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Dynamic connectedness between crude oil and equity markets: What about the effects of firm's solvency and profitability positions?

Faruk Balli [a,b,*], Hatice O Balli [a], Thi Thu Ha Nguyen [a]

[a] School of Economics and Finance, Massey University , Albany, New Zealand
[b] Higher School of Economics and Business, Al-Farabi Kazakh National University, Almaty, Kazakhstan

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ABSTRACT

The paper aims to explore the presence of connectedness between oil price changes and stock returns of oil & gas sector. The analysis, adopting the connectedness approach developed by and the frequency connectedness developed by demonstrates a high level of connectedness, especially during the extreme economic meltdown. The short-term (1–5 days) level of total connectedness is substantially higher than the medium-term (5–30 days) and long-term levels (30–262 days). In addition, when examining the impact of the sectors' financial characteristics on the extent of the connectedness, we found that sectors with greater solvency position (lower debt to asset ratio and higher interest coverage) are less connected with the oil price changes. The impact of sector's solvency position on connectedness (between stock return and oil prices) is even more obvious for financially more open markets. Also, change in oil prices have a less impact on the returns of sectors with higher profitability ratios. The paper, therefore, brings several implications to both policy makers and investors.

1. Introduction

In the last decade, given the increasingly significant position of the oil market in the global economy and its spectacular price fluctuations, studies working on the oil-stock relationship have received large attention. One of the earliest studies is by. Diebold and Yilmaz (2012); Jones and Kaul (1996); Baruník and Křehlík (2018) which state the robust impact of oil shocks on stock returns by the use of the standard present value model. Even though different methods and studied periods are employed, similar conclusions are reached in subsequent studies of Arouri et al. (2011); Broadstock et al. (2012). The interdependence between oil and stock markets, indeed, is justified by both direct and indirect channels. In terms of the direct channel, as the fact that oil price variation, as stated by Jones and Kaul (1996), is highly likely to cause changes in the inflation rate, interest rate, and industrial production cost; the shocks from the oil market can spread to stock markets through the way linked with cash flows and the discount rate used in the stock valuation models (Jones and Kaul, 1996; Ma et al., 2019). On the other hand, Antonakakis et al. (2017); Broadstock and Filis (2014); Ma et al. (2019) highlight the inevitable phenomenon of financialization as the indirect oil-stock nexus's determinant. The increased speculative activities and the development of derivative products enable higher interdependence between them.

While the test of the oil-stock relationship has been first devoted to the aggregate stock markets. The recent work emphasis has been

* Corresponding author.
E-mail addresses: f.balli@massey.ac.nz (F. Balli), h.ozerballi@massey.ac.nz (H. O Balli), h.nguyen2@massey.ac.nz (T.T.H. Nguyen).

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shifted to the oil-stock market connection from the sector perspective, owing to the fact that stocks from different sectors may have a heterogenous reaction to oil shocks (Arouri et al., 2011; Bouri et al., 2016; Broadstock et al., 2012; Broadstock and Filis, 2014; Hamdi et al., 2019; Tiwari et al., 2018). As noted by Broadstock and Filis (2014); Tiwari et al. (2018), the magnitude and sign of the effects differ across industries, depending on whether the sector is more oil-dependent or not.

In this respect, the main objective of this paper is to investigate the existence of interconnection between oil price shocks and the stock returns of oil & gas sector by the use of the connectedness approach developed by Diebold and Yilmaz (2012) and the frequency connectedness analysis developed by Baruník and Křehlík (2018). Our focus has been paid to the oil & gas sector because of its higher sensitivity to the oil shocks in comparison with the other industries (Bouri et al., 2016; Broadstock et al., 2012). Furthermore, due to common industrial information, the link between oil shocks and the oil & gas sector is rational to justify (Arouri et al., 2011). The connectedness approaches have specific advantages as they allow for assessing the bi-directional link between markets. Rather than the unidirectional effect from the oil to stock markets, stock markets appear to transmit information to the oil market as well (Arouri et al., 2011; Arouri et al., 2011; Awartani and Maghyereh, 2013). Moreover, the findings from the combination of connectedness approach developed by Diebold and Yilmaz (2012) and the frequency connectedness approach developed by Baruník and Křehlík (2018) should be of wide interest, particularly from investor's perspectives due to its ability to examine the linkage between markets across time, events, and frequencies (short, medium, and long-term).

Analysing a dataset of 22 OECD countries from December 31, 1999 to September 1, 2020 reveals that there are indeed some variances in terms of connectedness when we consider the country-level analysis. Previous research shows that countries may react differently to oil price changes due to country-level idiosyncratic characteristics, such as the balance of payment position, inflation, growth productivity differences (Conrad et al., 2014; X. Wang, 2020; Wen et al., 2019; Yang et al., 2019), or whether they are oil importer or exporter (Boldanov et al., 2016; Filis et al., 2011; Wang et al., 2013). Therefore, in addition to controlling country-level factors, the key contribution of this paper is the investigation of the significance of a sector's financial conditions (profitability and solvency ratios) on the magnitude of the connectedness between oil & gas sector returns and oil price changes. The fact that being in a financially vulnerable position may influence foreign investors' decisions justifies why sectors' stock returns may vary significantly because of sudden changes in oil prices A higher level of connectedness between stock returns of oil & gas sector and oil price shocks can be observed consequently. In contrast, the higher profitability and solvency position might help sectors to create a better signal in the markets and offer them protection to oil price shocks, which in turn lower connectedness between oil shocks and the sector. To our knowledge, this is the first research investigating the potential effect of the sector's financial positions on the level of connectedness between sector returns and oil price changes whereas earlier studies have mostly focused on the position of macroeconomic factors (Conrad et al., 2014; X. Wang, 2020; Wen et al., 2019; Yang et al., 2019).

Our empirical findings report a high level of connectedness between crude oil and stock returns of oil & gas sector. The relationship's dynamics are highlighted, with evidence of a dramatic increase in connectedness magnitude during turbulent periods. The connectedness is found bidirectional but the critical role of oil shocks in explaining the performance of oil & gas stock market is more pronounced in Japan. By contrast, in Canada, the UK, and the US, the transmission of shocks from the stock markets to crude oil prices is stronger. Prominently, we further acknowledge a statistically significant impact of the sector's profitability and solvency ratios on explaining the connectedness level. When connectedness' level is positively impacted by the debt to asset ratio, the negative impact is found in the cases of interest coverage-, profit margin, and P/E ratios. When testing the role of the financial openness of the markets on the sector's solvency and profitability positions by employing interaction variables, we find that for the countries that have more international investors (financially more open), the impact of the solvency positions of the sectors on the connectedness is much higher compared to less financially open countries. On the final note, when we document connectedness across various frequencies, including short (1–5 days), medium (5–30 days), and long-run (30–262 days), the latter results remain significant, yet the short-run effect is found stronger in comparison with the long-run effect, signifying the stronger presence of oil-stock connectedness in short term.

The rest of the paper is structured as follows. A brief literature review is presented in section 2. Section 3 introduces the methodology, followed by the data description given in section 4. Section 5 reports empirical findings and concluding remarks are given in section 6.

2. Literature review

An ever-increasing interest in the relationship between oil prices and the stock market performance has been recorded in the last two decades with the majority of the literature supporting a statistically significant relationship between them (Arouri et al., 2011; Broadstock et al., 2012). To illustrate, Kaneko and Lee (1995)' findings show that among various economic variables, oil price movement is defined as the most significant factor explaining Japanese stock market returns. Then, Jones and Kaul (1996), analysing the response of international stock prices to the oil shocks during the post-war periods for the cases of four countries (Canada, Japan, US, and the UK), find that the stock markets rationally reflect the change of oil prices. Regarding OECD countries, Miller and Ratti (2009) report a significant long-run linkage between two series from 1971 to 1980 and from 1988 until 1999. Even in the intervening period, the result is not statistically significantly different from those in the previous periods. Several explanations for the linkage between them, therefore, have been proposed. As noted by Jones and Kaul (1996), since oil is taken as important input in the production of goods and services, the oil price's fluctuation appears to impact companies' future cash flows, causing the movement of stock prices. In addition, given the fact that expected inflation and real interest rate, which is employed to estimate the discount rate in calculating stock prices, is strongly affected by oil's fluctuation, the impact of oil price movement on the stock market is apparent (Jones and Kaul, 1996). Financialization is a recent phenomenon that can further explain the oil-stock market association (Ma et al., 2019). Due to the development of oil-related financial derivative products, it is much easier to use oil as an asset for forming portfolios and diversifying risk. The interdependence between oil and stock markets, thus, has been strengthened thanks to financialization.

The literature on the oil-stock relationship has further directed its attention to the sector since the linkage appears to differ widely across industries (Arouri et al., 2011; Bouri et al., 2016; Broadstock et al., 2012; Broadstock and Filis, 2014; Hamdi et al., 2019; Tiwari et al., 2018). For instance, Bouri et al. (2016), testing the causality between oil prices and sectoral equity returns in Jordan, suggest significant linkage in financial and service sectors, whereas, regarding the industrial sector, the effect is negligible. The paper by Hamdi et al. (2019) embraces the fact that the effect of oil on the stock market differs across sectors when considering alternative market conditions. Notably, according to Broadstock and Filis (2014); Tiwari et al. (2018), oil prices have a positive impact on oil-related (oil & gas, mining) and oil-substitute sectors, but have a negative impact on oil-using sectors (Airline, Transportation, Manufacturing, Automobile, Food, Chemicals, Medical, Computer, Real Estate, and General Services), and have no impact on non-oil-related sectors (financial sector).

Realizing the relationship between oil shocks and stock markets is industry-specific, this paper complements a growing literature on the oil-stock nexus by focusing on the connectedness between oil price changes and stock market returns at sectoral/industrial levels. Specifically, the oil&gas sector is selected as the fact that among different sectors, the energy sector appears to be more sensitive to oil prices (Broadstock et al., 2012). The link between oil prices and the stock market of oil & gas sector is easy to justify by the industrial-level common information (Arouri et al., 2011b) and it is more likely to exist than the other industries (Bouri et al., 2016; Broadstock et al., 2012). Indeed, Arouri et al. (2011) marks the dominant role of the oil & gas industry when assessing the interdependence between the oil shocks and four energy sectors of oil & gas, electricity, coal, and alternative energy in the US. Likewise, the investigation by Boyer and Filion (2007); El-Sharif et al. (2005); Sadorsky (2001, 2003) reveals a significant impact of oil shocks to stock returns in the oil & gas sector in Canada and the UK. The most recent and related study to our paper is by Antonakakis et al. (2018). Antonakakis et al. (2018)'s study identifies the transmission channel and contagion of volatility between oil prices and stocks of major oil and gas corporations through the same connectedness approach of Diebold and Yilmaz, 2009, 2012, 2014, 2015) and the dynamic correlation coefficient model of Engle (2002). The significant connectedness between two markets with the dominant role of oil as the net shock transmitter is found. Nevertheless, while Antonakakis et al. (2018)'s paper use the firm level data, our study differs by the use sector level data.

Additionally, while the majority of prior research seems to explore the unidirectional effect from the oil market to the stock market, employing the Diebold and Yilmaz (2012) and Baruník and Křehlík (2018) approaches offer a test of the bidirectional connectedness between markets and its variation over time. When Arouri et al. (2011), using the generalized VAR-GARCH approach, report the unidirectional link from the oil market to the stock markets in Europe, the bidirectional effect is found in the US. Similarly, Awartani and Maghyereh (2013), employing the methodology developed by Diebold and Yilmaz, highlights bi-directional connectedness between oil and stock markets in GCC countries. It is also worth noting that rather than a constant relationship, the connection between oil and stock markets should be examined in a time-varying perspective (Antonakakis et al., 2017; Broadstock et al., 2012). Indicatively, Broadstock et al. (2012) found that the correlation is not constant in China and it appears to be strengthened after the Global Financial crisis. Similarly, Martín-Barragán et al. (2015) state that the correlation between oil price changes and stock market returns is almost zero during calm periods, whereas this correlation changes during oil and financial shocks. Although studies on connectedness have been conducted by several authors, there has been less previous evidence for the variation of connectedness across frequencies. Our paper contributes to the literature by using the frequency connectedness approach developed by Baruník and Křehlík (2018). There is a clear advantage in following the method as it can decompose the frequencies into short, medium-, and long-term. Significant ramifications for investors are provided accordingly.

Prominently, the interdependence between oil and sectors is pronounced, yet relatively few document its driving factors. Some authors suggest that countries may react differently to oil prices due to country-level idiosyncratic characteristics. Conrad et al. (2014), exploring the effect of changes in the macroeconomic factor on the long-term correlation between crude oil and the US stock market, find that these variables can be used to predict the movements in the long-term correlation. Similarly, Yang et al. (2019) provide strong evidence of the significant effect of the economic activity, inflation rate, risk-free rate, credit spread, the term spread on oil-stock correlation. The wide range of variables, which measure the global and domestic macroeconomy, monetary policies, and other financial markets, to explain oil-stock market dependence patterns are documented by Wen et al. (2019) in the context of emerging countries. The role of interest rate is especially focused on by X. Wang (2020) when investigating the frequency dynamics of volatility spillovers among crude oil and international stock markets. While earlier studies have mostly focused on the position of macroeconomic factors, the role of a sector's financial conditions (profitability and solvency ratios) on the magnitude of the connectedness between sector returns and oil prices is rarely analysed in the literature. This study sheds light on the potential impact of sectoral profitability and solvency on the connectedness level. We conjecture that a sector with stronger profitability and solvency position is less vulnerable to the oil price fluctuations.

3. Methodology

In this paper, our empirical approach combines two steps. The first step is to estimate the connectedness between crude oil and the stock returns of oil & gas sector through the use of the Diebold and Yilmaz (2012) and Baruník and Křehlík (2018) models. The analysis is followed by the panel data regressions to assess the effect of sectoral solvency and profitability positions on the magnitude of connectedness.

3.1. Total connectedness

To document the presence and magnitude of connectedness between oil price changes and the returns of the oil & gas sector, we employ the connectedness index methodology developed by Diebold and Yilmaz (2012). Through the variance decomposition matrix, the approach is further utilized for exploring the direction of connectedness, revealing the information transmission channel.

We start with the covariance stationary vector autoregressive lag of p, VAR(p) in a set up using N variables,

$$x_t = \sum_{i=1}^{p} \varphi_i x_{t-i} + \varepsilon_t \tag{1}$$

where φ represents the coefficient matrices, t is the time index (specifically days within our sample) and $\varepsilon_t \sim (0, \Sigma)$ is the vector of the disturbances distributed independently and identically. Each variable (referring to each market) in this model is regressed on its own p lags and the p lags of each other variable in the systems, allowing us to acquire the coefficient matrices that disclose the connections between the variables. The N x N matrix lag polynomials can be expressed as $\varphi(L) = [I_N - \varphi_1 L - \ldots - \varphi_p L^p]$ with I_N identity matrix.

The VAR process can also be represented by moving average modelling as

$$x_t = \Psi(L)\varepsilon_t \tag{2}$$

where $\Psi(L)$ is N x N infinite lag polynomials following the rule $\varphi(L) = [\Psi(L)]^{-1}$ with the assumption that $\varphi(L)^{-1}$ exists. Because an infinite number of lags are contained in $\Psi(L)$, it needs to be estimated approximately by the moving average coefficients Ψ_h calculated at h = 1, …., H horizons.

As the results of variance decomposition were found to be influenced by the order of variables in the system, we applied the generalized vector autoregression (VAR) framework. This methodology was initially introduced by Koop et al. (1996) and Pesaran and Shin (1998), and was further developed by Diebold and Yilmaz Diebold and Yilmaz (2012) to address this issue.

Accordingly, as denoted by $\theta_{j,k}(H)$, the H step-ahead generalized variance decomposition is defined as

$$\theta_{j,k}(H) = \frac{\sigma_{kk}^{-1} \sum_{h=0}^{H} \left(\Psi_h \Sigma_{j,k}\right)^2}{\sum_{h=0}^{H} \left(\Psi_h \Sigma \Psi_h^{'}\right)_{j,j}} \tag{3}$$

where σ_{kk} is the standard deviation of the kth equation for the variance matrix of error term. The $\theta_{j,k}(H)$ denotes the contribution of the kth variable to the variance of forecast error of the factor j, at the horizon h.

Considering that the total variance decomposition in each row is different from 1, the normalization process is used to generate the connectedness index. Each entry of the variance decomposition matrix is normalized by the row sum as

$$\widetilde{\theta}_{j,k}(H) = \frac{\theta_{j,k}(H)}{\sum_{k=1}^{N} \theta_{j,k}(H)} \tag{4}$$

In other words, $\widetilde{\theta}_{j,k}(H)$ is the pairwise directional connectedness from k to j. The total variance decomposition of each row, therefore, equals 1 after normalization, $\sum_{j=1}^{N} \widetilde{\theta}_{j,k}(H) = 1$, and the sum of all elements in $\widetilde{\theta}(H)$ is N.

3.2. Directional connectedness

The question of whether any given market is a source or a recipient of shocks can be resolved by examining the direction of connectedness. Firstly, the directional connectedness from all other markets to market j, $C_{j.}(H)$, is computed as

$$C_{j.}(H) = \frac{\sum_{k=1(j\neq k)}^{N} \widetilde{\theta}_{j,k}(H)}{\sum_{j,k=1}^{N} \widetilde{\theta}_{j,k}(H)} \times 100 = \frac{\sum_{k=1(j\neq k)}^{N} \widetilde{\theta}_{j,k}(H)}{N} \times 100. \tag{5}$$

Similarly, the total directional connectedness transmitted by market j to all other markets k, $C_{.j}(H)$, is then calculated as

$$C_{.j}(H) = \frac{\sum_{k=1(j\neq k)}^{N} \widetilde{\theta}_{k,j}(H)}{\sum_{j,k=1}^{N} \widetilde{\theta}_{k,j}(H)} \times 100 = \frac{\sum_{k=1(j\neq k)}^{N} \widetilde{\theta}_{k,j}(H)}{N} \times 100. \tag{6}$$

By taking the difference between the total directional connectedness from the market j transmitted to other markets and the total directional connectedness to the market j received from other markets, the net total connectedness from market j to all other markets, $NetC_j(H)$, is

$$NetC_j(H) = C_{.j}(H) - C_{j.}(H). \tag{7}$$

The positive (negative) value of net directional connectedness indicates that the market is the shock transmitter (receiver).

3.3. Frequency decomposition of connectedness measures

To further decompose the aggregate connectedness into short-, medium-, and long-term, we apply the frequency connectedness framework developed by Baruník and Křehlík (2018). The primary steps for delivering connectedness measures at a certain frequency band are outlined in this section, and more details can be found in Baruník and Křehlík (2018)'s study.

The variance is decomposed into spectral components to find the connectedness at different frequencies. Accordingly, a frequency response function is firstly constructed by the use of Fourier transform of the coefficients Ψ_h, $\Psi(e^{-i\Theta}) = \sum_{h=-\infty}^{\infty} e^{-i\Theta h}\Psi_h$, with $i = \sqrt{-1}$. The spectral density of x_t via the Fourier Transform for MA(∞) at frequency Θ is computed as

$$PS_x(\Theta) = \sum_{\mathrm{h}=-\infty}^{\infty} E\left(x_t x_{t-\mathrm{h}}^{'}\right) e^{-i\Theta h} = \Psi\left(e^{-i\Theta}\right) \sum \Psi^{'}\left(e^{+i\Theta}\right), \tag{8}$$

where $PS_x(\Theta)$ represents the power spectrum, indicating the distribution of x_t's variance over the frequency component Θ. Additionally, by the use of the spectral presentation for covariance as $E(x_t x_{t-h}^{'}) = \int_{-\pi}^{\pi} PS_x(\Theta) e^{i\Theta h} d\Theta$, the frequency domain counterparts of variance decomposition is defined as

$$(f(\Theta))_{j,k} = \frac{\sigma_{kk}^{-1} \left| \left(\Psi(e^{-i\Theta}) \sum\right)_{j,k} \right|^2}{\left(\Psi(e^{-i\Theta}) \sum \Psi^{'}(e^{+i\Theta})\right)_{j,j}} \tag{9}$$

$(f(\Theta))_{j,k}$ is the component of the jth variable's spectrum at the Θ frequency due to the shocks in the kth variable. It can be weighted by the frequency share of the jth variable variance to acquire the generalized decomposition of variance decomposition in the frequency dynamics, as noted in equation (11). The weighting function shows the power of the jth variable at a given frequency, which sums through frequencies to a value of 2π. It is calculated as

$$\Gamma_j(\Theta) = \frac{\left(\Psi(e^{-i\Theta}) \sum \Psi^{'}(e^{+i\Theta})\right)_{j,j}}{\frac{1}{2\pi}\int_{-\pi}^{\pi} \left(\Psi(e^{-i\lambda}) \sum \Psi^{'}(e^{+i\lambda})\right)_{j,j} d\lambda} \tag{10}$$

The frequency band b is estimated as $\mathrm{b} = (\mathrm{c}, \mathrm{d}) : \mathrm{c}, \mathrm{d} \in (-\pi, \pi), \mathrm{c} < \mathrm{d}$. We can have the generalized variance decomposition (GFEVD) on frequency band b as

$$\theta_{j,k}(b) = \frac{1}{2\pi}\int_b \Gamma_j(\Theta)(f(\Theta))_{j,k} d\Theta \tag{11}$$

As the fact that GFEVD under the frequency band b needs to be normalized, the scale GFEVD can be found as $\widetilde{\theta}_{j,k}(b) = \frac{\theta_{j,k}(b)}{\sum_k \theta_{j,k}(\infty)}$, where $\theta_{j,k}(b)$ is the pairwise connectedness at a given frequency b and $\theta_{j,k}(\infty) = \frac{1}{2\pi}\int_{-\pi}^{\pi} \Gamma_j(\Theta)(f(\Theta))_{j,k} d\Theta$. Then, we can find the total connectedness at frequency band b as

$$TC^F(b) = 100.\left(\frac{\sum \widetilde{\theta}(b)}{\sum \widetilde{\theta}(\infty)} - \frac{Tr\{\widetilde{\theta}(b)\}}{\sum \widetilde{\theta}(\infty)}\right) \tag{12}$$

where $\sum \widetilde{\theta}(b)$ is defined as the sum of all elements of the $\widetilde{\theta}(b)$ matrix and where Tr{.} indicates the trace operator.

3.4. Determinants of total spillover from oil price changes to stock returns of oil & gas sector

After identifying the magnitude of connectedness between oil price changes and the oil & gas sector returns, we explore factors driving the level of connectedness. Macroeconomic factors are the focus of earlier research that attempted to forecast the movement of connectedness. Those variables can be used to forecast alterations in the long-term correlations, according to Conrad et al. (2014). The later research by Yang et al. (2019) provides evidence of the importance of the impact of economic activity, inflation rate, risk-free rate, credit spread, and term spread on the connection between oil prices and stock prices. Wen et al. (2019) have identified monetary policy as one of the factors that influence connectedness in the context of emerging countries. While past research has mostly concentrated on the position of macroeconomic factors, the impact of a sector's financial circumstances (profitability and solvency ratios) on the degree of the connectedness between sector returns and oil prices has not been examined. Profitability and solvency, therefore, are measured by the use of leverage, interest expense coverage, price-earnings ratio, and profit margin of sectors.

We hypothesize that the connectedness between oil shocks and sectoral equities is linked to market capitalization, total assets, leverage, interest expense coverage, price-earnings ratio, and profit margin of sectors in the oil & gas sector. We convert daily connectedness into an annual average for regression as the financial position variables are available annually. A panel regression equation is specified for the sectoral stock markets. This equation is given as follows:

$$CONN_{kt} = \alpha_0 + \alpha_1 MCAP_{kt} + \alpha_2 TOTAL\_ASSETS_{kt} + \alpha_3 DEBT/ASSET_{kt} + \alpha_4 INTEREST\_COVER_{kt} + \alpha_5 P/_E RATIO_{kt} + \alpha_6 P\_MAR_{kt} + \alpha_7 EPU_t + \alpha_8 OIL\_EXP_{kt} + \alpha_9 Inflation_t + \alpha_{11} GDP_t + \varepsilon_{kt} \quad (13)$$

Here, the dependent variable, $CONN_{kt}$ is created in four ways including pairwise, long-run, medium-run, and short-run connectedness. The pairwise connectedness, is defined in equation (4) while the connectedness at different frequencies, $TC^F(b)$, are defined in equation (12). We decompose total return connectedness into frequency bands up to 1 week (1–5 days), 1 week to 1 month (5–30 days), and 1 month to 262 days (30–262 days), which correspond to short-term, medium-term, and long-term. The dependent variable refers to the net connectedness of oil price changes (global) with the stock returns of oil & gas sector of country k at year t. In detail, the Oil and Gas sector equity returns for each country(k) identified and we have calculated the connectedness of each countries (k) oil and gas sector equity indices with oil price changes. In order to capture the country specific effects, we employ GDP per capita, and inflation levels as well. Among the independent variables, $MCAP_{kt}$ and $TOTAL\_ASSETS_{kt}$ refer to the market capitalization and total asset value of the equity market of oil & gas sector of country k at time t, respectively. Likewise, for the same sector, $DEBT/ASSET_{kt}$ stands for the debt to asset ratio, $INTEREST\_COVER_{kt}$ denotes how many times the profit covers interest expense, $P/_E RATIO_{kt}$ refers to the price-earnings ratio and P_MAR_{kt} refers to the profit margin. The control variables include EPU_t, which stands for the World Economic Policy Uncertainty at time t, and OIL_EXP, which acts as a dummy variable to capture the country's status being a net oil exporter when the value is one and zero otherwise. We have controlled for time fixed and country fixed effects in our models.[1] The independent variables are not perfectly correlated with each other, so we rule out the multicollinearity problem.[2] Nonlinearity (RESET) and normality test results indicate the suitability of using the OLS to run the model.

We also extend the model in equation (14) with the Financial Openness (FIN_OPEN) variable. FIN_OPEN corresponds to the financial openness of the market k, which is measured as the sum of financial assets and liabilities to GDP. We interact the financial openness with the X_{kt} vector where X_{kt} contains $DEBT/ASSET_{kt}$, $INTEREST\_COVER_{kt}$, $P/_E RATIO_{kt}$, P_MAR_{kt}..

$$CONN_{kt} = b_0 + b_1 MCAP_{kt} + b_2 TOTAL\_ASSETS_{kt} + b_3 DEBT/ASSET_{kt} + b_4 INTEREST\_COVER_{kt} + b_5 P/_E RATIO_{kt} + b_6 P\_MAR_{kt} + b_7 EPU_t + b_8 OIL\_EXP + b_9 FIN\_OPEN_{kt} + b_x FIN\_OPEN_{kt} * X_{kt} + b_{10} Inflation_t + b_{11} GDP_t + \varepsilon_{kt} \quad (14)$$

4. Data description

To investigate the connectedness between oil prices and the oil & gas stock returns, our analysis employs the dataset of 22 OECD countries, running from December 31, 1999 to September 1, 2020. The selection of the OECD countries is based on the availability of the sectoral financial variables.[3] The Brent Crude oil is taken from the Energy Information Administration database, which has been used as a key benchmark of the crude oil market, considering that about two-thirds of the world's traded oil are priced based on the Brent complex. In terms of oil & gas sector, we obtain sector indices of Australia, Belgium, Chile, Canada, Spain, France, Greece, Hungary, Ireland, Israel, Italy, Japan, Korea, Netherlands, Norway, New Zealand, Austria, Poland, Slovenia, Turkey, United Kingdom, United States. All data are collected from DataStream and expressed in US dollars. Return series are measured by taking the first difference of the logarithmic prices multiplied by 100.

Table 1 provides the descriptive statistics for crude oil returns and stock returns of oil & gas sector across studied countries. While the average daily return of oil (BRT) is reported at 0.000112, its standard deviation at 0.026552 indicates its high volatility. These figures are consistent with the previous studies. Concerning the stock returns of the oil & gas sector across countries, Belgium and Korea report the highest returns while the lowest returns are found in Greece and Turkey, again consistent with previous literature. The standard deviation of the oil & gas sector ranges from 0.015540 (Slovenia) to 0.045541 (Ireland). The Jarque-Bera test provides evidence of normality at the 1% significance level. The null hypothesis of unit root existence is rejected by the Augmented Dickey-Fuller test, confirming the stationary of data.

The descriptive statistics of factors driving the connectedness between the oil price and the stock returns of oil & gas sector are given in Table 2. The variables include MCAP, which stands for market capitalization, and TOTAL_ASSETS, defined as the natural logarithm of total assets, as well as DEBT/ASSET, a measure of a company's total debt relative to assets, and INTEREST_COVER, which measures a company's ability to make interest payments on its debt. P/E RATIO refers to the price-earnings ratio, and P_MAR stands for profit margin. The variable EPU represents the World Economic Policy Uncertainty, while FINOPEN corresponds to the financial openness of the markets. Data for these variables were collected from DataStream, except for EPU, which was obtained from the website of the Economic Policy Uncertainty Index developed by Baker et al. (2016).

As can be seen, the sector debt ratio is found at 0.19 on average, which implies that net debt accounts for 19% of the total asset. More importantly, the debt ratio has a range of 0.56 to 0.08, which shows a greater variance between countries. The ability of a company's profits to make the interest payments on its debt is shown on the interest ratio, which is recorded at 8.3, but it is ranging from 85.81 to 0.65, indicating the greater variance among sectors. It is also noticeable that the sector of oil & gas has a negative average profit margin (−2.45) as the value varies widely between −729.48 and 48.82. We also report the financial openness measures

[1] We removed EPU variable to test for time fixed effect.

[2] The correlation matrix has valued between −0.20 and 0.36, for the sake of brevity we did not print the correlation table, results are available upon request from the author.

[3] As not all OECD countries have published sectoral financial ratios, we were constrained to limit our analysis to only 22 countries.

Table 1
Descriptive statistics of Brent crude oil returns and stock returns of oil & gas sector.

Countries	ABB	Mean	Std. Dev.	Skewness	Kurtosis
Australia	AU	0.0002	0.0189	−0.7460	12.2532
Belgium	BG	0.0002	0.0157	−0.4264	11.8315
Chile	CL	0.0001	0.0177	−0.0692	8.5161
Canada	CN	0.0001	0.0195	−0.9936	17.5593
Spain	ES	−0.0001	0.0186	−0.2776	10.4270
France	FR	0.0001	0.0178	−0.2885	12.7525
Greece	GR	−0.0002	0.0212	−0.1214	7.3956
Hungary	HN	0.0001	0.0234	0.0830	10.7331
Ireland	IR	0.0000	0.04551	0.0982	20.5504
Israel	IS	0.0002	0.01964	−0.1469	13.4563
Italy	IT	−0.0000	0.01839	−0.3139	15.5492
Japan	JP	0.0000	0.01844	−0.1281	5.9437
Korea	KO	0.0002	0.0311	0.0092	9.2113
Netherland	NL	0.0001	0.0221	−0.3838	11.9050
Norway	NW	0.0001	0.0211	−0.4566	10.4990
New Zealand	NZ	0.0002	0.0175	−0.1361	12.2793
Austria	OE	0.0002	0.0222	−0.5140	11.8088
Poland	PO	0.0002	0.0204	−0.1020	5.3635
Slovenia	SJ	0.0001	0.0156	−0.0228	9.0330
Turkey	TK	−0.0004	0.0269	−0.1502	9.3284
United Kingdom	UK	−0.0001	0.0177	−0.2626	16.8183
United States	US	0.0001	0.0172	−0.8288	20.4634
Brent Crude Oil	BRT	0.0001	0.0265	−2.1411	88.7763

Notes: ABB stands for Abbreviation. Std. Dev represents the standard deviation. The Jarque-Bera test is the test of normality. ADF represent the p value of the Augmented Dicky-Fuller test of stationary. *** indicates the significant level at 1%. Jarque-Bera Test and ADF test statistics P values all less than 1% for all observations.

Table 2
Descriptive statistics of determinants of total spillover from oil price shocks to stock returns of oil & gas sector.

Variables	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
DEBT/ASSET	0.19	0.56	0.08	0.13	−0.45	6.76	0.00***
INTEREST_COVER	8.30	85.81	0.65	24.43	−13.86	249.76	0.00***
MCAP	3.56	54.76	0.01	8.94	3.99	18.49	0.00***
P/E RATIO	44.56	1910.40	−963.30	192.97	4.59	37.39	0.00***
P_MAR	−2.45	48.82	−729.48	57.38	−8.88	93.75	0.00***
TOTAL_ASSETS	0.19	0.56	−0.58	0.13	−0.45	6.76	0.00***
EPU	127.71	429.53	48.89	67.39	1.59	2.68	0.00***
FIN_OPEN	0.64	1.24	0.32	0.49	−0.40	1.18	0.00***

Notes: MCAP refers to the market capitalization indicating the size of the firms in energy sector while TOTAL_ASSETS is the firm size which is defined as the natural logarithm of total assets. DEBT/ASSET defines the total amount of debt relative to assets. INTEREST_COVER is a measure of the ability of a company's profits to make the interest payments on its debt. P/E RATIO stands for price-earnings ratio while P_MAR refers to profit margin. EPU stands for World Economic Policy Uncertainty. FINOPEN corresponds to financial openness of the markets. Std. Dev represents the standard deviation. The Jarque-Bera test is the test of normality. *** indicates the significant level at 1%.

between markets, which is ranging from 124% to 32% with a mean of 64%. All these figures indicate a great spread among independent variables across different markets and testing these differences help us to explain the extent of the connectedness.

5. Empirical results

5.1. Connectedness between oil price and stock returns of oil & gas sector

5.1.1. Diebold and Yilmaz (2012)'s total connectedness

In order to investigate the connectedness between markets, we employ both the static and dynamic connectedness analysis. The static connectedness provides an overview of connectedness on average, whereas the dynamic approach illustrates the evolution of connectedness through time, given the impact of certain events. The estimation of dynamics of connectedness is based on the 100-day forecast horizon and the 262-day rolling windows to assess.[4] The optimal VAR lag length is selected by Schwarz's Bayesian Information

[4] As mentioned by Antonakakis et al. (2018); Xu et al. (2019), the results based on alternative rolling windows and forecast horizon are qualitatively similar. Xiao and Huang (2018) notes that the variation in the forecast horizon (6, 12, 18) and rolling windows (100, 200, or 300) has no effect on connectedness trend.

Criterion (SIC). This section documents the total connectedness across all studied markets before examining its time-varying feature accordingly.

Based on the entire sample estimation, Table 3 depicts the static connectedness across markets. The high value of total connectedness, which is recorded at 65.63 percent, denotes a high level of interconnectedness between oil price and stock returns of oil & gas sector on average. Furthermore, the time-varying aspect of total connectedness can be clearly seen in Fig. 1, which is consistent with Broadstock and Filis (2014). During the commencement of a financial tsunami, such as the GFC or the COVID 19 outbreak, the peak of connectedness is generally witnessed.

In particular, the total connectedenss between oil prices and oil & gas sector's stock market started to record high in the years 2005–2006, which corresponds to some geopolitical events and natural disasters, such as Hurricane Katrina in 2005, the Iranian nuclear program, and the North Korean missile test (2006). The index declined slightly in 2007, before increasing again in 2008 due to the impact of the GFC, which caused the decrease of oil demand and the collapse of oil prices. Owning to the effect of the Gulf of Mexico oil spill (2010), the 2011 uprisings in the Arab Middle East, and the European sovereign debt crisis (ESDC) of 2009–2012, the figure rose to a high point in 2010 and remains substantial in magnitude until 2012. From 2015 onwards, the sharpest increase of connectedness is witnessed during the shale-oil revolution of 2014–2016. Most recently, stemming from the 2019 coronavirus disease (COVID-19) pandemic impact, another strike of connectedness between crude oil and the stock market of oil & gas sector is noted in 2020. The variation of connectedness and its increasing pattern during the period of economic and financial uncertainty, in fact, is well documented in prior studies by Antonakakis et al. (2017); Antonakakis et al. (2018); Broadstock et al. (2012); Broadstock and Filis (2014). As the economic uncertainty increases, the flow of negative information is transmitted across the system. As a result, more assets are subject to a readjustment of valuation, leading to rising interconnectedness.

5.1.2. Diebold and Yilmaz (2012)'s directional connectedness

Although there is a clear link between oil shocks and stock markets in OECD countries, the question of which markets are the key shock transmitters (receivers) remains unanswered. This section presents findings based on the net directional connectedness as well as the pairwise connectedness between oil shocks and stock reruns of oil & gas sector. The purpose of this section is to show the position of each market to other market.

First, in terms of net connectedness, these figures identify the sources of shocks as the fact that markets having positive net connectedness (NET) are regarded as the net transmitters. As indicated in Table 3, the oil & gas sector's stock markets of France, Canada, and the UK appear to be the leading shock transmitters in the system, considering their highest value of net connectednessm (48.85, 43.06, and 42.91, respectively). Japan's sectoral stock market, on other side, has the lowest level of net connectedness (−51.11), followed by the stock market of Korea (−32.63). These countries, therefore, are highly likely to be affected by the movement of oil prices and other oil & gas stock markets.

Regarding crude oil (BRT), the negative net connectedness value (−21.91) reveals that it is generally a shock receiver, which is influenced by the fluctuation of stock markets. It is a well-established fact that changes in the price of oil can impact the stock market. However, it is important to note that movements in the stock market can also have a significant impact on the oil market, resulting in a bidirectional relationship between the two markets. One key reason for this relationship is that the stock market is often considered to be a leading indicator of economic activity. The prices of stocks are determined by the expectations of investors regarding the future profitability of the companies they invest in. When investors are optimistic about economic growth and corporate earnings, they tend to buy stocks, resulting in an increase in stock prices. This increase in stock prices can boost consumer confidence and spending, leading to higher demand for commodities such as oil. Conversely, when investors are pessimistic about the economy and future corporate earnings, they tend to sell stocks, driving down stock prices. This decrease in stock prices can dampen consumer confidence and spending, leading to lower demand for oil. Additionally, the stock market can also reflect broader financial trends that can impact the price of oil. For example, changes in interest rates, which can be reflected in the stock market, can also have an impact on the price of oil and other commodities. Overall, the relationship between the stock market and the oil market is complex and change in the stock market can provide insights into the oil market.

The results are reconfirmed when we look at the pairwise directional connectedness (PAIRWISE) between crude oil and stock markets across countries, the highest positive value of pairwise connectedenss in Canada, Norway, the US, and the UK are discovered. The movement of these oil & gas stock markets, therefore, is emphasized as the source of shocks, leading to the variation in oil prices accordingly. On the other hand, oil & gas stock markets in Japan, Korea, and New Zealand stands out as the dominant shock receivers, which are heavily impacted by the movement of oil prices. The heterogeneous responses concerning the direction of connectedness between crude oil and stock markets across countries, as underlined by Antonakakis et al. (2017); Maghyereh et al. (2016), can be associated with the proposition of countries as the net oil-importers or the net oil-exporters. For instance, Canada is considered the world's top oil exporter among the studied countries, primarily due to its Athabasca oil sand reserves. Norway also has a significant presence in the global oil market as a producer and exporter of oil to Europe and other regions, contributing significantly to its economy. Additionally, with the shale oil revolution and the lifting of the export ban on crude oil export since 2015, accompanied by the expansion of domestic oil production and infrastructure, the United States has emerged as one of the top oil exporting countries. By contrast, the Japanese economy appears to depend largely on energy imports. In 2019, as reported by U.S Energy Information Administration (EIA), Japan was the world's fifth-largest oil consumer and fourth-largest crude oil importer. As a result, in line with Kayalar et al. (2017)' findings, we attribute the market position difference across countries to the degree of reliance of the country on foreign oil, with higher country's oil dependence suggests the higher impact of oil shocks to the country's oil and gas sector.

Prominently, because the movement of US, the UK, and Canadian oil & gas stock markets can cause the variation in oil prices while oil prices' fluctuation, in turn, is associated with the movement of oil and gas sectors in Japan, the role of oil as a global intermediary

Table 3
Full sample static connectedness between oil price shocks and stock returns of oil & gas sector.

	BRT	AU	BG	CL	CN	ES	FR	GR	HN	IR	IS	IT	JP	KO	NL	NW	NZ	OE	PO	SJ	TK	UK	US
BRT	41.01	2.57	0.13	1.33	8.39	3.75	4.88	0.98	1.47	0.32	0.72	4.15	0.49	0.33	4.04	6.75	0.37	3.32	1.35	0.27	0.41	5.91	7.07
AU	2.50	21.54	0.55	2.52	8.85	4.22	5.74	2.10	3.20	0.88	1.52	5.21	2.09	1.67	5.00	6.74	2.13	4.06	2.77	1.32	1.62	5.97	7.78
BG	0.23	1.77	67.12	0.64	1.70	2.05	2.42	1.41	2.47	0.61	0.33	2.67	0.51	0.23	2.46	2.25	1.20	2.35	1.94	2.50	0.65	1.57	0.91
CL	1.29	2.85	0.30	39.61	5.00	4.54	5.06	1.81	3.28	0.97	1.55	4.62	0.20	0.96	3.95	4.37	0.93	2.96	3.28	0.86	2.43	4.64	4.54
CN	3.85	3.84	0.46	2.50	20.22	5.17	7.08	1.60	2.70	0.83	1.30	6.10	0.60	0.53	5.20	7.45	0.86	4.25	2.47	0.75	1.16	8.08	13.00
ES	1.90	2.54	0.60	2.34	5.46	20.11	10.41	2.51	3.06	0.65	1.58	9.74	0.42	0.55	5.43	6.86	1.00	5.30	3.14	1.00	1.29	8.91	5.23
FR	2.00	2.71	0.58	2.14	6.29	8.65	16.75	2.09	3.20	0.67	1.53	10.79	0.44	0.58	5.43	7.33	0.86	5.19	3.00	1.04	1.17	11.01	6.55
GR	0.96	3.40	0.81	1.95	3.53	4.99	5.07	39.21	3.63	0.73	1.62	4.88	0.64	0.95	4.05	4.29	0.91	3.86	4.25	1.63	1.93	3.84	2.89
HN	1.05	3.51	0.95	2.55	4.36	4.53	5.70	2.79	29.86	0.85	1.95	5.28	0.43	0.75	4.82	5.29	1.18	4.33	7.20	1.92	2.55	4.56	3.59
IR	0.58	2.16	0.57	1.84	3.11	2.09	2.69	1.15	1.83	62.92	0.51	2.53	0.47	0.54	2.42	2.72	0.75	2.42	1.77	0.76	0.77	2.91	2.48
IS	0.84	2.34	0.21	1.89	3.15	3.74	4.34	1.69	3.07	0.39	48.24	4.19	0.39	0.65	2.86	4.43	0.92	3.00	3.73	0.51	2.09	4.38	2.95
IT	1.84	2.83	0.70	2.10	5.76	8.77	11.67	2.17	3.19	0.74	1.59	18.10	0.41	0.46	5.77	7.04	0.95	5.05	3.10	1.27	1.31	9.70	5.48
JP	3.06	4.11	0.37	1.79	7.82	4.19	5.48	1.45	1.92	0.73	0.91	4.69	31.57	1.12	4.54	5.86	0.75	3.39	1.78	0.73	0.83	5.58	7.33
KO	0.87	4.23	0.19	2.24	3.32	2.87	3.60	1.85	2.32	0.53	1.10	2.81	1.50	51.52	2.85	3.53	1.25	2.27	2.42	0.53	1.22	3.60	3.36
NL	2.27	3.26	0.78	2.29	6.27	6.12	7.35	2.28	3.64	0.84	1.36	7.18	0.43	0.67	22.43	8.02	1.15	5.01	3.41	1.37	1.52	7.01	5.33
NW	3.09	3.93	0.59	2.07	7.83	6.33	8.19	1.97	3.25	0.72	1.70	7.21	0.75	0.66	6.56	18.35	1.01	5.16	3.33	0.88	1.41	8.47	6.56
NZ	0.90	4.93	0.82	1.94	4.13	3.00	3.43	1.42	2.60	0.69	1.30	3.37	0.74	1.03	3.38	3.49	47.55	2.64	2.20	1.37	1.37	3.66	4.02
OE	2.03	3.27	0.72	1.90	5.98	6.34	7.60	2.38	3.56	0.91	1.56	6.77	0.66	0.54	5.44	6.92	1.06	23.80	3.35	1.23	1.85	7.04	5.09
PO	0.99	3.05	0.84	2.65	4.15	4.77	5.48	3.18	7.34	0.86	2.40	5.22	0.27	0.89	4.63	5.53	1.16	4.15	30.23	1.33	3.38	4.13	3.38
SJ	0.31	3.25	1.95	1.64	2.63	2.86	3.53	2.27	3.55	0.69	0.68	3.80	0.74	0.65	3.56	2.65	1.48	2.84	2.40	52.21	1.44	2.55	2.33
TK	0.46	2.73	0.36	3.08	2.93	3.07	3.36	2.17	4.07	0.56	2.08	3.46	0.13	0.95	3.30	3.65	1.14	3.48	5.35	1.08	47.47	3.03	2.10
UK	2.51	2.96	0.37	2.02	7.44	7.65	11.45	1.64	2.65	0.75	1.60	9.33	0.57	0.59	5.37	7.82	0.93	4.93	2.33	0.76	1.10	17.42	7.82
US	3.53	2.62	0.17	2.45	14.75	5.25	7.67	1.31	2.37	0.70	1.36	6.00	0.43	0.57	4.52	6.30	0.62	3.68	2.07	0.53	0.85	8.96	23.27
TO	37.08	68.88	13.01	45.86	122.85	104.95	132.19	42.24	68.37	15.61	30.26	120.02	13.32	15.85	95.56	119.29	22.60	83.64	66.66	23.64	32.35	125.49	109.78
FROM	58.99	78.46	32.88	60.39	79.78	79.89	83.25	60.79	70.14	37.08	51.76	81.9	68.43	48.48	77.57	81.65	52.45	76.2	69.77	47.79	52.53	82.58	76.73
NET	−21.91	−9.58	−19.87	−14.53	43.06	25.06	48.95	−18.55	−1.76	−21.47	−21.51	38.11	−55.11	−32.63	18.00	37.64	−29.85	7.43	−3.11	−24.15	−20.18	42.91	33.05
PAIRWISE		0.07	−0.1	0.04	4.54	1.85	2.88	0.02	0.42	−0.26	−0.12	2.31	−2.57	−0.54	1.77	3.66	−0.53	1.29	0.36	−0.04	−0.05	3.4	3.54
TOTAL CONNECTEDNESS					65.63																		

Notes: FEVD is based on 23-variate VAR and 100-day predictive horizons. 'FROM' denotes total directional connectedness from all others whereas 'TO' denotes total directional spillovers to all others. 'NET' spillovers are the difference between the contribution to others and the contribution from others. Positive (negative) values of net connectedness indicate that the corresponding variable is a net transmitter (receiver) of return connectedness to (from) other studied markets. 'PAIRWISE' denotes the pairwise connectedness between crude oil and each equity market. They are estimated by subtracting the directional "from BRT" connectedness from the directional "to BRT" connectedness. Positive (negative) values of net pairiwse connectedness indicate that the corresponding variable is a net transmitter (receiver) of return connectedness to (from) oil shocks (BRT). AU, BG, CB, CL, CN, ES, FR, GR, HN, IR, IS, IT, JP, KO, NL, NW, NZ, OE, PO, SJ, TK, UK, US refer to the oil & gas stock markets of Australia, Belgium, Colombia, Chile, Canada, Spain, France, Greece, Hungary, Ireland, Israel, Italy, Japan, Korea, Netherland, Norway, New Zealand, Austria, Poland, Slovenia, Turkey, United Kingdom, and United States respectively.

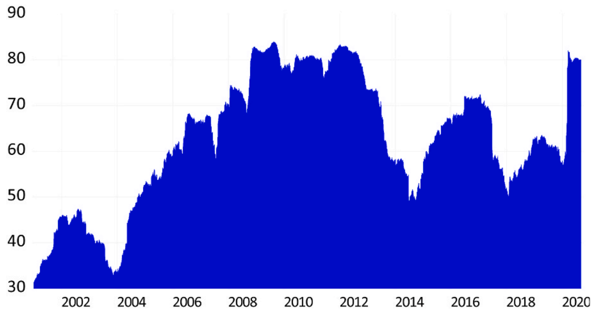

Fig. 1. Dynamic total connectedness between oil price shocks and stock returns of oil & gas sector based on the Diebold and Yilmaz (2012)
Notes: The dynamic total connectedness is calculated from the forecast error variance decompositions using a rolling window size of 262 days and a forecast horizon of 100 days.

channel of risk transmission from the US and Canada to other countries, especially for the cases of net oil-importers should be noted (Nguyen et al., 2021).

5.1.3. Baruník and Křehlík (2018)'s frequency connectedness

While (static and dynamic) total connectedness is a valuable measure for revealing the status of connectedness across markets, it does not disclose how connectedness varies across frequencies. Understanding the connectedness across frequencies is crucial since investors may focus on multiple investment horizons. In this section, we use the time-frequency method of Baruník and Křehlík (2018) to decompose total return connectedness into frequency bands up to 1 week (1–5 days), 1 week to 1 month (5–30 days), and 1 month to 262 days (30–262 days), which correspond to short-term, medium-term, and long-term. Fig. 2 presents the results of this approach.

Overall, that the red-shaded area (short-term) surpasses the yellow (medium-term) and green-shaded (long term) areas show that total connectedness places a significant emphasis on the high-frequency band. Shocks in the short run are thought to be the primary driver of overall connectedness. Since the financial markets process information quickly, shocks can spread from one market to another within just a week. As we increase the investment term, we can see that overall connectedness reduces significantly and remain stable throughout the sample period, implying that the connectedness across markets does not last long. Naeem et al. (2020), using the same methodology of frequency connectedness to study the association among electricity, carbon and clean energy markets, and oil price demand and supply shocks, reached the same conclusion that short-term connectedness exceeds long-term connectedness in their study.

5.2. Determinants of connectedness between oil price and stock returns of oil gas factors

Given the apparent difference of connectedness magnitude between oil prices and the oil & gas stock returns when it comes to different countries, it is of great interest to identify factors driving the degree of connectedness.

Tables 4 and 5 present the panel data regressions of Eq. (13) and Eq. (14) for the determinants of the connectedness magnitude. To assess the impact of the sign and loading of the control variables on the dependent variables, control variables are included separately

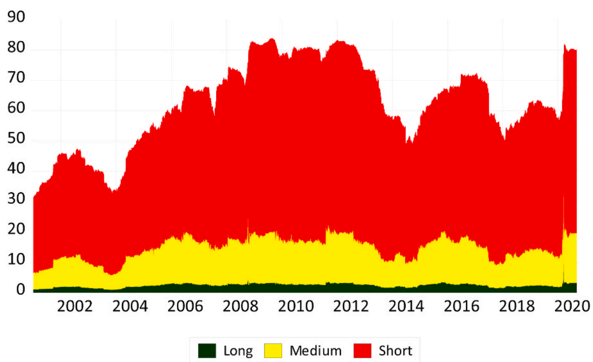

Fig. 2. Dynamic total connectedness between oil price shocks and stock returns of oil & gas sector based on the frequency-domain method of Baruník and Křehlík (2018)
Notes: The red-shaded, yellow-shaped, and green-shaped areas indicate total connectedness at the three frequency bands, which correspond to movements from 1 to 5 days (short), 5–30 days (medium), and 30–262 days (long), respectively. The dynamic connectedness is calculated from the forecast error variance decompositions using a rolling window size of 262 days and a forecast horizon of 100 days. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Determinants of total spillover from oil price shocks to stock returns of oil & gas sector.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
MCAP	−0.08*** (0.01)								−0.06*** (0.02)	−0.06*** (0.02)	−0.05*** (0.02)
TOTAL_ASSETS		0.22** (0.01)							0.11*** (0.01)	0.11*** (0.01)	0.10*** (0.01)
DEBT/ASSET			0.06*** (0.01)						0.09** (0.01)	0.09** (0.01)	0.09** (0.01)
INTEREST_COVER				−0.09*** (0.01)					−0.08** (0.01)	−0.08** (0.01)	−0.09** (0.01)
P/E RATIO					−1.85*** (0.07)				−1.21*** (0.22)	−1.41*** (019)	−1.36*** (0.22)
P_MAR						−0.89*** (0.22)			−0.35*** (0.05)	−0.25*** (0.06)	−0.27*** (0.05)
EPU							0.05*** (0.01)		0.05** (0.02)	0.07** (0.02)	0.05** (0.02)
OIL_EXP								−0.05** (0.02)	−0.05*** (0.02)	−0.06*** (0.02)	−0.06*** (0.02)
FIN_OPEN										1.59** (0.40)	1.43** (0.42)
FIN_OPEN * DEBT/ASSET											0.67*** (0.04)
FIN_OPEN * INTEREST_COVER											−0.12** (0.06)
FIN_OPEN * P/E RATIO											−0.54** (0.26)
FIN_OPEN * P_MAR											0.05 (0.12)
R^2	0.07	0.04	0.05	0.05	0.04	0.06	0.06	0.04	0.55	0.61	0.61
N	397	397	397	397	397	395	397	397	395	395	

Notes: Dependent variable is the DY spillover from crude oil to stock returns of oil & gas sector. HAC Standard errors are in parenthesis. MCAP refers to the market capitalization indicating the size of the firms in oil & gas sector while TOTAL_ASSETS is the firm size which is defined as the natural logarithm of total assets. DEBT/ASSET defines the total amount of debt relative to assets. INTEREST_COVER is a measure of the ability of a company's profits to make the interest payments on its debt. P/E RATIO stands for price-earnings ratio while P_MAR refers to profit margin. Among the control variables, EPU acts as a proxy for World Economic Policy Uncertainty and OIL_EXP acts as a dummy variable to capture the country's status being a net oil exporter when the value is one and zero otherwise. Financial Openness (FIN_OPEN) corresponds the financial openness of the market k, which is measured as the sum of financial assets and liabilities to GDP. Superscripts are symbolizing ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Table 5
Determinants of total spillover from oil price shocks to stock returns of oil & gas sector in short-, medium-, and long-run.

	Long Run	Middle Run	Short Run
MCAP	−0.03**	−0.08***	−0.12***
	(0.01)	(0.01)	(0.01)
TOTAL_ASSETS	−0.01	0.03***	0.16***
	(0.03)	(0.01)	(0.01)
DEBT/ASSET	0.04***	0.12***	0.04***
	(0.01)	(0.02)	(0.01)
INTEREST_COVER	1.41	−0.88	−0.88**
	(2.59)	(0.65)	(0.40)
P/E RATIO	−0.09***	−0.04**	−0.29***
	(0.03)	(0.01)	(0.01)
PMAR	−0.05	−0.12	−0.08***
	(0.04)	(0.05)	(0.02)
EPU	0.03***	0.05***	0.08***
	(0.01)	(0.01)	(0.01)
OIL_EXP	0.04	−0.06***	−0.06***
	(0.04)	(0.01)	(0.01)
FIN_OPEN	1.14* (0.59)	1.45** (0.32)	2.1*** (1.12)
FIN_OPEN * DEBT/ASSET	0.14*** (0.04)	0.34** (0.15)	0.53*** (0.20)
FIN_OPEN * INTEREST_COVER	0.05* (0.03)	0.12*** (0.03)	0.45*** (0.15)
FIN_OPEN * P/E RATIO	0.00 (0.02)	0.01 (0.02)	−0.03** (0.01)
FIN_OPEN * P_MAR	0.01 (0.02)	0.03 (0.02)	0.02 (0.02)
R^2	0.34	0.35	0.38
N	395	395	395

Notes: Dependent variable is the DY spillover from crude oil to stock returns of oil & gas sector. HAC Standard errors are in parenthesis. MCAP refers to the market capitalization indicating the size of the firms in oil & gas sector while TOTAL_ASSETS is the firm size which is defined as the natural logarithm of total assets. DEBT/ASSET defines the total amount of debt relative to assets. INTEREST_COVER is a measure of the ability of a company's profits to make the interest payments on its debt. P/E RATIO stands for price-earnings ratio while P_MAR refers to profit margin. Among the control variables, EPU acts as a proxy for World Economic Policy Uncertainty and OIL_EXP acts as a dummy variable to capture the country's status being a net oil exporter when the value is one and zero otherwise. Financial Openness (FIN_OPEN) corresponds the financial openness of the market k, which is measured as the sum of financial assets and liabilities to GDP. Superscripts are symbolizing ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

in the regression estimation before considering them collectively. The results of the Hausman tests suggest that random effect is rejected from our panel data analysis. Therefore, we have controlled for fixed effects. We also test for time and cross-section fixed effects. The joint test for time dummies is found to be statistically significant, while the joint test for cross-section dummies is not found to be statistically significant. As a result, the time-fixed effect is applied for all the following estimations. In addition, the White and Breusch-Pagan and the Breusch-Godfrey tests are performed to check the issues of heteroskedasticity and autocorrelation, respectively. As both tests show significant results, we calculate Newey-West standard errors to minimize biases from heteroskedasticity and autocorrelation in our estimations. Finally, we test for residuals normality through the Jarque-Bera statistic and fail to reject the null hypothesis. We conclude that the non-normality of residuals would not bias our results.

Univariate estimations are provided between columns 1–8, and the complete model is presented in columns 9 &10 of Table 4. Almost all variables are statistically significant at the 1% or 5% levels, indicating the strong explanatory power of sectoral profitability and solvency on the level of connectedness. Column 1 states a significant impact of the country-level capitalization rate on the connectedness, indicating that bigger oil & gas stock markets are affected less by oil price fluctuations. This finding is aligned with Narayan and Sharma (2011) and Sadorsky (2008), who also find that oil prices affect firms differently depending on size. In column 2, total assets are proposed to determine connectedness from oil to the oil & gas stock market. The result indicates they are positively and significantly correlated with the extent of connectedness.

In columns 3–6, we have tested the significance of the financial and solvency ratios of the sectors. The magnitude of connectedness is affected positively with an increase in debt to asset ratio, but negatively with interest expense coverage, profit margins, and P/E ratios. In particular, positive debt to asset coefficients indicates that sectors having more debt are more vulnerable to liquidity and are likely to get more oil price fluctuations. These results are consistent with Niţoi and Pochea (2019)'s paper, which indicates debt position to be a significant driver in explaining the correlation of stock markets. Regarding the interest exposure coverage, since it is to measure the turnover that how many times the profit covers the interest expense, the sector's liquidity position is reflected. A negative coefficient of the interest experience coverage in both univariate and multivariate models imply that for sectors in the oil & gas sector having a higher interest rate coverage, the magnitude of the connectedness declines. Generally, for oil & gas sector, of country i, with better interest coverage, and lower debt to asset ratios, the spillover transmissions from oil price changes to oil & gas stock market would be lesser. The finding might be in line with Korotin et al. (2017) and Teti et al. (2020), who argue that sudden oil price changes can impose liquidity and cash flow stress on oil companies due to costlier refinancing.

We observe significant and negative P/E ratio coefficients both in univariate and multivariate models, indicating an intuitive result in terms of the firms' valuation. For oil & gas stock markets or sectors having higher P/E, because of higher growth expectations by the investors, oil price fluctuations do not make these stock markets vulnerable. In other words, investors' expectation on these firms/sectors-higher P/E ratios makes oil & gas stock markets less vulnerable to oil price changes. When it comes to profitability margin,

Table 6
Determinants of end-of-year spillover from oil price shocks to stock returns of oil & gas sector.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
MCAP	−0.09*** (0.02)								−0.09*** (0.01)	−0.09*** (0.02)	−0.09*** (0.02)
TOTAL_ASSETS		0.16** (0.01)							0.13*** (0.02)	0.13*** (0.01)	0.13*** (0.02)
DEBT/ASSET			0.06*** (0.01)						0.07** (0.04)	0.07** (0.01)	0.07** (0.01)
INTEREST_COVER				−0.12*** (0.01)					−0.05** (0.01)	−0.06** (0.01)	−0.06** (0.01)
P/E RATIO					−2.13*** (0.12)				−1.25*** (0.20)	−1.21*** (0.19)	−1.22*** (0.20)
P_MAR						−1.33*** (0.20)			−0.11 (0.12)	−0.13 (0.12)	−0.13 (0.12)
EPU							0.03*** (0.01)		0.08*** (0.02)	0.09** (0.02)	0.09** (0.02)
OIL_EXP								−0.32** (0.02)	−0.22*** (0.04)	−0.22*** (0.03)	−0.22*** (0.03)
FIN_OPEN										1.44*** (0.24)	1.44*** (0.23)
FIN_OPEN * DEBT/ASSET											0.71*** (0.06)
FIN_OPEN * INTEREST_COVER											−0.25* (0.13)
FIN_OPEN * P/E RATIO											−0.54** (0.16)
FIN_OPEN * P_MAR											0.05 (0.154)
R^2	0.13	0.12	0.04	0.02	0.3	0.11	0.08	0.07	0.44	0.50	0.52
N	397	397	397	397	397	395	397	397	395	395	395

Notes: Dependent variable is the DY spillover from crude oil to stock returns of oil & gas sector(end of year values). HAC Standard errors are in parenthesis. MCAP refers to the market capitalization indicating the size of the firms in oil & gas sector while TOTAL_ASSETS is the firm size which is defined as the natural logarithm of total assets. DEBT/ASSET defines the total amount of debt relative to assets. INTEREST_COVER is a measure of the ability of a company's profits to make the interest payments on its debt. P/E RATIO stands for price-earnings ratio while P_MAR refers to profit margin. Among the control variables, EPU acts as a proxy for World Economic Policy Uncertainty and OIL_EXP acts as a dummy variable to capture the country's status being a net oil exporter when the value is one and zero otherwise. Financial Openness (FIN_OPEN) corresponds the financial openness of the market k, which is measured as the sum of financial assets and liabilities to GDP. Superscripts are symbolizing ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

a significant and negative impact shown in columns 6, 9 and 10 indicates that profit margin is a determining factor in explaining the direction and magnitude of the spillovers.

The estimations for Eq. (14) are in the last column (10). We combined the financial ratios with the financial openness variable to see how the financial ratios affect the countries that are more open. First, the financial openness coefficient is significant and positive, showing that spillover from oil markets to the oil & gas stock markets is stronger when the market is more open worldwide. Financial openness*Debt/Asset is similarly found positive and significant, illustrating that for markets that are more financially open to international investors, the impact of the liquidity ratio is greater in determining the magnitude of the spillovers from oil prices to oil & gas stock returns. Likewise, a negative and significant interaction term for (FIN_OPEN* INTEREST_COVER) reveals that the negative impact of interest coverage on the level of spillovers gets bigger when the country is opened up more.

5.2.1. *Robustness checks*

In Table 5, we have used different connectedness indices in the short-, medium-, and long-run to investigate if the result differs. Overall, all the coefficients estimated in Table 5 are consistent with that of Table 4, highlighting the strong explanatory power of profitability and solvency factors of energy sectors in explaining the magnitude of connectedness between sector returns and oil shocks. Particularly, when studying connectedness in the short, medium, and long run, an increase in debt to asset ratio affects the magnitude of connectedness positively, but adversely with interest expense coverage, profit margins, and P/E ratios. The result also confirms that when the market is more open internationally, spillover from oil markets to the stock returns of oil& gas sector is higher.

Additionally, it should be highlighted that when connectedness is decomposed into short, medium, and long term, there is variation in terms of determinants' significance. The influence of profit margin and interest expense coverage on connectedness is found to be substantial in the short term, but not in the medium- or long-term. As previously mentioned, there is a strong connectedness between changes in oil prices and stock returns in the oil and gas sector in the short run. However, the degree to which oil price changes are connected to stock returns in the oil and gas sector declines significantly in the medium and long run, suggesting that internal shocks play a larger role in influencing long-term movements in the sector than shocks from oil prices. It is possible that the oil and gas sector's increased adaptability to oil price shocks over time, resulting in improved efficiency and better production management, may explain this phenomenon. As a result, due to the reduced connectedness between oil prices and stock returns over extended investment horizons, factors such as profitability and solvency have a weaker influence on the degree of connection in the long run, as compared to the short and medium term."

In Tables 6 and 7, we estimate equation (14) but changed the dependent variable. Instead of creating the year-by-year averages of the connectedness, we have obtained end of year estimations for the connectedness and considered it as the independent variable. The

Table 7
Determinants of total spillover (end of year) from oil price shocks to stock returns of oil & gas sector in short-, medium-, and long-run.

	Long Run	Middle Run	Short Run
MCAP	−0.04**	−0.08***	−0.17***
	(0.01)	(0.02)	(0.02)
TOTAL_ASSETS	−0.02	0.03***	0.13***
	(0.04)	(0.01)	(0.02)
DEBT/ASSET	0.04***	0.11***	0.03***
	(0.01)	(0.03)	(0.05)
INTEREST_COVER	0.89	−1.33	−0.86**
	(1.77)	(1.33)	(0.41)
P/E RATIO	−0.08**	−0.05**	−0.29***
	(0.04)	(0.02)	(0.02)
PMAR	−0.05	−0.11	−0.12***
	(0.05)	(0.12)	(0.04)
EPU	0.04***	0.05***	0.09***
	(0.01)	(0.01)	(0.05)
OIL_EXP	0.04	−0.07***	−0.06***
	(0.05)	(0.01)	(0.05)
FIN_OPEN	1.35** (0.55)	2.33** (1.11)	1.08 (1.33)
FIN_OPEN * DEBT/ASSET	0.51*** (0.12)	0.41** (0.10)	0.42** (0.29)
FIN_OPEN * INTEREST_COVER	0.05** (0.02)	0.14*** (0.04)	1.45*** (0.51)
FIN_OPEN * P/E RATIO	0.00 (0.03)	0.02 (0.02)	−0.03** (0.01)
FIN_OPEN * P_MAR	0.01 (0.03)	0.02 (0.04)	0.02 (0.04)
R^2	0.30	0.36	0.40
N	395	395	395

Notes: Dependent variable is the DY spillover from crude oil to stock returns of oil & gas sector(end of year values). HAC Standard errors are in parenthesis. MCAP refers to the market capitalization indicating the size of the firms in oil & gas sector while TOTAL_ASSETS is the firm size which is defined as the natural logarithm of total assets. DEBT/ASSET defines the total amount of debt relative to assets. INTEREST_COVER is a measure of the ability of a company's profits to make the interest payments on its debt. P/E RATIO stands for price-earnings ratio while P_MAR refers to profit margin. Among the control variables, EPU acts as a proxy for World Economic Policy Uncertainty and OIL_EXP acts as a dummy variable to capture the country's status being a net oil exporter when the value is one and zero otherwise. Financial Openness (FIN_OPEN) corresponds the financial openness of the market k, which is measured as the sum of financial assets and liabilities to GDP. Superscripts are symbolizing ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

results are not so different from the estimations in Tables 4 and 5 The Financial position of the sectors (profitability and solvency ratios) matter in explaining the connectedness between oil price changes and Oil and Gas equity returns. Also, the size of the sector and economic policy uncertainty influence the connectedness.

In Table, 8 we have performed the estimations in Tables 4 and 6 by employing a GMM method in order to remedy the possible weak exogeneity of the independent variables. Since the dependent variables are calculated as getting the average of daily observations, in the estimations of equation (13), error terms might be correlated with the exogenous variables. Therefore, we implement GMM (we used the lagged the independent variables as instruments. And performed the equations.

The estimated model is as follows;

$$\Delta CONN_{kt} = \beta_1 \Delta MCAP_{kt} + \beta_2 \Delta TOTAL\_ASSETS_{kt} + \beta_3 \Delta DEBT/ASSET_{kt} + \beta_4 \Delta INTEREST\_COVER_{kt} + \beta_5 \Delta P/_E RATIO_{kt} + \beta_6 \Delta P\_MAR_{kt} + \beta_7 \Delta EPU_t + \beta_8 \Delta OIL\_EXP_{kt} + \beta_9 \Delta Inflation_t + \beta_{11} \Delta GDP_t + \varepsilon_{kt}$$

In both 2 models in Table 8, models the first- and second-order correlation A tests have p-values bigger than 10%, support the idea error terms are not correlated for the first and second orders. This gives us the green light that lagged endogenous variables are appropriate to use as instruments. Additionally, the p-values of the Sargan test of over-identifying restrictions fails to reject the null hypothesis that the instruments are exogenous in any specification. In the first column, we have employed the per year average connectedness (for every year), and in the second column, we have employed end of year connectedness measure. Estimations in both columns reveal that again, the financial position of the sectors (profitability and solvency ratios) matter in explaining the connectedness between oil price changes and Oil and Gas equity returns. Also, the size of the sector and economic policy uncertainty influence the connectedness.

Overall, as the fact that there is a divergence in the degree of connectedenss between the oil prices and the stock returns of oil & gas sector across studied countries, the position of profitability and solvency position of sectors is emphasized. It is evident that a bigger oil & gas stock market with better interest coverage, higher profitability, and lower debt to asset ratio is more resistant to oil price fluctuations.

6. Conclusion and implications

By the use of the connectedness index approach developed by Diebold and Yilmaz (2012) and Baruník and Křehlík (2018), the paper provides additional insights into the relationship between oil prices and the stock returns of oil & gas sector across 22 OECD

Table 8
Determinants of total spillover from oil price shocks to stock returns of oil & gas sector: GMM estimations.

	(1)	(2)
$Spillover_{t-1}$	0.67*** (0.02)	0.74*** (0.001)
MCAP	−0.04*** (0.01)	−0.14*** (0.02)
TOTAL_ASSETS	0.01*** (0.00)	0.21*** (0.05)
DEBT/ASSET	−0.15*** (0.01)	−0.85* (0.03)
INTEREST_COVER	−0.04*** (0.01)	−0.05*** (0.01)
P/E RATIO	−0.01 (0.03)	−0.01 (0.03)
PMAR	−0.04*** (0.01)	−0.15*** (0.02)
EPU	0.06 (0.11)	0.04***, (0.01)
OIL_EXP	0.14*** (0.03)	0.02*** (0.03)
FIN_OPEN	0.04** (0.02)	0.05*** (0.01)
FIN_OPEN * DEBT/ASSET	0.06*** (0.01)	0.07*** (0.02)
FIN_OPEN * INTEREST_COVER	0.08*** (0.01)	0.12*** (0.04)
FIN_OPEN * P/E RATIO	0.10 (0.06)	0.13 (0.10)
FIN_OPEN * P_MAR	−0.06*** (0.01)	−0.03 (0.03)
P(J statistic)	0.29	0.41
N	395	395
AR(1)	0.23	0.12
AR(2)	0.45	0.21

**Notes: Dependent variable (in first column) is the DY spillover from crude oil to stock returns of oil & gas sector (average values).Dependent variable (in second column) is the DY spillover from crude oil to stock returns of oil & gas sector(end of year values). HAC Standard errors are in parenthesis. MCAP refers to the market capitalization indicating the size of the firms in oil & gas sector while TOTAL_ASSETS is the firm size which is defined as the natural logarithm of total assets. DEBT/ASSET defines the total amount of debt relative to assets. INTEREST_COVER is a measure of the ability of a company's profits to make the interest payments on its debt. P/E RATIO stands for price-earnings ratio while P_MAR refers to profit margin. Among the control variables, EPU acts as a proxy for World Economic Policy Uncertainty and OIL_EXP acts as a dummy variable to capture the country's status being a net oil exporter when the value is one and zero otherwise. Financial Openness (FIN_OPEN) corresponds the financial openness of the market k, which is measured as the sum of financial assets and liabilities to GDP. Superscripts are symbolizing ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$ Estimation method: GMM. P(J statistics) refer to the overidentifying test.

countries from 1999 to 2020. Several implications to policymakers and investors are provided.

The results first indicate the existence of connectedness, which intensifies during extreme economic events, such as the GFC of 2007–2009, ESDC of 2009–2012, and the recent COVID-19 pandemic. The strong level of connectedness indicates limited diversification benefit for investors who hold both crude oil and equities of oil & gas sector in their portfolios. From the perspective of policy implication, policymakers should acknowledge the interdependence between oil and stock markets to incorporate measures stabilizing financial markets, especially when countries hit hard by the financial and oil crisis.

Findings based on the direction of connectedness can be used to have a better forecast of volatility in both oil and stock markets. Particularly, given the dominant role of crude oil in the movement of stock markets in Japan, oil price variation should be considered as a vital element in developing equity valuation models. In contrast, in the US, the UK, and Canada, the risk is transferred in the opposite direction, which is mainly from oil & gas sectors to the oil prices. Forecasting the oil price movement, therefore, can be improved by paying attention to the variation of the US and Canada oil & gas sectors. Importantly, the fact that the oil & gas stock markets in net oil importers are more vulnerable to oil price fluctuations recommends countries reduce their oil dependence to lower the adverse effect of oil price uncertainty to stock markets.

Our results also reveal that there is a distinction between short-, medium-, and long-term connectedness. It has significant ramifications for both active and passive investors. Because active investors focus on the short term, the risk of holding crude oil and equities of oil & gas sectors may be higher than that of passive investors who focus on the long term. In other words, the long-term diversification benefits will outweigh the short-term benefits.

Importantly, given the apparent heterogeneity in terms of connectedness across OECD countries, the role of sectors' profitability and solvency ratios on the level of connectedness is extensively investigated. Our paper suggests that portfolio managers who hold an oil & gas portfolio can partially be "immune" to the shocks of oil prices or global EPU by selecting assets of the sectors that have better solvency and profitability positions.

CRediT authorship contribution statement

Faruk Balli: Writing – review & editing, Writing – original draft, Data curation. **Hatice O Balli:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Hannah Nguyen:** Writing – review & editing, Writing – original draft, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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