and end of the sample period, and the rest of the time performs as the net-contributor. The *Energy* sector of Canada (Norway) is the biggest net-transmitter (net-receiver) of volatility to (from) petroleum.

In the case of petroleum importing countries, sectors of the Unites States and Japan, excluding the *Utilities* sector that appears to receive some portion of volatility from petroleum towards the end of February 2021, consistently remain the net-transmitters of volatility to petroleum. For India, Brent crude petroleum is also the net-recipient, but contributes volatility to sectors between December 2020 and January 2021. Interestingly, Australian sectors are the major net-receivers of volatility from petroleum during September and October 2020, but they act as the net-contributors thereafter. In net terms, Brent crude petroleum receives more volatility from sectors of China during the study period, not counting relatively minor volatility transmissions in the reverse direction. The positive values of net pairwise volatility spillovers overweight for sectors of South Africa, the Eurozone and United Kingdom, indicating that Brent crude

[11] EFMA conference paper submissions only allow a Maximum File Size of 10 MB. Therefore, due to this limitation, Figures 7 and 8 are only available upon request.

petroleum is the net-contributor of volatility. The only exception is the *Energy* sector of the Eurozone, where net volatility spillovers to petroleum are observed starting from November 2020. The net pairwise volatility transmissions related to sectors of South Korea more frequently swing in positive and negative domains. Furthermore, petroleum mostly takes the net-receiver position from the mid-November 2020 to the mid-March 2021. The magnitude of net volatility spillovers is the largest from the *Consumer Cyclicals* sector of India to petroleum, and in the opposite course from petroleum to the *Basic Materials* sector of South Africa.

3.4. Robustness tests

Following Diebold and Yilmaz (2012), the study re-estimates the total volatility spillover indices utilising different lag orders of the VAR process, ranging from 1 to 14, which are specific to each market, and forecast horizons of 3 to 7 days. Fig. D2 (panels A to B) and Fig. D3 (panels A to B) in Appendix illustrate that the computed total volatility spillover indices of both petroleum exporters and importers exhibit almost identical patterns, albeit with minor variations in the magnitude, regardless of the considered lag orders and predictive horizons. Thus, it can be concluded that the obtained empirical findings are robust.

Fig. 3. Time-varying total volatility spillovers between petroleum and sectors of petroleum exporters.

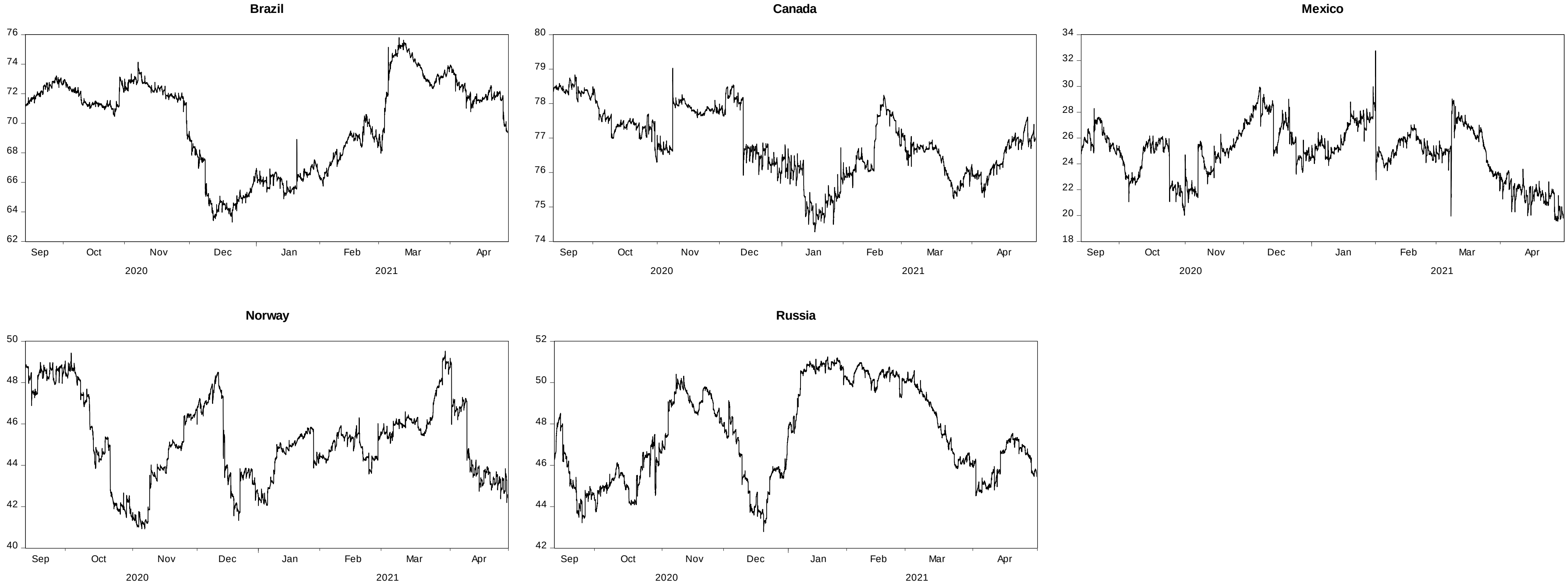
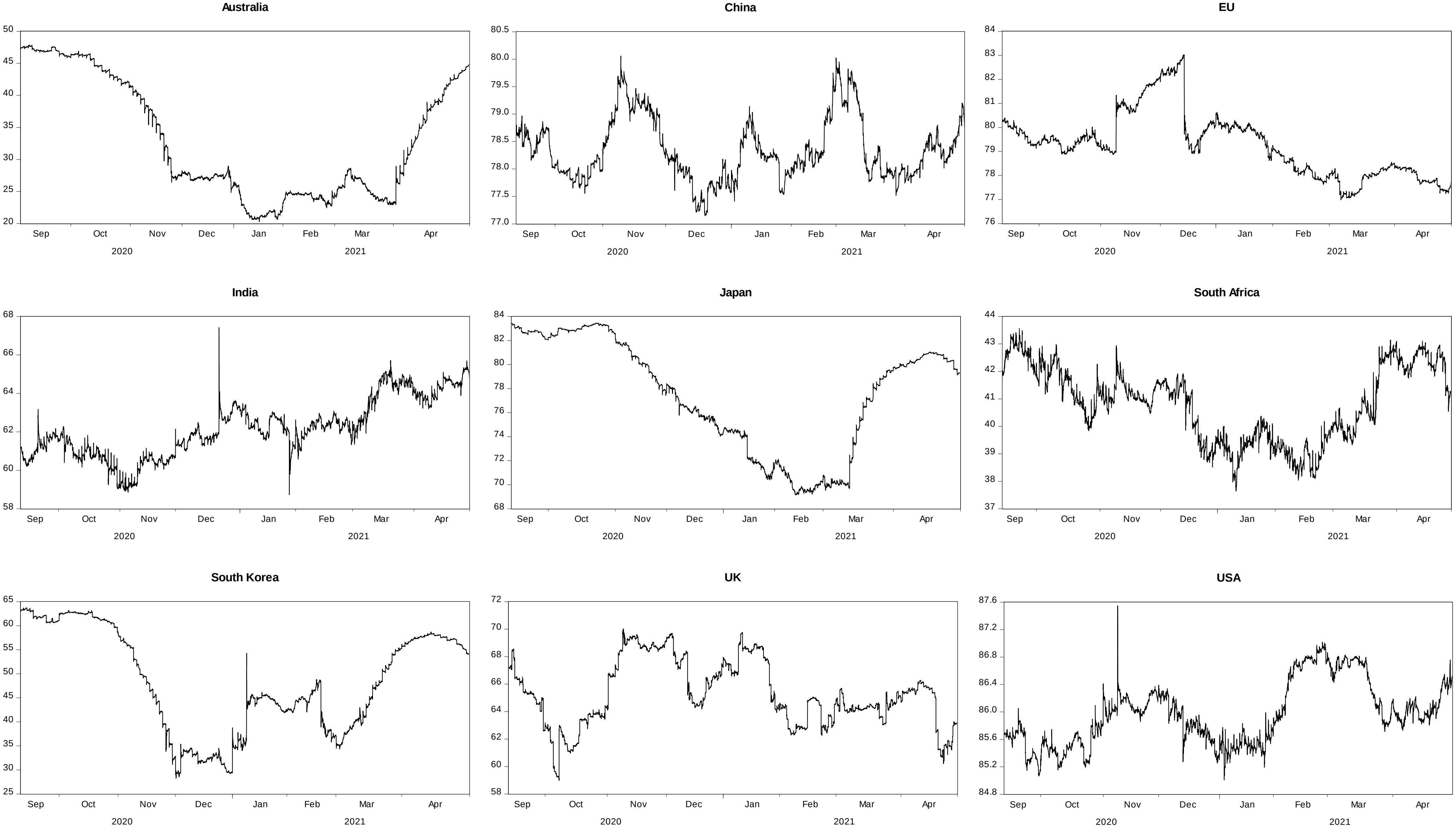


Fig. 4. Time-varying total volatility spillovers between petroleum and sectors of petroleum importers.



4. Conclusion

The adverse impact of the recent global health crisis on the financial markets across the world, although alleviated throughout time due to measures taken by policymakers, induced great concerns among market participants. From the perspectives of managing investment portfolios and risks, understanding volatility spillover patterns between the strategic commodity as petroleum and sectors of petroleum exporting and importing countries during the post pandemic period amid the swift spread of information is essential. Considering the unavailability of sector indices comprising largest and liquid stocks from a broad range of developed and emerging markets, the study adopts the methodology proposed by Mateus et al. (2017) to manually construct sector indices utilising 5-minute data of 1,689 unique stocks listed in ten sectors, namely *Basic Materials*, *Consumer Cyclicals*, *Consumer Non-Cyclicals*, *Energy*, *Financials*, *Healthcare*, *Industrials*, *Real Estate*, *Technology* and *Utilities*, over the period from July 31, 2020 to April 30, 2021. Thus, the present work examines intraday static and dynamic volatility interdependencies between Brent crude petroleum futures prices and self-built stock sector indices of five net petroleum exporters (Brazil, Canada, Mexico, Norway and Russia) and nine net petroleum importers (Australia, China, Eurozone, India, Japan, South Africa, South Korea, the United Kingdom and United States). Furthermore, net pairwise volatility linkages are scrutinised through the construction of spillover networks. The connectedness measure of Diebold and Yilmaz (2012), which grounds on forecast error variance decompositions of a generalised VAR model, is applied to attain research objectives.

The estimates of the Diebold and Yilmaz (2012) approach provide evidence of intraday volatility interdependencies between petroleum and sectors of petroleum exporting and importing countries. It should be accentuated that the reported spillovers exhibit heterogeneous directions and intensities across considered markets and sectors, confirming validity of the sectoral investigation. Additionally, the empirical findings indicate that the total static volatility connectedness is fairly high across most systems during the post pandemic period. Brent crude petroleum accounts for a greater portion of variations in sectors’ volatilities of Norway and Russia (exporters), and South Africa, the Eurozone and United Kingdom (importers). However, sectors of Canada and Brazil (exporters), and Japan, India and the United States (importers) exercise larger effects on the volatility of Brent crude petroleum.

The differences between "To Others" and "From Others" figures suggest that petroleum is the net-transmitter of volatility to sectors of two exporters (Norway and Russia) and four importers

(South Africa, South Korea, the Eurozone and United Kingdom). On the other hand, petroleum is the net-recipient of volatility from sectors of three exporters (Brazil, Canada and Mexico) and five importers (Australia, China, India, Japan and the United States). The results are in line with the view that petroleum is no longer exogenous in the equity-petroleum nexus (Zhang, 2017; Gomez-Gonzalez et al., 2020). Furthermore, the network analysis of static pairwise volatility transmissions, while reaffirms the position of petroleum as the net-contributor or net-receiver, reveals sectors that act as major drivers of volatility spillovers in each market that should be taken into account when making investment decisions. The total and net pairwise volatility spillovers display a dynamic nature and mostly react to short-term market events observed during the study period. The time-varying net pairwise volatility transmissions show that the role of petroleum does not always remain the same. The *Energy* sector of Canada and *Consumer Cyclicals* sector of India are the biggest net-contributors of volatility to petroleum, whereas the *Energy* sector of Norway and *Basic Materials* sector of South Africa are the largest net-recipients of volatility from petroleum. Overall, the low volatility linkages between petroleum and sectors are documented for Australia, China, Mexico and South Korea, thereby pointing to potential diversification opportunities.

The empirical results of the present study carry valuable insights for market participants. Petroleum risk should not be disregarded given the sizable and simultaneously heterogeneous volatility connectedness between petroleum and sectors. Therefore, an accurate comprehension of the dynamic intraday sensitivities of sectors in petroleum exporting and importing countries to the petroleum price volatility, along with identification of the key volatility drivers, are essential elements for efficient implementation of intersectoral asset allocation and risk mitigation strategies. Furthermore, the observed bilateral volatility spillovers point to potential benefits of monitoring information emerging from markets of exporters and importers, particularly those that exhibit the largest effects, for prospective changes in the petroleum market.

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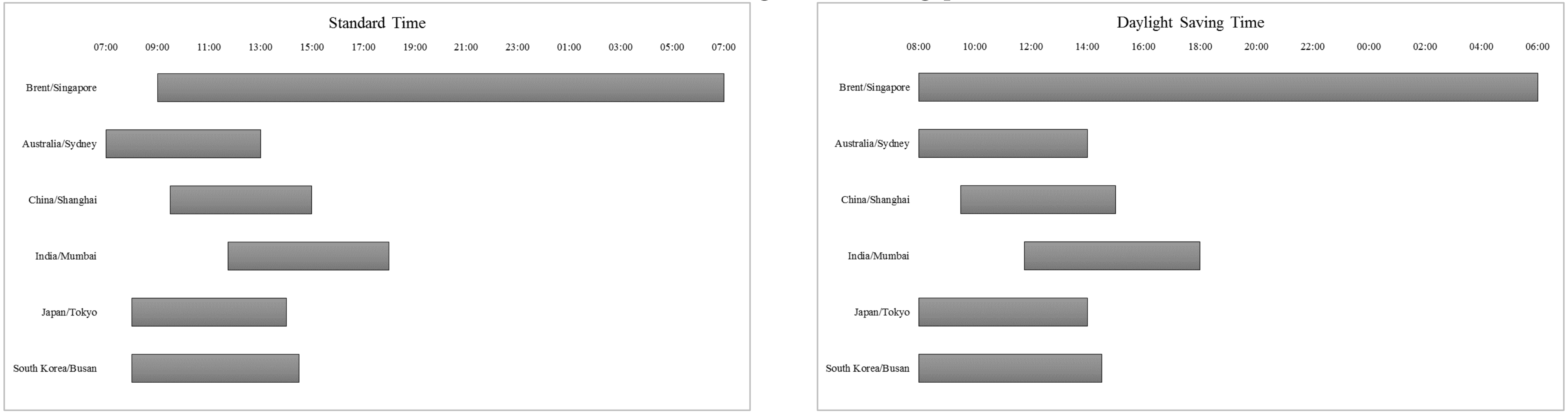
Appendix

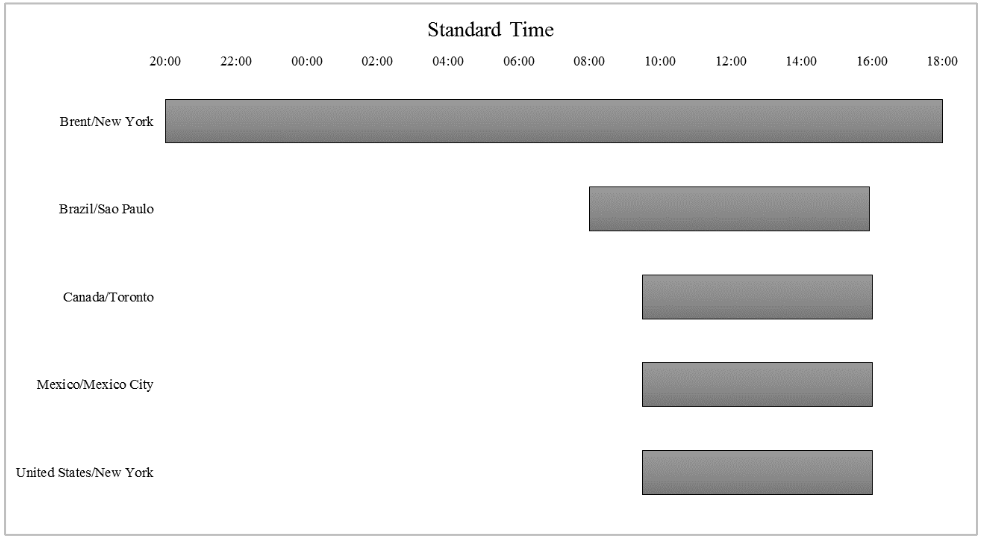
Fig. D1. Stock markets' trading hours converted to local times of the ICE Brent crude petroleum futures contracts.

Panel A: Trading location – Singapore



Panel B: Trading location – London

Panel C: Trading location – New York



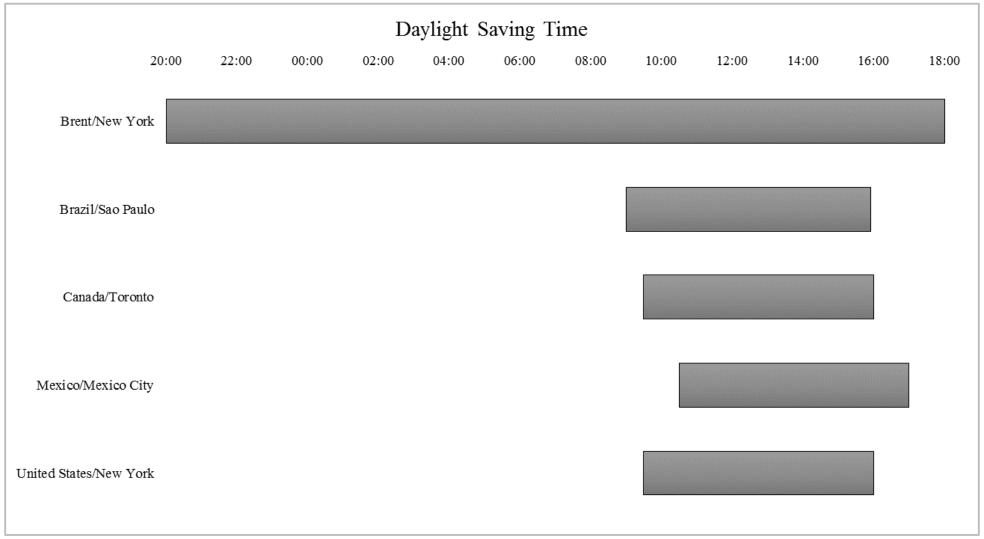


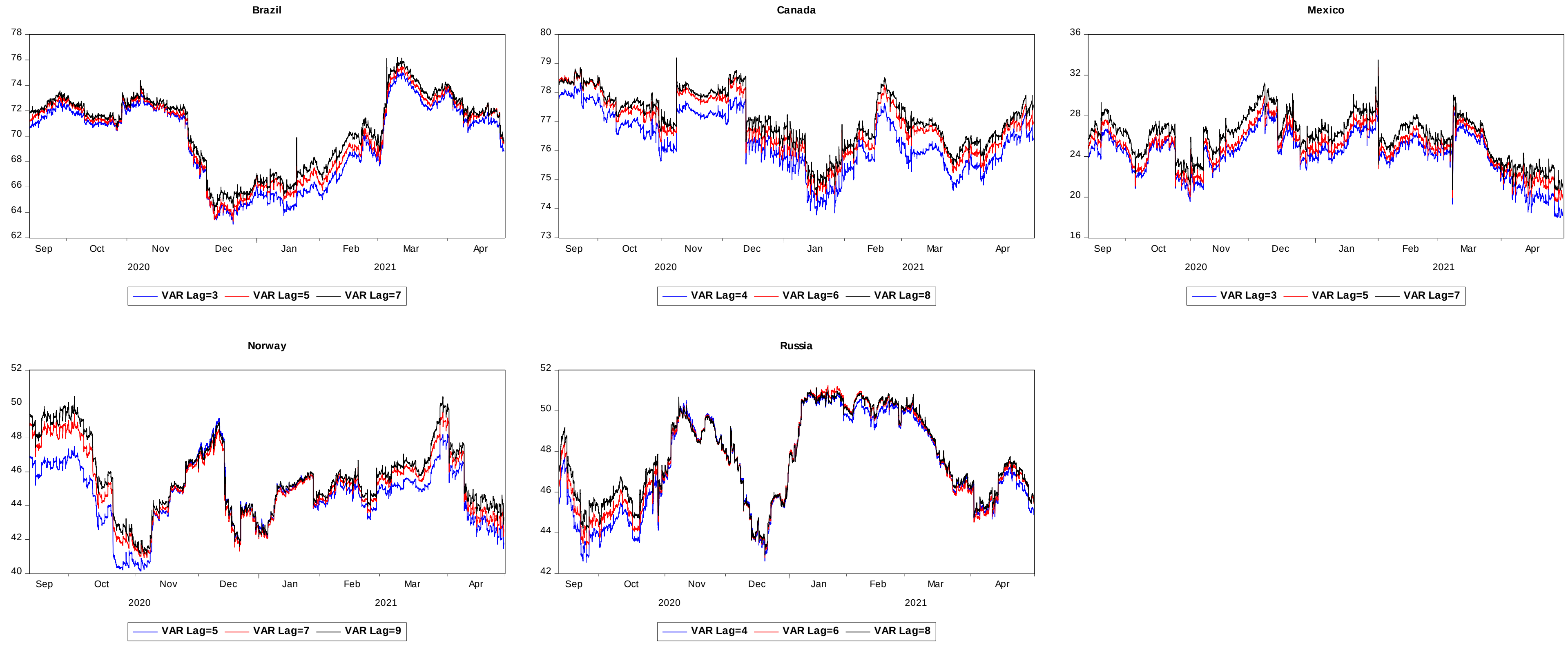
Table D1: Specifications of the empirical model for each market.

	SBC Lag	Forecast Horizon (Days/Observations)	Rolling Window (Months/Observations)
Panel A: Petroleum Exporters			
Brazil	5	5/415	1/1892
Canada	6	5/390	1/1776
Mexico	5	5/390	1/1824
Norway	7	5/440	1/2112
Russia	6	5/520	1/2496
Panel B: Petroleum Importers			
Australia	4	5/360	1/1728
China	3	5/240	1/1152
Eurozone	6	5/510	1/2448
India	6	5/375	1/1800
Japan	4	5/305	1/1464
South Africa	12	5/470	1/2253
South Korea	6	5/380	1/1748
United Kingdom	6	5/510	1/2346
United States	6	5/390	1/1776

Notes: This table reports details of lag orders, forecast horizons and rolling samples employed in estimating volatility spillovers between petroleum and sector indices of petroleum exporters and importers. SBC denotes the Schwarz Bayesian Criterion.

Fig. D2. Sensitivity of the total time-varying volatility spillovers to lag orders and forecast horizons for petroleum exporters.

Panel A – Lag orders



Panel B – Forecast horizons

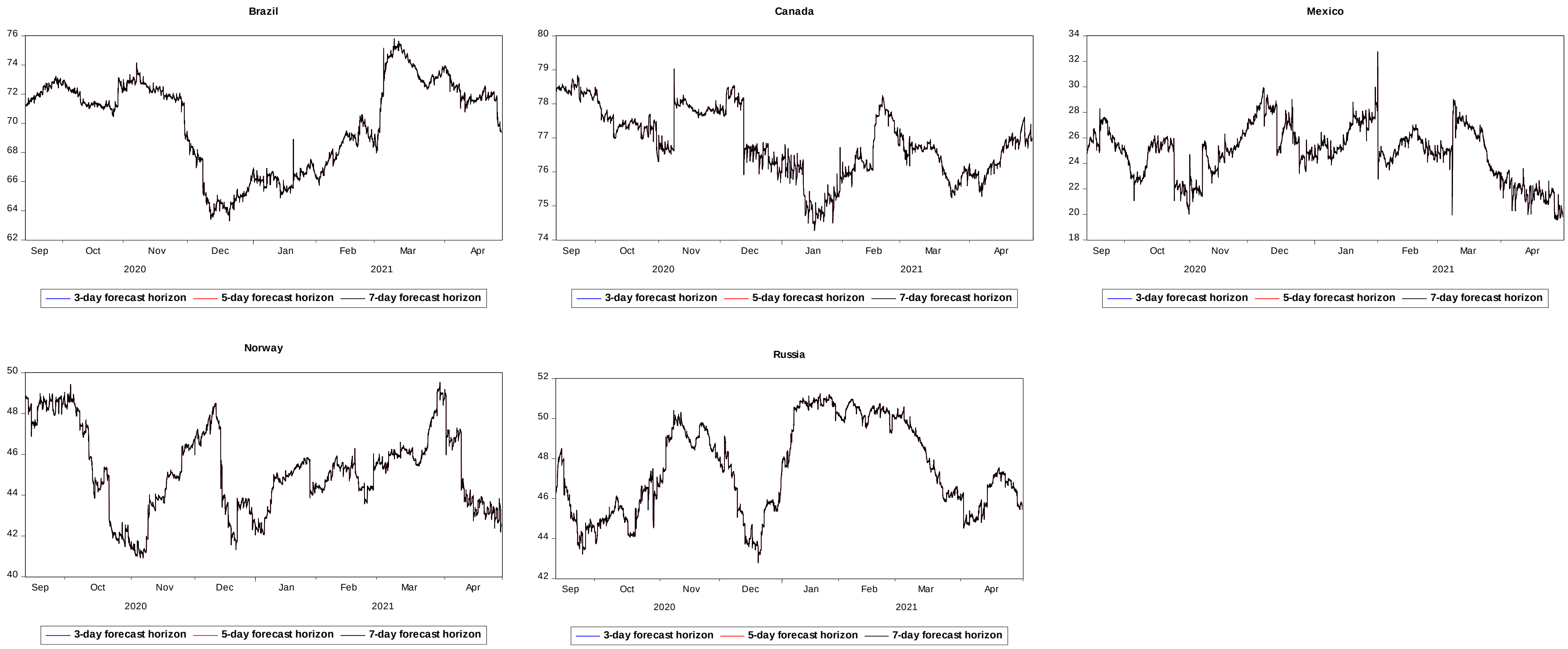
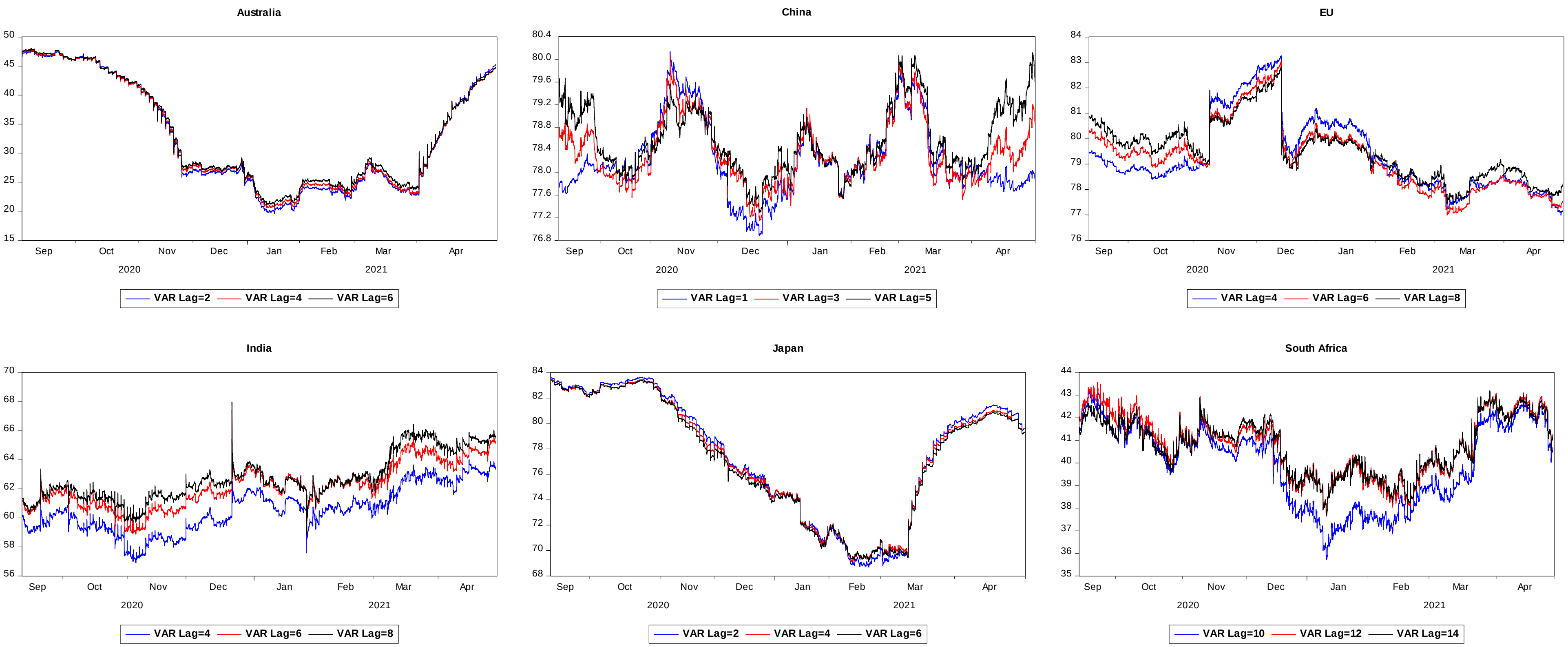
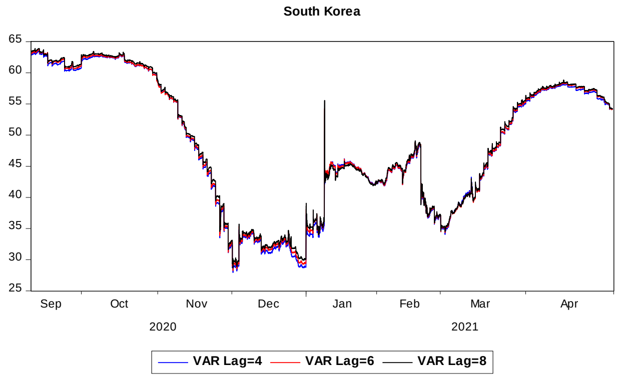
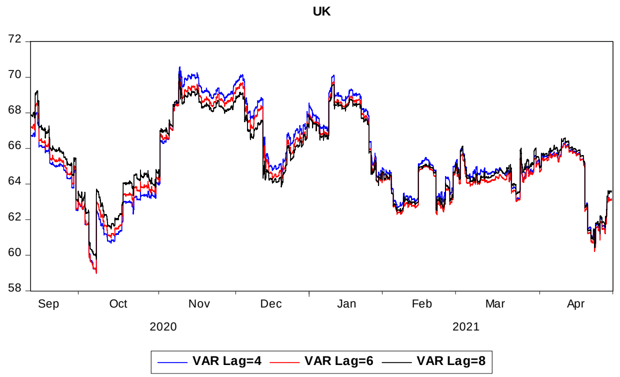


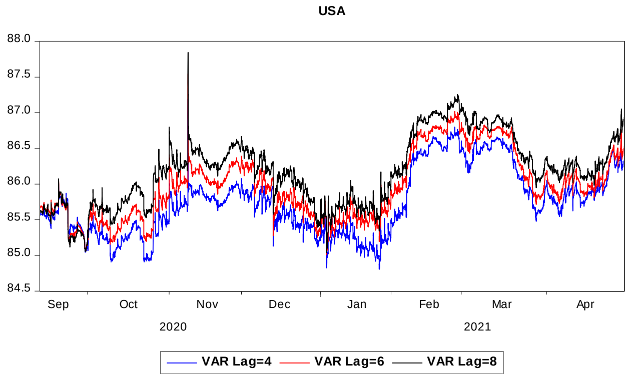
Fig. D3. Sensitivity of the total time-varying volatility spillovers to lag orders and forecast horizons for petroleum importers

Panel A – Lag orders

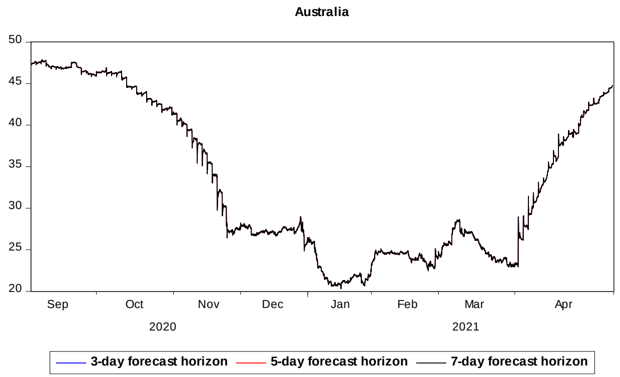


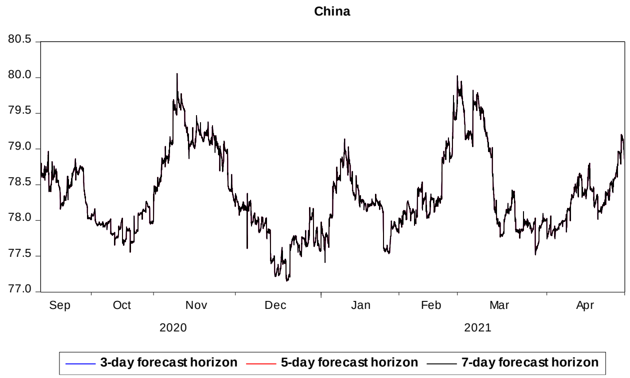


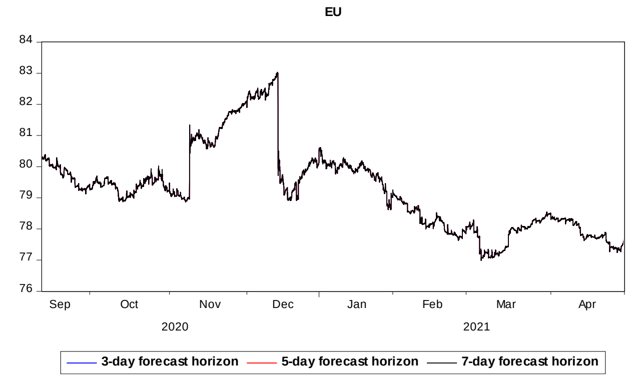


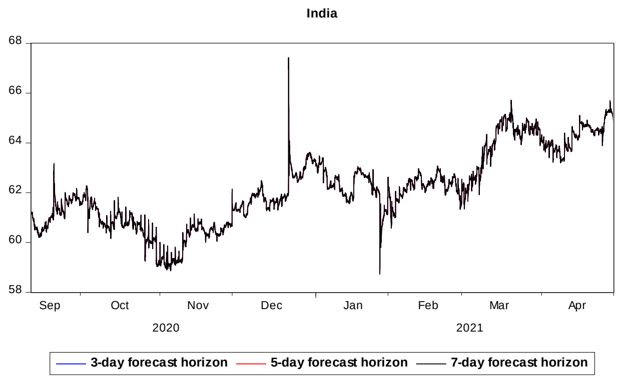


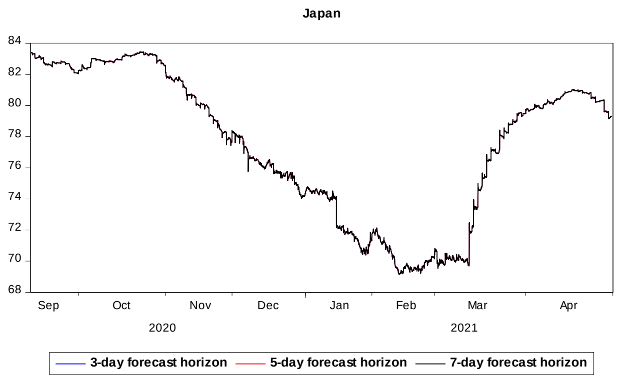
Panel B – Forecast horizons

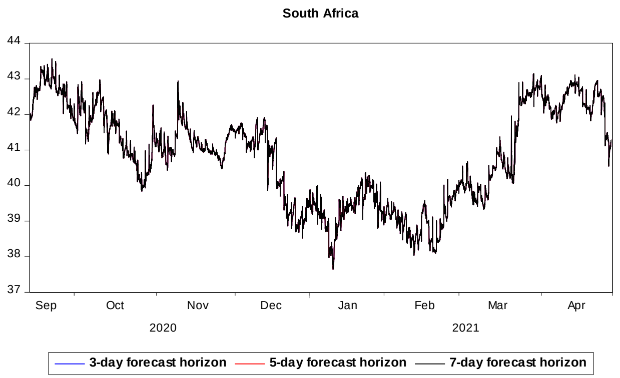


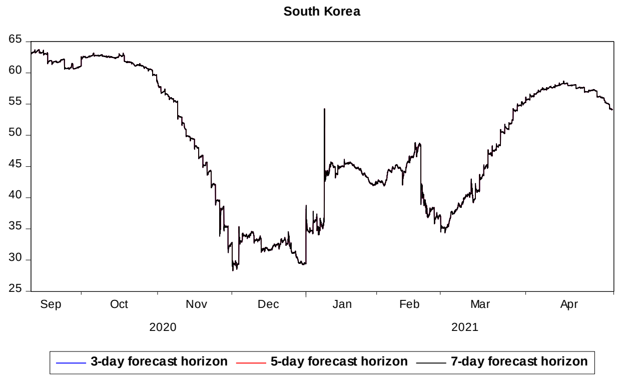


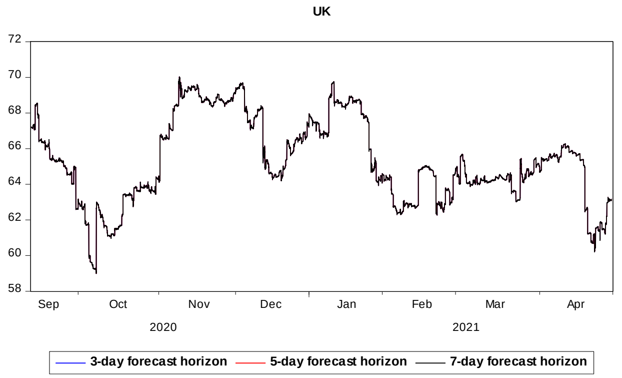


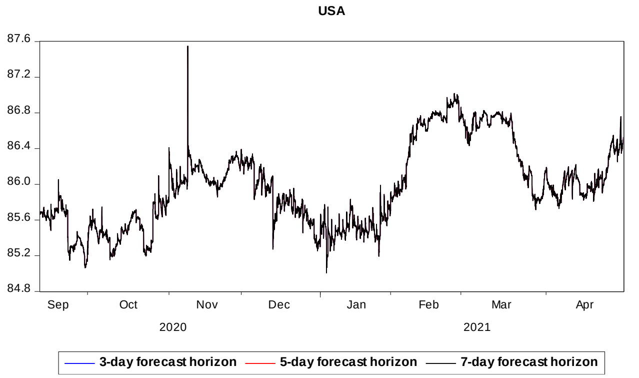







South Korea
65
60
55
50
45
40
35
30
25
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2020
2021
3-day forecast horizon
5-day forecast horizon
7-day forecast horizon


UK
72
70
68
66
64
62
60
58
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2020
2021
3-day forecast horizon
5-day forecast horizon
7-day forecast horizon


USA
87.6
87.2
86.8
86.4
86.0
85.6
85.2
84.8
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2020
2021
3-day forecast horizon
5-day forecast horizon
7-day forecast horizon