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RESEARCH ARTICLE

Determining the COVID-19 effects on spillover between oil market and stock exchange: a global perspective analysis

Ran Yan[1,2] · Fuguo Cao[1] · Ke Gao[3,4]

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Abstract

This paper investigates volatility spillovers between the global crude oil market and the stock markets of the global oil stock markets (Russian, Canada, China, Kuwait, and the USA) pre and after the COVID-19 pandemic. We use wavelet Granger causality methods to study the volatility spillovers between global oil stock markets, mainly from January 1, 2019, to March 31, 2021. Our Results (1) shows that WTI and Brent oil prices had a negative mean return before COVID-19 but a positive mean return during the pandemic spread. Other Results (2) find the positive, significantly lowest, and highest frequency during the COVID-19 outbreak for all selected countries. The results also show that the link between oil WTI & Brent prices and stock markets return in the lowest (33-66 days) and highest frequency range (4-16) before the Covid-19 epidemic, especially in the first quarter of 2020. Before the COVID-19 period, the Russian oil stock market is seriously prejudiced with oil prices on a modest scale, but not after the pandemic's start. This study also perceives direction opposite between the COVID-19 period. The Canadian and United States America oil and stock markets influence the lowest scale in the previous COVID-19 sample for the U.S. market. Moreover, this paper exposed that oil marketing highest oil futures in their portfolios than stock shares for all times. We found that oil price shocks had a more significant impact on the stock markets of the United States and Canada than on the stock markets of other countries.

Keywords VAR model · volatility spillovers crude oil markets · stock markets · Covid-19

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✉ Fuguo Cao
caofuguo@cufe.edu.cn

Ran Yan
2018110012@email.cufe.edu.cn

Ke Gao
gkfly@126.com

[1] School of public finance and tax, Central University of Finance and Economics, Beijing 100081, China

[2] Fanli business school, Nanyang Institute of Technology, Nanyang 473004, China

[3] School of Economics, Peking University, Beijing 100871, China

[4] Development Research Center of Shandong Provincial People's Government, Jinan 250011, China

Introduction

Crude oil's dominance in the energy sector is well documented (Irfan et al. 2021c; Tanveer et al. 2021). Oil and stock markets took a historic tumble in the spring of 2020. Several publicly traded corporations have lost more than a third of their value in just these few weeks, and oil prices have dropped to their lowest levels in a decade. The Covid-19 pandemic has sparked widespread fear (Ahmad et al. 2022; Irfan et al. 2022a), and the impact on the energy and stock markets has been extraordinary (Wen et al. 2019; Jiang and Yoon 2020; Yu et al. 2020; Heinlein et al. 2021). Specifically, In comparison to the global financial disaster of 2008, it appears that the impact of the ongoing Covid-19 pandemic disaster is rather systematic (Yang et al. 2021; Wen et al. 2022), as all asset classes are impacted (Iqbal et al. 2021; Irfan et al. 2021e), and shocks are widely transmitted across markets (Dong and Hao 2018; Ahmad et al. 2021). Its impact on real-world and financial activity has heightened market risk aversion to levels not seen since the global financial disaster and oil price falls month of spring

2020, including the 996 455 deaths of September 16, 2020. The two main major oil price shocks 2008 and a Covid-19 epidemic 2020, both shocks mutual with the complexity of nowadays financial oil marketing systems, have had a significant impact on stock prices, on a scale that has never been seen before (Agyekum et al. 2021) and (Zhang et al. 2021).

While the coronavirus produced with the Spartan severe respiratory syndrome (SARS-CoV-2) coronavirus (Irfan et al. 2021b, d, 2022b), the exacerbated financial and commodity market uncertainties significantly (Elavarasan et al. 2021). The rising number of 29,444,199 confirmed cases and more than 40 million deaths worldwide. Therefore, has encouraged to impose closed all regions markets and other businesses and starting most effective methods of social isolation, wear masks, which have had economic consequences; China, for example, experienced an 8.9% reduction in the starting Covid-19 in 2020, the most significant quarterly gross domestic production contraction since records began. Ongoing COVID-19 pandemic cases numbers expanded dramatically (Irfan et al. 2021a); stock markets began to reduce and risk increase to commodity and equity investors as a result of the rapid rise in cases and deaths. (Lokhandwala and Gautam 2020) exposed that Covid-19 pandemic well-being news improves the accuracy of expected stock markets returns, authorizing the connection between the finical and stock market and public health., exposed that data on the 2014 to 2016 Ebola outbreaks, joint with broad national and international media reporting, was more relevant for businesses located near both the source of Ebola epidemics and financial markets. (Mukanjari and Sterner 2020) The highest regions of COVID-19 cases have influenced the risk-return nexus' reliance structure has been suggested.

The crude oil market, the largest traded commodity worldwide, considerably impacts the global economy (Zhang et al. 2021), (Hsu et al. 2021) and (Ehsanullah et al. 2021). Furthermore, crude oil prices impact macroeconomic policies and affect the nation's leading economic policy apparatuses, inflation rate, and additional events related to the economy. Academics and scholars have paid more with spillovers among the oil markets and stock markets as crude oil's importance in the global economy has grown, documenting significant (Iqbal et al. 2021) and (Zhang et al. 2021).

Regardless of whether a region is an oil-importing and exporting economy, oil price shocks significantly affect stock returns and volatility (APERC 2007; Ang et al. 2015; Erahman et al. 2016). The overall effect of the price of oil on the financial markets is decided by that of the nation's net oil market job due to this variability (Mugableh 2017).

These paper contributions are different from overhead-cited research in approach. Moreover, focus on the VAR and Granger causality analysis approach sample of six oil-producing and consumption countries, including (Russian, Canada, China, Brazil, Kuwait, and the USA). Countries allow us to understand the relationship between the oil and stock markets. Secondly, we evaluate oil–stock co-movement; we use separated analysis approaches into two coalitions covering the Covid-19 pandemic. The wavelet-based multi-time multiscale method utilizes the principal assessment of co-movement intensity at the variable frequency and the degree of this strength across time. Wavelet consistency and crossover maps can be used to verify the relationship of temporal variations between data. To double-check the results' robustness, we apply Granger causality analysis. Finally, we calculate the benefit of crude oil in a stock index portfolio. We further test whether WTI crude oil may well be used as a feasible offsetting instrument for equity investments in oil-based financial markets by evaluating the hedging efficiency of an uncertainty strategy during COVID-19 on the volatility of the oil stock markets effects.

The remainder of this paper is organized as follows. Section 2 presents a review of the relevant literature; Section 3 discusses the empirical methods; Section 4 describes the source of data and statistical analysis; Section 5 discusses the empirical results and discussion; and, finally, Section 6 conclusion and policy implication.

Literature Review

In 2020, the Covid-19 new virus pandemic affected the global economy, trading companies, and other sectors such as agriculture, the oil industry, etc. However, crude oil price fluctuations significantly impact listed companies' output, costs, and profits, resulting in stock price fluctuations (Gao et al. 2021), (Lee et al. 2019) and (Ding et al. 2020). Meanwhile, the achievements of the registered businesses may result in economic shifts. Furthermore, changes in the global economy can disrupt the steadiness of international crude oil supply and demand, resulting in crude oil price variations (Guan and Li 2020).

On a lesser scale, this co-movement is modest, but on a bigger scale, it becomes significant. Using a robustness analysis using Granger causality, this paper reveals that oil prices and stock markets have a bidirectional link (Sun et al. 2020b) and (Baloch et al. 2020). The causality from oil to stock markets of the Russian and USA oil price conflict (70 trading days). Irrespective of market circumstances, the findings of the investment study suggest that energy supplies should be given a higher weight than stocks (Sun et al. 2019) and (Tiep et al. 2021). We also show that the oil futures market is a better option for cross hedging than the stock market (Sun et al. 2020c), (Sun et al. 2020a) and (Sun et al. 2020b). Furthermore, many researchers find the time-varying frequency characteristics of co-movements, providing the most valued data for

investors and policymakers preparing for adverse disasters or epidemics in one of the worst situations (Alemzero et al. 2020b), (Sun et al. 2020a) and (Alemzero et al. 2020a).

Many research scholars and experts only focus on one link between oil and stock markets. For example (Raza et al. 2018), The autoregressive distributed (VAR) method is used to determine the wavelet method and casualty-based connection between oil price and variability of the stock market returns and oil markets. This association also means that crude oil prices may evaluate oil stock price in the coming days, given to the study.. (Ikram et al. 2019) The study discovers strong co-movements at low frequencies, increasing this interconnection following the great recession. Similarly, (Yu et al. 2020; Heinlein et al. 2021) Evaluate the relative relationship in-between oil and stocks in the U. S, Japan, and German countries on spillovers, short-term return between oil and stock markets, and also long-term market volatility, which was particularly evident during in the Global Depression. (Nwanna and Eyedayi 2016; Wen et al. 2016) investigated the In GCC countries, each finds a similar improvement of co-movement among price of oil and stocks.

For example (Wang et al. 2018) employ a GARCHSK method and CoVaR-Network, a method for examining the effects of stock market spillovers between the U.S. and China, as well as the crude oil market. Another study (Wen et al. 2016) investigated the risk connectedness of oil and stock markets using wavelet coherence and B.K. Frequency connectedness approaches (Ozoike-Dennis et al. 2019) and (Hilbers et al. 2019). Other studies(National and Stewardship 2005; Gurara and Ncube 2013; Dupor and Guerrero 2017; Dutta 2018; Bettendorf 2019; Wen et al. 2019; Yu et al. 2020; Pedauga et al. 2021; Yarovaya et al. 2021) also shows that risk spillovers are heterogeneous and change over the long and short term (Accastello et al. 2019), (Molla et al. 2019) and (Pinto et al. 2019). The Long-term scales exhibit considerable co-movements, according to the authors (Kordej-De Villa and Slijepcevic 2019) and (Khosravi et al. 2019). Oil and stock markets have a time-varying lead-lag structure. Furthermore, long-term risk spillovers are more significant than short- and intermediate-term risk spillovers.

This literature gap was filled by using two types of wavelet transformations to investigate the implications of the Covid-19 virus epidemic on nexus between the oil and stock markets using data from the top oil-importing (U.S. and China, Russia, Canada, Kuwait) countries. Finally, we investigate the ability of oil assets to hedge by examining hedging effectiveness and estimating the ideal weights of an oil market's stock markets portfolio and the best hedge ratios before and during pandemic times. We also used the new econometric method in terms of the time domain approach and the method based on frequency dynamics to produce dynamic findings of return and volatility.

Empirical methodology

VAR model

This present paper uses the spillovers in the generalized vector autoregression (VAR) approach combining the Generalized Forecast Error Variance of the VAR COVID-19 pandemic wave. Let M= (*Xt*) be a (3) dimensional vector of endogenous variables that includes data on stock, WTI, and oil returns, and let *st* stand for regimes, with *st*, M. As a result, the VAR model of order (p) can be defined as follows:

$$X_t = \begin{cases} v_1 + \sum_{j=1}^{p} A_{j1} X_{t-j} + \varepsilon_t, \text{if } s_t = 1 \\ \vdots \\ v_M + \sum_{j=1}^{p} A_{jM} X_{t-j} + \varepsilon_t, \text{if } s_t = M \end{cases} \quad (1)$$

The vector *Xt* is explained for each oil stock region with variable M with its lagged values, an intercept *vM*, (t) stochastic component, and the parameter matrix. s_t Is the variance-covariance matrix and generally distributed with (0). This paper's empirical analysis discovers a low and high-level volatility regime (Li et al. 2021), (Chien et al. 2021) and (Iqbal et al. 2021). An unobservable Markov chain process describes the dynamic behavior of a regime s_t, with a conditional transition probability from regime *I* at time t_1 to regime j at time t provided this method to estimation Eq. (2).

$$\text{pij} = \Pr \text{s}_\text{t} = \text{j} \mid \text{st1} = \text{i and j} = 12\text{pij} = 1. \quad (2)$$

Where P_r s_tOil and stock market feedback effects vary contingent on the volatility regime. A VAR model feature is significant for our investigation because it accounts for changes in oil stock market volatility after the first Covid-19 epidemic waves. The X_t density for the qualified on a regime s_t=*j* can be calculated as Eq. (3):

$$f\left(\text{X}_\text{t} \mid \text{s}_\text{t} = \text{j}, \Omega_{\text{t}-1}; \theta\right) = \frac{1}{(2\pi)^{\text{k}/2} \left|\Sigma_{\text{St}}\right|^{1/2}} \exp\left(-\frac{1}{2} \varepsilon_\text{t}' \Sigma_{\text{S}_\text{t}}^{-1} \varepsilon_\text{t}\right) \quad (3)$$

Data set availability at a time represents (t) and represents a list of procedure parameters contained in the parameter matrices in Eq. (3). Consequently, at the time (t), a function that calculates the probability of a given event:

$$f\left(X_t \mid \Omega_{t-1}; \theta\right) = \sum_{j=1}^{2} f\left(X_t \mid s_t = j, \Omega_{t-1}; \theta\right) \Pr\left(s_t = j \mid \Omega_{t-1}; \theta\right) \quad (4)$$

$Pr\text{s}_\text{t}$=j| *t*1; Given the information at time t1, what is the conditional probability of remaining in state j at time t?.

$$P\left(s_t = j \mid \Omega_{t-1}; \theta\right) = \sum_{i=1}^{2} \Pr\left(s_t = j \mid s_{t-1} = i, \Omega_{t-1}; \theta\right) \Pr\left(s_{t-1} = j, \Omega_{t-1}; \theta\right) \quad (5)$$

At each time t, this probability is updated using the conditional likelihood in Eq. (5) as follows:

$$P\left(s_t = j \mid \Omega_t;\theta\right) = \frac{f\left(X_t \mid s_t = j, \Omega_{t-1};\theta\right)P\left(s_t = j \mid \Omega_{t-1};\theta\right)}{\sum_{h=1}^{2} f\left(y_t \mid s_t = j, \Omega_{t-1};\theta\right)P\left(s_t = h \mid \Omega_{t-1};\theta\right)} \tag{6}$$

Equation 6 can be iterated for the initial transition probability and parameter values. For $t = 1, \ldots, T$ and calculate the likelihood value as follows:

$$\sum_{t=1}^{T} \log f\left(y_t \mid \Omega_{t-1};\theta\right) \tag{7}$$

As a result, the estimated parameters for and *pij* are obtained as the log-likelihood maximization values. After that, a conditional normal distribution is assumed for the VAR model. A Markov chain process generates the unobserved regime vector, and VAR (p) processes can be estimated using the Gibbs sampling technique, an iterative Monte Carlo technique with a Bayesian approach.

Measuring regime spillovers

This paper use the VAR(p) model to quantify the connectivity between variables (stock, gold, and oil returns) under either regime, as (Goodell and Goutte 2021) did. To that purpose, the VAR (p) model can be rewritten as an endless moving average (M.A.) Eq. (8):

$$X_t = \begin{cases} \sum_{i=1}^{\infty} \Phi_{i1} \mathrm{V}_1 + \sum_{i=1}^{\infty} \Phi_{i1} \Sigma_1^{1/2} \mathrm{u}_t, \text{if } s_t = 1 \\ \vdots \\ \sum_{i=1}^{\infty} \Phi_{iM} \mathrm{V}_M + \sum_{i=1}^{\infty} \Phi_{iM} \Sigma_M^{1/2} \mathrm{u}_t, \text{if } s_t = M \end{cases} \tag{8}$$

Where $\Phi_i$for each sample country 1, M is (3×3) matrix of M.A. coefficients that follows the recursion $\Phi_i = A1\Phi_i - 1 + A2\Phi_i - 2 + \cdots + Ap\Phi_i - p$, with Φ_0 as the identity matrix and$\Phi_i = 0\ for\ i < 0$. Finally, we compute 95 percent confidence intervals for the normalized *ij*, *Sth* using a Monte Carlo simulation of the MS-VAR(p) model with 1000 replications to assess the significance of such influences.

Data description and Statistical Analysis

Data description and Statistical Analysis

In this paper, our main concern is to examine the prices of WTI crude oil commodities and stock markets indices from six significant oil stock markets effects of Covid-19. These variables of the S&P 500 index are for the U.S., the Composite index is for Canada (TSX), China is represented by the SSE Composite Index, Russia by the RTS Index, and Kuwait by the IBC Index. We utilize Europe Brent crude oil futures as a comparison. Capturing data over this period from January 1, 2019, to March 31, 2021, the sample period is in effect. A data stream was used to collect the information. The sample period was separated into two sub-periods. The sample days during the pandemic period from March 20, 2020, when the World Health Organization acknowledged the COVID-19 pandemic. The critical events connected to COVID-19, as defined by the WHO, We chose March 20, 2020, as the crisis point among all these critical dates since it's on that day that the WHO classified the spreading rapidly coronavirus epidemic. (Jee 2020)Also, use this breakpoint (2020). The date on which the World Health Organization proclaimed COVID-19 a pandemic (March 20, 2020) has a long tail. As shown in the graph. After around 1.5 months, volatility declined and returned to a more normal level.

Statistical analysis

Table 1 shows a list of statistical analyses for the oil and stock markets variables in entire sample countries before and after the COVID-19 disaster. We analyze the effects of the WTI price, and Brent oil prices had a negative mean return before COVID-19 but a positive mean return during the pandemic's spread. During the pandemic disaster, WTI's mean return was more significant than Brent's was. The standard deviation of oil market returns is slightly higher than that of COVID-19. Except for Kuwait before the outbreak, oil prices were more volatile than the stock market before the pandemic and during the pandemic. Except for Canada before the disaster, all equity indices showed positive average returns before and after COVID-19. During the outbreak, all equity markets except China and Kuwait posted higher average returns. The asymmetry and flattening tests confirming the Jarque-Bera test show that all return series are asymmetrical and with peaks. Both WTI and Brent oil had strong relationships with stock markets before and after COVID-19, as showed by augmented standard deviation. We notice that WTI is more associated with the stock markets under consideration than Brent is.

Table 1 represents summary of oil and stock market price.

Empirical Results and Discussion

Comparison between two variables crude oil and stock markets on a multiscale level

This fresh paper main objective to provide multiscale evidence of the COVID-19, With the exception of the Kuwait market, as we can see in the low-frequency market, At high frequencies, as a result shows a loss in terms of diversification advantages. In January 2019, however, all frequency

Table 1 Oil and stock market price returns

	WTI	BRENT	US	Russia	China	Canada	Kuwait
A_Panel: Prior the COVID-19 (January 1, 2019, to April 11, 2020)							
Mean values	−0.1231	−0.1609	0.0299	0.0059	0.0619	−0.0019	1.3759
Minimum values	−33.30	−61.59	−8.924	−17.99	−9.051	−18.91	−19.30
Maximum values	16.71	16.69	5.911	5.111	6.512	3.019	35.77
Std. dev.	2.635	2.589	1.120	1.419	1.199	0.901	5.197
Kurtosis	29.61	38.09	20.11	20.11	8.009	69.41	6.751
Skewness	−2.209	−4.531	−2.481	−4.759	−2.121	−5.449	2.880
Jarque Bera	19 811.***	24 611.***	2188.4***	18 244.***	1234.7 ***	77 098.***	988.5***
ADF	−19.60***	−19.15***	−16.19***	−19.34***	−20.21***	−4.237**	−16.62***
PP	−19.67***	−19.71***	−22.74***	−19.65***	−19.25***	−19.79***	−18.81***
KPSS	0.534*	0.711*	0.345*	0.866**	0.299	0.751**	0.431**
B_Panel: during the Covid-19 (Mar 12, 2020, to Mar 31, 2021)							
Mean values	0.4819	0.2491	0.1678	0.1419	0.0549	0.0996	2.210
Minimum Values	−20.21	−30.86	−11.54	−20.12	−3.987	−14.25	−6.324
Maximum values	30.023	30.24	7.547	9.325	4.257	10.856	19.368
Standard deviation	5.318	4.126	1.933	2.229	1.133	1.864	3.802
Kurtosis	21.32	17.21	15.55	8.652	4.786	20.45	9.457
Skewness	0.514	−0.039	−0.745	−0.69	−0.004	−2.578	2.054
Jarque Bera	2014.7***	1952.3***	2032.7***	420.06***	99.4***	39.452***	745.6***
ADF	−10.66***	20.12***	−19.41***	−17.12***	−14.52***	−27.44***	−16.40**
PP	−20.21***	14.23***	−30.65***	−20.82***	−15.30***	−30.14***	−10.74**
KPSS	0.214	0.060	0.043	0.039	0.046	0.030	0.054

Note: This table illustrates statistical analysis. The letters*, **, and *** indicate significance levels of 10%, 5%, and 1% are indicated by the letters *, **, and ***.

bands in the stock market had considerable High and medium frequency. During the epidemic, however, the U.S. and Canadian markets with both WTI and Brent oil prices, as well as a few black islands in both nations between the months of March and June of the following year. For Russia, on the other hand, these islands will materialize between March and June 2020, as well as in November 2020. The higher the founder' strength on a regular basis, the larger the rate of return over a limited time horizon (Delmas-Marty et al n.d.) establish Before the epidemic, there was a one-way causation between oil and stock returns. Declaration and a parallel relationship Upon the announcement in a comparable analysis. There are few huge red islands in the high-frequency range of the radio spectrum US, Russian, Chinese, and Canadian markets near the conclusion of the era preceding COVID-19, implying that these markets have a co-movement to a high degree. From October 2019 to April 2020, the Co-movement is more effective. The Canadian, Russian, and U.S. stock markets are notable for medium-sized scales. The thick red island, on the other hand, arrives in the Kuwait market at the start Prior to COVID-19, there was a period known as the pre-COVID-19 period. Our findings are in line with those of (Ju et al. 2015), who demonstrate substantial WTI oil prices and the dollar are moving in lockstep. US On both medium and large scales, there is a stock market. prior to the COVID-19 disaster. From January to April 2019, the outcome of the lead–lag relationship demonstrates that the price of oil, with the exception of the Chinese market, lead stock market returns at low frequency (70 days).

As shown in Fig. 1. The Brent is high as (87.4766), indicted that get highest frequency level during Covid-19 in virtually all cases, red islands all stock markets, notably at the start of the sample period. The S&P and ADF methods second highest (56.388 and, 310.8443) throughout the sample period, the results reveal favorable correlations between oil price returns and stock market returns in Russia and Canada.

Risk spillovers analysis

We use GARCHSK-Mixed Copula-CoVaR results to establish networks to investigate full-sample and dynamic risk spillovers across oil and stock markets, in order to study the multidimensional links between markets in the panoramic frame work. To depict the full-sample (whole) risk spillover fromx_i, *tto* x_j, *t* (*ij*), the average dynamic CoVaR (S_i|j) series are calculated. The averages are then combined into an array, referred to as a full-sample network

adjacency matrix. Table 2 shows average of ΔCoVaR during the COVID-19.

The full-sample networks for the COVID-19 period and the average period are shown in Fig. 2, respectively.

Pre-COVID-19 period Granger causality results

In the pre-COVID-19 period, Table 3 displays the Granger causality results for the U.S., Russia, China, Canada, Kuwait stock indices, and West Texas Intermediate crude o oil

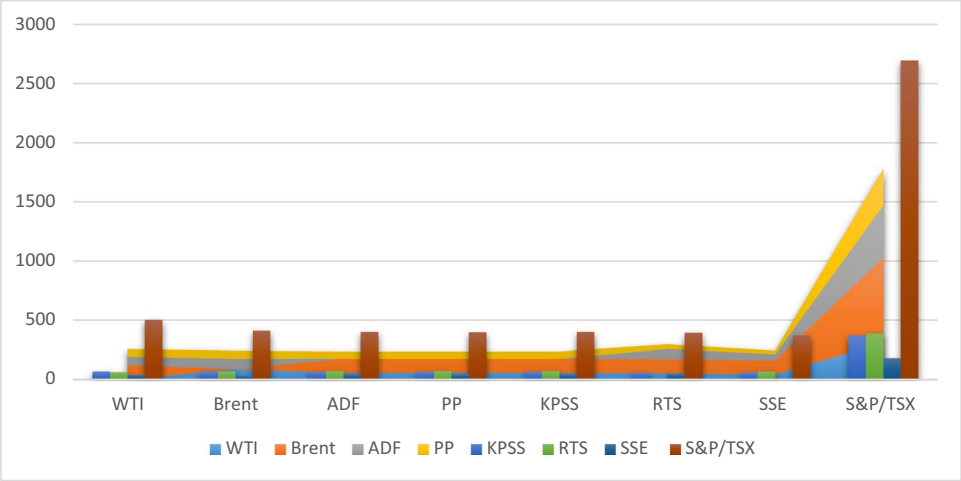

Fig. 1 Lockstep between oil prices and five distinct financial markets during COVID-19

Table 2 The average of ΔCoVaR ($S_i|j$) during the COVID-19 period

	WTI	Brent	ADF	PP	KPSS	RTS	SSE	S&P/TSX
WTI	0	87.4766	56.388	57.389	56.381	54.05189	42.44185	310.8443
Brent	120.161	0	117.577	117.577	117.577	116.09	116.811	720.223
ADF	73.566	86.172	0	0	0	88.241	54.677	441.985
PP	61.332	68.977	60.845	60.841	60.845	38.411	29.17	311.464
KPSS	67.009	68.777	64.8012	64.8012	64.8012	56.797	60.105	370.019
RTS	62.096	69.08	71.322	71.322	71.322	0	65.611	385.782
SSE	36.599	31.812	41.891	41.891	41.891	47.451	0	178.573
S&P/TSX	499.622	411.222	399.602	397.602	399.602	393.015	369.824	2696

Source: Author calculation

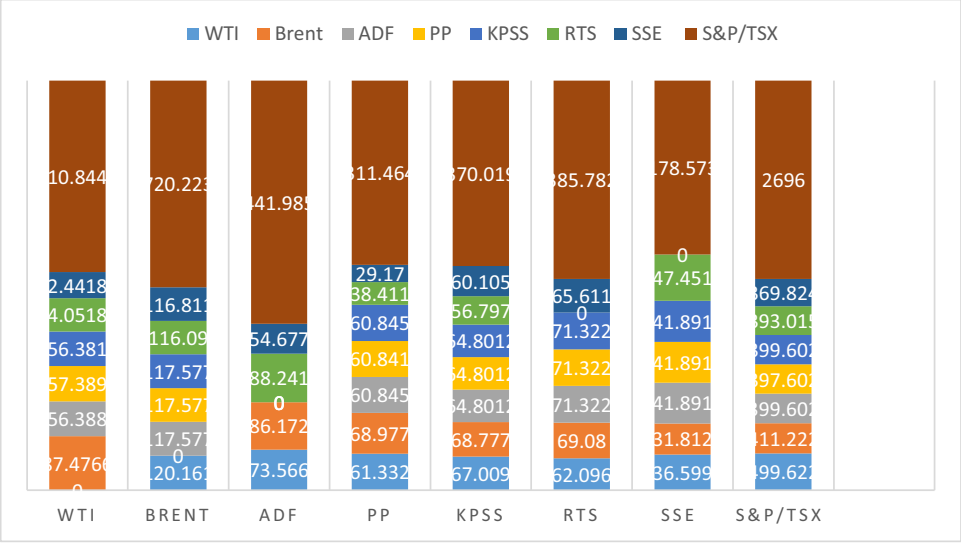

Fig. 2 sample networks for the COVID-19 period and the normal

Table 3 Finding of wavelet-based Granger causality analysis

Direction towards indicator	Scale time for R	Lag(one)	Lag(two)	Lag(three)	Lag(four)	Lag(five)
US **Direction** towards (WTI)	R	7.68**	3.32*	2.05	1.6	1.52
Canada **Direction** towards (WTI)		19.16***	11.05***	8.62***	6.68***	5.63***
China **Direction** towards (WTI)		6.03*	3.94*	2.93*	2.67*	1.99
Russia **Direction** towards (WTI)		0.73	3.31*	2.27	1.78	1.42
Kuwait **Direction** towards (WTI)		0.7	0.52	0.33	1.08	1.52
US **Direction** 1 towards (WTI)	D1	0.25	0.59	1.36	0.43	0.39
Canada **Direction 1** towards (WTI)		0.75	3.04*	2.53	2.57*	2.69*
China **Direction** 1 towards (WTI)		3.79	2.39	2.11	0.86	0.56
Russia **Direction** 1towards (WTI)		3.84	1.69	0.97	1.52	1.05
Kuwait **Direction** 1 towards (WTI)		0.66	0.25	0.17	0.41	0.7
US **Direction** 2 towards (WTI)	D2	4.18*	4.65*	4.91**	0.75	2.02.
Canada **Direction 2** towards (WTI)		18.54***	2.31	11.93***	2.36.	7.54***
China **Direction** 2towards (WTI)		7.49**	1.44	5.55**	1.36	4.97***
Russia **Direction** 2 towards (WTI)		18.6***	4.05*	4.65**	0.92	1.8
Kuwait **Direction** 2 towards (WTI)		5.78*	0.24	0.11	1.05	0.6
US **Direction 3** towards (WTI)	D3	21.62***	14.89***	10.79***	1.37	2.1.
Canada **Direction 3** towards (WTI)		92.57***	8.76***	11.8***	0.47	0.24
China **Direction** 3 towards (WTI)		91.28***	6.33**	22.98***	0.96	0.62
Russia **Direction 3** towards (WTI)		3.85	7.72***	4.46**	1.52	1.88
Kuwait **Direction 3** towards (WTI)		7.23**	17.68***	13.83***	2.89*	2.1

Source: Author calculation.

Notes: Prior to the COVID-19 pandemic disaster, from January 1, 2019, to March 20, 2020, this table's wave-based Granger causal analysis expresses the price outcome using Eqs. 1, 2, 3, and 4. pertaining to stocks. Return. The Standard & Poor's 500 index is often regarded as a barometer of the American stock market. The S & P / TSX Composite Index, on the other hand, represents the market, while the Shanghai Composite Index, RTS Index, and IBC Index, respectively, reflect China, Russia, and Kuwait. Scale 1 (short term) corresponds to a time of 4 to 8 days, while scale 3 (long term) corresponds to an interval of 8 to 16 days. 1%, 5%, and 10%, respectively.

prices. Low scale, such as D1 (0.25, 0.75 lag (1) and 0.39, 2.69 lag-two), about the 10% significance of the U.S. For Brent oil, the outcome is identical (Table 3). Furthermore, at scale D1 (3.79, 3.84 lag (1) and 0.56, 1.69 lag-five), China and Russia stock market returns induce Brent oil returns, respectively. Furthermore, at scale D1 (0.66, lag (1) and 0.25, lag-two), Kuwait stock market returns induce Brent oil returns, respectively

Such as results supports the results of (Bartik et al. 2020; Chanda-Kapata et al. 2020; Gbadamosi et al. 2020; Khan et al. 2020; Renardy et al. 2020; Arif et al. 2021; Sachs et al. 2021)Other markets, such as Russia (D3, 3.85), China (D3, 91.28), and Kuwait (D3, 2.1). Table 3 contains the matrix. P.P. and KPSS are denoted in Table 3 by off-diagonal column sums and row sums (labeled From).

Wavelet-based bidirectional Granger causality analysis

The Table 4 estimated results of the substantial causality assessment in both direction Oil prices and stock indexes are affected by one another, especially at larger sizes (D3). Based on the results of our research, oil prices and stock market indices show fewer links in a smaller range, but show more links over a larger range. On a small scale, these changes are negligible in nearly all countries during the COVID-19 era. Furthermore, these results indicate that the relationship between the oil inventory index is different between the pre-COVID-19 era and the post-COVID-19 era. (Banerjee et al. 2021) showed that there was a one-way causal relationship between oil price returns and stock returns prior to the COVID-19 announcement, but the causal relationship between crude oil prices and the oil yields was full. However, they believe that in the post-COVID-19 disclosure stage, causality is a two-way street. However, our data shows that there is bidirectional causation before and after the COVID-19 period, but there are varying degrees of causality across countries and scales. (Erahman et al. 2016) showed that the ripple effect of oil price returns on the US stock market is constant regardless of frequency; these results indicate that bidirectional

Table 4 Wavelet-based Granger causality analysis results

Direction towards indicator	Scale time for R	Lag(one)	Lag(two)	Lag(three)	Lag(four)	Lag(five)
US **Direction** towards (WTI)	R	1.91	0.78	0.90	0.85	3.05
Canada **Direction** towards (WTI)		5.89**	3.97	2.17	1.79	2.04
China **Direction** towards (WTI)		0.43	0.9	0.61	0.97	0.9
Russia **Direction** towards (WTI)		1.75	2.4	2.31	1.55	3.53**
Kuwait **Direction** towards (WTI)		0.09	0.80	0.7	0.8	0.35
US **Direction** 1 towards (WTI)	**Direction** 1	3.57.	2.59.	4.89**	6.9***	3.99**
Canada **Direction 1** towards (WTI)		17.62***	8.44***	8.10***	8.41***	5.11***
China **Direction** 1 towards (WTI)		0.5	0.009	2.07	2.38	0.58
Russia **Direction** 1towards (WTI)		4.16*	5.12*	3.79*	4.3*	4.6**
Kuwait **Direction** 1 towards (WTI)		3.5	0.70	0.81	0.8	0.27
US **Direction** 2 towards (WTI)	**Direction** 2	0.71	7.32**	7.18**	2.62**	7.34***
Canada **Direction 2** towards (WTI)		8.29*	0.44	6.46**	3.19	7.62***
China **Direction** 2towards (WTI)		15.61***	0.82	5.68**	0.67	1.78
Russia **Direction** 2 towards (WTI)		11.9**	2.9	9.15***	3.58*	8.06***
Kuwait **Direction** 2 towards (WTI)		4.92*	0.14	0.89	3.28	0.88
US **Direction 3** towards (WTI)	**Direction** 3	34.63***	21.05***	11.87***	7.58***	8.02***
Canada **Direction 3** towards (WTI)		115.13***	16.69***	24.93***	6.57***	7.08***
China **Direction** 3 towards (WTI)		4.87.	7.56**	4.68*	2.02	0.86
Russia **Direction 3** towards (WTI)		87.34***	12.9***	14.42***	5.47**	5.18**
Kuwait **Direction 3** towards (WTI)		3.16	14.18***	8.35***	3.58*	3.52*

Notes: The direction values in Table 4 are based on the results of the Wavelet Granger causation study, which compares equity returns to those prior to the Covid-19 pandemic (10 January 2019 - 31 March 2019) linked to oil prices.

Table 5 Granger's Causal Survey Results of WTI Stock Returns and Oil Prices During the Covid-19 Outbreak.

Direction towards indicator	Scale time for R	Lag(one)	Lag(two)	Lag(three)	Lag(four)	Lag(five)
U.S. **Direction** towards (WTI)	R	18.36***	15.68***	5.52**	4.14*	3.66*
Canada **Direction** towards (WTI)		17.29***	14.4***	3.9**	3.44**	4.3***
China **Direction** towards (WTI)		0.57	1.19	1.97	2.23	1.69
Russia **Direction** towards (WTI)		2.73	2.99	1.04	2.23	9.89**
Kuwait **Direction** towards (WTI)		0.67	0.36	1.65	1.54	1.21
US **Direction** 1 towards (WTI)	D1	12.22***	13.3***	3.19*	4.42**	3.35**
Canada **Direction 1** towards (WTI)		12.87***	6.6**	5.83***	6.05***	2.44*
China **Direction** 1 towards (WTI)		5.88*	3.19*	4.78**	1.32	1.77
Russia **Direction** 1towards (WTI)		2.59	0.04	8.54***	7.27***	3.01*
Kuwait **Direction** 1 towards (WTI)		1.78	1.85	0.86	0.13	1.03
US **Direction** 2 towards (WTI)	D2	0.13	8.5***	4.44**	2.44*	2.37*
Canada **Direction 2** towards (WTI)		0.01	18.83***	11.22***	3.94**	2.67*
China **Direction** 2towards (WTI)		0.91	1.31	2.4	1.75	2.63*
Russia **Direction** 2 towards (WTI)		5.42*	9.65***	4.79**	2.55*	2.03
Kuwait **Direction** 2 towards (WTI)		0.02	4.53*	3.84*	1.95	1.96
US **Direction 3** towards (WTI)	D3	15.98***	9.06***	10.33***	1.62	1.24
Canada **Direction 3** towards (WTI)		18.93***	8.31***	12.28***	2.4.	2.25*
China **Direction** 3 towards (WTI)		0.09	1.63	1.97	0.88	1.81
Russia **Direction 3** towards (WTI)		0.21	7.9***	11.96***	4.84***	3.55**
Kuwait **Direction 3** towards (WTI)		0.35	0.02	1	2.39	3.29**

Notes: WTI Direction 1, 2, and 3 with 1 to 5 lags, respectively. The wavelet-based Granger causality employed to analyze stock returns pandemic disaster is presented in the Table 5 values (from March 14, 2020, to March 31, 2021).

causality is stronger over a wider range than a smaller range and that -19 is consistent in the before and after samples.

The 2020 stock markets crash is a worldwide oil and other industries markets crash with large scale. On a lesser scale. Russian, Canada, China, Kuwait, and the USA are net risk receivers, as seen in Table 6. (D1). For Brent oil, the outcome is identical (Table 6). WTI, on the other hand, has a significant impact on the U.S., Canadian, and Chinese markets at bigger scales. These findings also show that oil price changes on a bigger scale substantially affect the United States, China, and Canada, implying a long-term unidirectional causality. Oil price swings have the most significant impact on the Canadian market, followed by the U.S. and China, with Russia having a negligible effect. In terms of the causal relationship between the stock market and WTI oil (Table 6), we find that there are several reasons to link these five stocks to oil over a wide range (D3). The Granger wavelet-based causal results are the same as those obtained before the COVID-19 disaster in the oil price war between Russia and Saudi Arabia. Granger is responsible for the D2 Brent crude oil market in the United States, China and Kuwait.

However, the results for the raw data were inconsequential. In addition, we can see in Table 7 that the impact of stock index movement in the United States and Canada is considerable in influencing WTI oil prices, even when using raw data.

To investigate the impact of the "temporal proximity effect," which asserts that some of the interconnection develops just as a result of non-synchronized trading hours, we synchronize data using the proposed method. Table 8, and Fig. 3, show the empirical results based on data synchronization. It is undeniable that it has a significant impact on the outcomes. On the other hand, the primary conclusions align with section 5, which demonstrates the reliability and robustness of empirical results.

Robust Analysis

In this sub-section, we reselect data processing methods to ensure the empirical validity of our findings. Then we look at risk spillovers that are weighted by market size. To analyze oil-stock risk spillovers, we use WTI, Brent, and Daqing 25 spot prices to represent oil markets. The full-sample risk spillovers data for the COVID-19 and regular periods are

Table 6 Granger's Causal Analysis of WTI Oil Price and Stock Performance

Direction towards indicator	Scale time for R	Lag(one)	Lag(two)	Lag(three)	Lag(four)	Lag(five)
US **Direction** towards (WTI)	R	0	0.89	3.85*	3.42*	3.75*
Canada **Direction** towards (WTI)		3.33	0.53	0.78	0.89	0.96
China **Direction** towards (WTI)		0.62	1.62	3.34*	2.34	3.36*
Russia **Direction** towards (WTI)		0.21	0.97	1.4	0.72	2.4
Kuwait **Direction** towards (WTI)		0.75	0.42	0.19	0.46	0.7
US **Direction** 1 towards (WTI)	D1	3.91	2.88	1.19	3.47*	2.04
Canada **Direction 1** towards (WTI)		2.31	0.53	1.92	4.87**	5.27**
China **Direction** 1 towards (WTI)		11.71**	3.19	3.32*	1.28	1.84
Russia **Direction** 1towards (WTI)		6.03*	0.34	1.84	1.9	1.34
Kuwait **Direction** 1 towards (WTI)		0.27	0.05	1.61	1.29	1.13
US **Direction** 2 towards (WTI)	D2	24.36***	13.13***	9.1***	10.75***	7.66***
Canada **Direction 2** towards (WTI)		2.03	1.65	0.81	0.98	1.43
China **Direction** 2towards (WTI)		9.23**	12.16***	7.86***	10.53***	8.01***
Russia **Direction** 2 towards (WTI)		5.05*	3.88*	2.68.	2.81*	2.76*
Kuwait **Direction** 2 towards (WTI)		1.46	1.94	1.32	2.2	1.76
US **Direction 3** towards (WTI)	D3	19.73***	127.14***	52.31***	21.08***	19.77***
Canada **Direction 3** towards (WTI)		1.47	5.61**	6.8**	0.58	0.66
China **Direction** 3 towards (WTI)		20.6***	45.02***	25.79***	5.46**	1.85
Russia **Direction 3** towards (WTI)		10.92**	14.53***	5.21**	10.25***	16.69***
Kuwait **Direction 3** towards (WTI)		5.16*	5.92**	4.34*	2.33	1.28

Notes: The values in the table represent Granger's causal analysis of the oil price war's spillover effects on stock performance (8 March 2020 - 30 April 2020). The Standard & Poor's 500 index is a barometer of the United States stock market. Scale D1 (short term) corresponds to a period of two to four days, scale 2 (medium duration) to a period of four to eight days, and scale 3 (long term) to a time of eight to sixteen days. The symbols ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

Table 7 summarizes the findings. Granger's causal analysis may be used to a wide variety of variables, from stock prices to WTI oil returns.

Direction towards indicator	Scale time for R	Lag(one)	Lag(two)	Lag(three)	Lag(four)	Lag(five)
US **Direction** towards (WTI)	R	1.97	2.88	2.9	2	2.09
Canada **Direction** towards (WTI)		0.31	0.25	0.65	3.90*	3.21*
China **Direction** towards (WTI)		4.38*	2.83	1.88	1.60	2.55
Russia **Direction** towards (WTI)		0.97	0.58	0.51	0.49	0.31
Kuwait **Direction** towards (WTI)		0.75	0.57	0.38	0.29	0.19
US **Direction** 1 towards (WTI)	D1	2.77	2.78	1.69	0.99	0.98
Canada **Direction 1** towards (WTI)		0.56	0.04	6.24**	1	1.55
China **Direction** 1 towards (WTI)		6.49*	0.99	3.55*	1.34	1.89
Russia **Direction** 1towards (WTI)		4.55*	0.19	0.89	0.59	0.63
Kuwait **Direction** 1 towards (WTI)		2.67	1.78	0.68	0.20	0.90
US **Direction** 2 towards (WTI)	D2	4.32	7.68***	5.76**	4.21*	6.21**
Canada **Direction 2** towards (WTI)		10.45**	9.95***	7.49***	1.82	1.33
China **Direction** 2towards (WTI)		0.29	14.42***	10.53***	5.12**	5.05**
Russia **Direction** 2 towards (WTI)		2.46	0.1	0.53	2.63.	3.64*
Kuwait **Direction** 2 towards (WTI)		0.57	0.14	0.09	0.56	0.81
US **Direction 3** towards (WTI)	D3	14.88***	14.56***	17.32***	2.99*	1.51
Canada **Direction 3** towards (WTI)		0.76	18.02***	9.05***	4.31**	3.28*
China **Direction** 3 towards (WTI)		9.49**	36.74***	17.28***	3.02*	0.94
Russia **Direction 3** towards (WTI)		15***	2.63.	5.05**	4.33**	2.6.
Kuwait **Direction 3** towards (WTI)		5.67*	6.62**	3.99*	2.6	4.88**

Notes: See the notes of Table 07.

Table 8 The average of △CoVaR in the COVID-19 period

	WTI	Brent	ADF	PP	KPSS	RTS	SSE	S&P/TSX
WTI	0	56.588	8.3811	96.057	95.781	7.1424	2.1	263.058
Brent	19.888	0	19.529	38.835	30.638	22.789	10.93	139.645
ADF	45.941	40.711	0	32.632	32.19	35.82	35.059	207.350
PP	41.288	47.999	25.226	0	64.957	29.241	29.41	230.039
KPSS	27.580	54.835	32.122	62.868	0	35.096	34.630	249.053
RTS	21.210	13.344	39.157	10.556	12.592	0	37.075	126.97
SSE	66.917	49.651	40.22	26.633	62.236	66.211	0	306.869
S&P/TSX	199.888	257.064	164.635	267.584	298.397	196.298	149.210	1567.99

Fig. 3 empirical results based on data synchronization

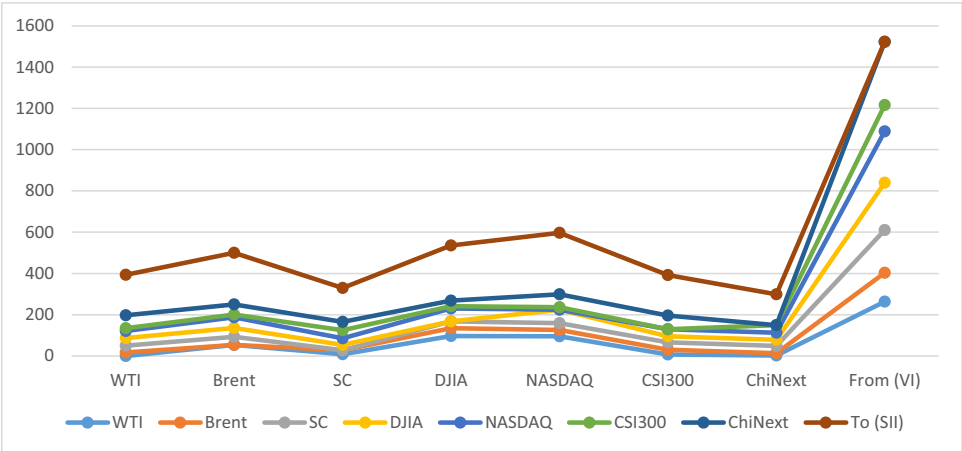

Table 9 The average of ΔCoVaR during the COVID-19 period and oil stock prices

	WTI	Brent	ADF	PP	KPSS	RTS	SSE	S&P/TSX
WTI	0	88.4766	57.388	57.389	57.381	53.05189	43.44185	311.8645
Brent	121.161	0	117.577	117.577	117.577	116.09	116.811	720.223
ADF	72.566	89.176	0	0	0	89.244	54.685	441.985
PP	61.332	68.977	60.845	60.841	60.845	38.411	29.17	311.464
KPSS	68.009	68.777	64.8012	64.8012	64.8012	56.797	60.105	370.019
RTS	67.096	69.08	71.322	71.322	71.322	0	65.611	385.782
SSE	36.599	31.812	41.891	41.891	41.891	47.451	0	178.573
S&P/TSX	499.622	411.222	399.602	397.602	399.602	393.015	369.824	2696

Source: Author calculation

shown in Tables 8 and 9. In fact, the Brent oil futures are just as essential in crude oil pricing as the WTI oil futures (Cologni and Manera 2009; Al-mulali 2011). Furthermore, the primary conclusions Tables 9 and 10 demonstrating that the empirical results in section 5 are valid and robust.

Discussion

Wavelet analysis shows that there is a significant correlation between oil prices and the six major equity markets before and after the COVID-19 pandemic. These relationships fluctuate with time and frequency. These findings require more research, such as portfolio analysis. As the global crisis has led to an increasing integration of equity and oil market trends, investors are looking for suitable alternatives to help them build a diversified investment portfolio and manage risk. To determine the best hedging strategy, we calculate the best portfolio weight, the best hedge ratio and the effectiveness of the hedge. We are testing these indicators in the context of the COVID-19 pandemic to provide investors with a clear picture in times of crisis.

Investors should have more energy assets than equities over the long term, according to the survey results (Graph A). Finally, investors should allocate 60% of their portfolio to oil-related assets and 40% to IBCs in the Kuwatn market.

With the exception of the Kuvat market, the year before the COVID-19 outbreak, the capital allocation of oil assets remained relatively stable as the value of the ideal weight of oil remained almost unchanged. On the other hand, the allocation of the Kuvat market index is lower than the allocation of oil assets during the epidemic. Compared to the stock index portfolio, we found oil to be a good investment both before and after the COVID-19 era. The market environment has no effect on the weight of the portfolio structure and we need to pay attention to it.

Table 8 shows that the beta of the Chinese stock market is lower than that of other regions of the world, indicating that its risk diversification portfolio is higher. These results are remarkable because they indicate that a US short index can hedge a long position in the $ 1 WTI of 0.09 cents. The WTI $ 1 long position can hedge 0.05 cents, short Canadian index positions, 0.05 cents Chinese index, 0.05 cents Russian index, and 0.14 cents short position in the pre-era. -pandemic Position on the Kuwait index.

During the COVID-19 catastrophe, the hedging ratio between oil prices and equities indices varied between 0.02 and 0.10 in the WTI / Canada portfolio. Shorting the US index can be used to hedge a 0.10 cent long position in US dollar WTI. Similarly, the WTI $ 1 long position may be hedged against a 0.09 cent Canadian short position, a 0.02 cent Chinese short position, a 0.05 cent Russian short position, and a 0.05 cent Kuwait short position. The oil / Kuwait equity portfolio coverage ratio varied between 0.0009 and 0.0217 in the COVID-19 sample. Travel restrictions and

Table 10 The average of ΔCoVaR during the normal period and oil stock prices

	WTI	Brent	ADF	PP	KPSS	RTS	SSE	S&P/TSX
WTI	0	82.947	67.024	63.572	48.358	53.451	14.139	329.492
Brent	28.335	0	26.956	19.835	26.669	16.088	10.971	128.855
ADF	40.277	32.665	0	45.415	37.343	34.152	16.748	206.599
PP	58.071	49.721	51.866	0	68.048	60.091	59.398	344.068
KPSS	37.970	48.733	38.207	59.861	0	38.2883	37.833	261.699
RTS	39.422	19.698	21.736	40.132	36.769	0	69.388	277.998
SSE	19.699	11.533	27.676	31.641	32.897	42.326	0	156.833
S&P/TSX	211.830	230.257	236.345	260.466	245.079	236.389	203.281	1921.599

Source: Author calculation

blockades have pushed oil prices down 30%, and the US-Russian pricing war has aggravated the issue. In comparison to the global financial crisis of 2008, the COVID-19 epidemic has had a stronger effect on stock market volatility. Our study indicates that this crisis has an effect on oil spills, but the extent of the effect differs by nation. Prior to the COVID-19 pandemic, oil prices had a significant influence on the Russian market, even on a minor scale; however, this impact will be mitigated during the epidemic. As a result of the detrimental impact of the COVID-19 epidemic on investor mood, individual Russian investors are likely to over- or under-value stocks, lowering the degree of correlation between oil and stocks. The COVID-19 epidemic, according to (Goodell and Goutte 2021), enhanced individual investor engagement in the stock market. The author demonstrates that when prices fall from March to April 2020 as a result of the collapse of COVID-19, Russian private investors increase their purchases. Individual investors accounted for 38% of Russian stock transactions as the pandemic expanded. According to (Herrero and Bouzarovski 2014), the Russian stock market has been particularly heavily struck by the current viral shock, with the index's spot price coming to an unprecedented standstill. The Canadian and US markets had a little impact on oil prices during the COVID-19 epidemic, but this effect was not obvious in pre-COVID-19 samples. The outcomes of the portfolio construction and the efficacy of the Brent crude oil hedging are shown in Table 6. The outcome is identical to that of WTI crude oil. The Brent portfolio, like the WTI portfolio, has a large Wtc value for the United States, Canada, China, and Russia. On the other side, the Kuwat Wtc is a compact structure. Stock investors should hold a higher proportion of Brent crude oil than stocks. Additionally, the data indicates that coverage with Brent crude is more expensive before to and during the epidemic than coverage with WTI crude. Except in Kuwait, the EO of Brent crude is more than that of WTI in all stock markets.

The study's findings are reported in Table 1. Granger causality results for wavelet and Brent oil prices are remarkably similar to those for WTI oil prices. We discovered a substantial two-way causal relationship between oil prices and equity indexes, particularly over a large range (D3). Oil prices are also affected by the US and Canadian stock markets. Similarly, oil prices and market indexes show lesser correlations within a narrower range, but stronger correlations over a wider range. Figure 4 depicts the block diagram.

Conclusion and Policy Implication

This paper investigated the correlation between oil stock market return and the crude oil market through volatility spillover in the wake of the COVID-19 pandemic. Moreover, focus on the VAR and Granger causality analysis approach sample of five oil-producing and consumption countries, including (Russian, Canada, China, Brazil, Kuwait, and the USA). Data from January 1, 2019, to March 31, 2021, the sample period is in effect. A data stream was used to collect the information. The sample period was separated into two sub-periods. The sample days during the pandemic period from March 20, 2020, when the World Health Organization acknowledged the COVID-19 pandemic.

As a result, this study focuses on the multiscale interaction between oil prices and stock markets in oil-dependent nations, as well as the impact of the COVID-19 problem on the oil market's ripple effect.

The following are the article's major findings:

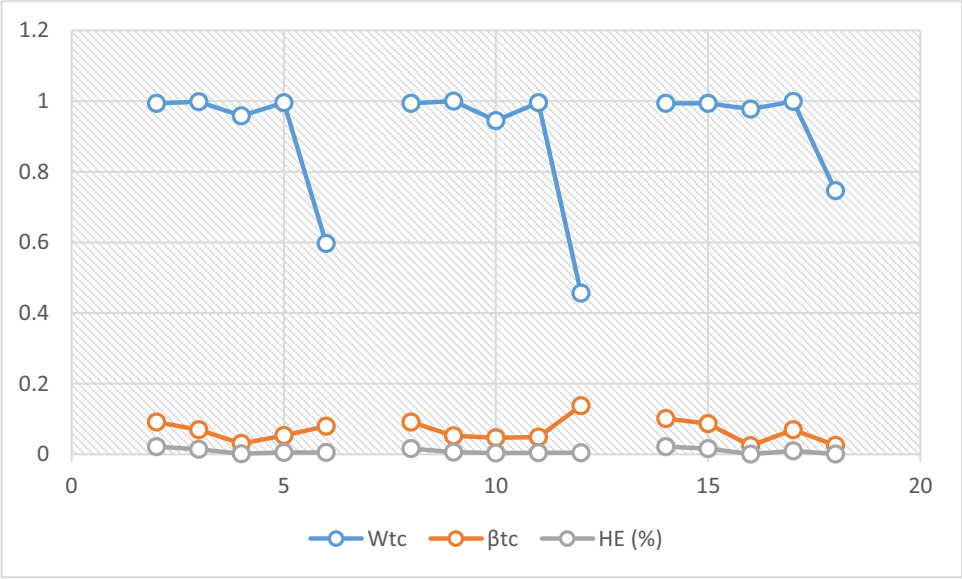

Fig. 4 oil prices and stock indices

1. The wave chart demonstrates a significant association between oil prices and stock returns, notably between March and May 2020 (the first phase of the COVID-19 outbreaks), implying that the gloomy sentiment in the stock market is going to wane. Oil price trend. As a result of the favorable connection between oil prices and stock markets in the United States, China, Russia, Canada, and Kuwait, oil is not a desirable asset class for investment portfolios. Diversified investments and oil futures may be beneficial for hedging at crossroads.
2. Second, we examine the investigation's findings that oil may be employed individual equity market investors' stake has grown as a result of the COVID-19 epidemic, particularly in Russia. When prices plummeted between March and April 2020 as a result of COVID-19's failure.
3. Finally, as the wavelet analysis demonstrates, not only oil prices will affect the performance of these nations' stocks, but also stock market indexes. Additionally, our research indicates that the relationship between oil prices and equity indices is weaker on a micro level but greater on a macro level. These movements are negligible on a lower scale in practically all nations during the COVID-19 epidemic.

The ratio of the oil inventory index varied between the periods prior to and following COVID-19, based on this data. Although the relationship between oil prices and small-cap equity indexes is tenuous and always changes across a larger range, even prior to the COVID-19 outbreak, the Russian market was heavily influenced by oil prices, regardless of their size. Ladder; however, this impact will be diminished in the event of a pandemic. The Canadian and US markets had a little impact on oil prices during the COVID-19 epidemic, but this effect was not obvious in pre-COVID-19 samples. The influence of oil prices on the Russian stock market is more erratic (Erahman et al., 2016), however (Wu et al. 2012) show that oil and gas prices have a major impact on the Russian stock market. Russia's market. The Russian market is heavily impacted by oil prices, since it has been demonstrated that foreign exchange risk prices alter over time in this market.

Our findings can be applied to future pandemic scenarios. Equity investors should be mindful that market fluctuations are catastrophe prone and unbalanced over time. As a result, businesses may use this knowledge into their hedging plans, particularly in the case of future losses, and more precisely when the bond is extremely expensive in the short term. Market volatility and the link between time and investment horizons may require these investors to adjust their hedging tactics. Portfolio managers may utilize data on oil stock ratios to forecast future connections, which is particularly useful during times of crisis. They want data and proof about oil price swings in order to forecast stock price movements and build equity strategies. Politicians are interested in the connections between oil and stocks amid financial, energy, and health crises, as these events have the potential to disrupt market connections.

In recent years, as a result of the financial crisis and increased globalization, the worldwide stock market and oil have grown increasingly inextricably interwoven. As a result of these patterns and occurrences, coverage becomes more complicated, eroding the diversity benefits. According to this data, a considerable two-way ripple effect exists between the five equities markets examined and the world's largest oil market. As a result of the risk transmission dynamics (or Granger causality), market players will carefully examine and hedge high market risks. Similarly, the release of negative oil risk in the equities market signals that traders with diverse investment portfolios should consider hedging all market risks over the next month or so following any positive shock in the oil market.

Policy implications

1. While all stock markets were net transmitters of energy market volatility during the 2008 global financial crisis, they acted differently during the Covid-19 crisis. The oil / stock ratio has increased the dangers for stock dealers, oil-producing nations, and regulators.
2. During the tragedy of the Covid-19 outbreak, the most pronounced difference in volatility is obvious, with unfavorable volatility spreading throughout the market and being deemed stronger than favorable volatility. Throughout the Covid-19 catastrophe, the crude oil spill's unfavorable asymmetry persisted in MSCI's global and Chinese equities markets, but they were timely and rapidly had a beneficial effect on emerging equity markets. Additionally, we address the impact on investors of portfolio diversification and hedging techniques.
3. This understanding of risk's unintended consequences enables educated judgments on energy storage and purchasing, particularly in major oil-dependent countries. Future papers may build on this work by analyzing the short, medium, and long-term consequences of oil stock interactions.

Availability of data and materials The data that support the findings of this study are openly available on request.

Author contribution **Ran Yan:** Writing - original draft, Data curation, Visualization, review & editing. **Fuguo Cao:** Guidance and supervision, conceptual design, substantive revision of results, conclusions and policy implications. **Ke Gao**: Writing - review & editing and software, Visualization, editing.

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Declarations

Ethical approval and consent to participate The authors declare that they have no Known competing financial interests or personal relationships that seem to affect the work reported in this article.

Consent for publication We do not have any individual person's data in any form.

Competing interest statement We declare that there is no conflict of interest.

References

Accastello C, Bieniasz A, Blaško R et al (2019) Conflicting Demands on the Natural Resources in Northern Sweden: A Participatory Scenario Development Study. J Environ Assess Policy Manag. https://doi.org/10.1142/S1464333219500170

Agyekum EB, Amjad F, Mohsin M, Ansah MNS (2021) A bird's eye view of Ghana's renewable energy sector environment: A Multi-Criteria Decision-Making approach. Util Policy. https://doi.org/10.1016/j.jup.2021.101219

Ahmad M, Akhtar N, Jabeen G et al (2021) Intention-based critical factors affecting willingness to adopt Novel Coronavirus prevention in Pakistan: Implications for future pandemics. Int J Environemntal Res Public Heal 18:6167. https://doi.org/10.3390/ijerph18116167

Ahmad B, Irfan M, Salem S, Asif MH (2022) Energy Efficiency in the Post-COVID-19 Era: Exploring the Determinants of Energy-Saving Intentions and Behaviors. Front Energy Res 9:824318. https://doi.org/10.3389/fenrg.2021.824318

Alemzero DA, Iqbal N, Iqbal S et al (2020a) Assessing the perceived impact of exploration and production of hydrocarbons on households perspective of environmental regulation in Ghana. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-10880-3

Alemzero DA, Sun H, Mohsin M et al (2020b) Assessing energy security in Africa based on multi-dimensional approach of principal composite analysis. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-10554-0

Al-mulali U (2011) Oil consumption, CO2 emission and economic growth in MENA countries. Energy 36:6165–6171. https://doi.org/10.1016/j.energy.2011.07.048

Ang BW, Choong WL, Ng TS (2015) Energy security: Definitions, dimensions and indexes. Renew. Sustain. Energy Rev 42:1077–1093

APERC (2007) A qu e s t f o r e n e rg y security in the 21

Arif M, Hasan M, Alawi SM, Naeem MA (2021) COVID-19 and time-frequency connectedness between green and conventional financial markets. Glob Financ J 49:100650. https://doi.org/10.1016/j.gfj.2021.100650

Baloch ZA, Tan Q, Iqbal N et al (2020) Trilemma assessment of energy intensity, efficiency, and environmental index: evidence from BRICS countries. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-09578-3

Banerjee R, Mishra V, Maruta AA (2021) Energy poverty, health and education outcomes: Evidence from the developing world. Energy Econ 101. https://doi.org/10.1016/j.eneco.2021.105447

Bartik AW, Bertrand M, Cullen ZB, et al (2020) How are small businesses adjusting to COVID-19? Early evidence from a survey. National Bureau of Economic Research

Bettendorf T (2019) Spillover effects of credit default risk in the euro area and the effects on the Euro: A GVAR approach. Int J Financ Econ 24:296–312. https://doi.org/10.1002/ijfe.1663

Chanda-Kapata P, Kapata N, Zumla A (2020) COVID-19 and malaria: A symptom screening challenge for malaria endemic countries. Int J Infect Dis 94:151–153. https://doi.org/10.1016/j.ijid.2020.04.007

Chien F, Pantamee AA, Hussain MS et al (2021) Nexus between financial innovation and bankruptcy: Evidence from information, communication and technology (ict) sector. Singapore Econ Rev. https://doi.org/10.1142/S0217590821500181

Cologni A, Manera M (2009) The asymmetric effects of oil shocks on output growth: A Markov-Switching analysis for the G-7 countries. Econ Model. https://doi.org/10.1016/j.econmod.2008.05.006

Delmas-Marty M, Broberg M, De Sadeleer N, et al (n.d.) 187 Taming COVID-19 by Regulation: An Opportunity for Self-Reflection Alberto Alemanno 195 Governing Globalisation through Law

Ding Y, Yao F, Lv H, Hu Y (2020) Interaction between Marine Economic Development and Talent Cultivation: The Result of Canonical Correlation Analysis. J Coast Res. https://doi.org/10.2112/SI103-017.1

Dong X-Y, Hao Y (2018) Would income inequality affect electricity consumption? Evidence from China. Energy 142:215–227

Dupor B, Guerrero R (2017) Local and aggregate fiscal policy multipliers. J Monet Econ 92:16–30. https://doi.org/10.1016/j.jmoneco.2017.07.007

Dutta A (2018) A note on the implied volatility spillovers between gold and silver markets. Resour Policy 55:192–195

Ehsanullah S, Tran QH, Sadiq M et al (2021) How energy insecurity leads to energy poverty? Do environmental consideration and climate change concerns matters. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-14415-2

Elavarasan RM, Pugazhendhi R, Shafiullah GM et al (2021) A hover view over effectual approaches on pandemic management for sustainable cities – The endowment of prospective technologies with revitalization strategies. Sustain Cities Soc 68:102789. https://doi.org/10.1016/j.scs.2021.102789

Erahman QF, Purwanto WW, Sudibandriyo M, Hidayatno A (2016) An assessment of Indonesia's energy security index and comparison with seventy countries. Energy 111:364–376. https://doi.org/10.1016/j.energy.2016.05.100

Gao H, Shi D, Zhao B (2021) Does good luck make people overconfident? Evidence from a natural experiment in the stock market. J Corp Financ 68. https://doi.org/10.1016/j.jcorpfin.2021.101933

Gbadamosi A-Q, Oyedele L, Olawale O, Abioye S (2020) Offsite Construction for Emergencies: A focus on Isolation Space Creation (ISC) measures for the COVID-19 pandemic. Prog Disaster Sci 8:100130

Goodell JW, Goutte S (2021) Co-movement of COVID-19 and Bitcoin: Evidence from wavelet coherence analysis. Financ Res Lett 38:101625

Guan Z, Li P (2020) Regional Differentiation Characteristics of the Development Ability of Coastal Villages and Towns under the Condition of Market Economy in the Reform and Transformation. J Coast Res 103:120–124. https://doi.org/10.2112/SI103-025.1

Gurara DZ, Ncube M (2013) Global economic spillovers to Africa: A GVAR approach. African Development Bank Abidjan

Heinlein R, Legrenzi GD, Mahadeo SMR (2021) Crude oil and stock markets in the COVID-19 crisis: Evidence from oil exporters and importers. Q Rev Econ Financ 82:223–229

Herrero ST, Bouzarovski S (2014) Energy transitions and regional inequalities in energy poverty trends: Exploring the EU Energy Divide. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2537067

Hilbers AM, Sijtsma F, Busscher T, Arts J (2019) Understanding Added Value in Integrated Transport Planning: Exploring

the Framework of Intelligence, Design and Choice. J Environ Assess Policy Manag. https://doi.org/10.1142/S146433321950011X

Hsu CC, Quang-Thanh N, Chien FS et al (2021) Evaluating green innovation and performance of financial development: mediating concerns of environmental regulation. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-14499-w

Ikram M, Sroufe R, Mohsin M et al (2019) Does CSR influence firm performance? A longitudinal study of SME sectors of Pakistan. J Glob Responsib. https://doi.org/10.1108/jgr-12-2018-0088

Iqbal W, Tang YM, Chau KY et al (2021) Nexus between air pollution and NCOV-2019 in China: Application of negative binomial regression analysis. Process Saf Environ Prot. https://doi.org/10.1016/j.psep.2021.04.039

Irfan M, Ahmad M, Fareed Z, et al (2021a) On the indirect environmental outcomes of COVID-19 : Short-term revival with futuristic long-term implications. Int J Environ Health Res 1–11. https://doi.org/10.1080/09603123.2021.1874888

Irfan M, Akhtar N, Ahmad M et al (2021b) Assessing public willingness to wear face masks during the COVID-19 pandemic: Fresh insights from the theory of planned behavior. Int J Environ Res Public Health 18:4577. https://doi.org/10.3390/ijerph18094577

Irfan M, Elavarasan RM, Hao Y et al (2021c) An assessment of consumers' willingness to utilize solar energy in china: End-users' perspective. J Clean Prod 292:126008. https://doi.org/10.1016/j.jclepro.2021.126008

Irfan M, Ikram M, Ahmad M et al (2021d) Does temperature matter for COVID-19 transmissibility? Evidence across Pakistani provinces. Environ Sci Pollut Res 28:59705–59719. https://doi.org/10.1007/s11356-021-14875-6

Irfan M, Razzaq A, Suksatan W et al (2021e) Asymmetric impact of temperature on COVID-19 spread in India: Evidence from quantile-on-quantile regression approach. J Therm Biol 103101. https://doi.org/10.1016/j.jtherbio.2021.103101

Irfan M, Salem S, Ahmad M et al (2022a) Interventions for the Current COVID-19 Pandemic: Frontline Workers' Intention to Use Personal Protective Equipment. Front Public Heal 9:793642. https://doi.org/10.3389/fpubh.2021.793642

Irfan M, Shahid AL, Ahmad M et al (2022b) Assessment of public intention to get vaccination against COVID-19: Evidence from a developing country. J Eval Clin Pract 28:63–73. https://doi.org/10.1111/jep.13611

Jee Y (2020) WHO international health regulations emergency committee for the COVID-19 outbreak. Epidemiol Health 42

Jiang Z, Yoon S-M (2020) Dynamic co-movement between oil and stock markets in oil-importing and oil-exporting countries: Two types of wavelet analysis. Energy Econ 90:104835

Ju K, Su B, Zhou D et al (2015) Oil price crisis response: Capability assessment and key indicator identification. Energy 93:1353–1360. https://doi.org/10.1016/j.energy.2015.09.124

Khan KA, Haq MI, Khan JM, et al (2020) Opinion on Impact of Covid-19 Lockdown on Agriculture, Food Security and livelihoods in Pakistan. Int J Agric Biol Sci 1–10

Khosravi F, Fischer TB, Jha-Thakur U (2019) Multi-criteria Analysis for Rapid Strategic Environmental Assessment in Tourism Planning. J Environ Assess Policy Manag. https://doi.org/10.1142/S1464333219500133

Kordej-De Villa Z, Slijepcevic S (2019) Assessment of Local Councillors' Attitudes towards Energy Efficiency Projects in Croatia. J Environ Assess Policy Manag. https://doi.org/10.1142/S1464333219500121

Lee WC, Hoe N, Viswanathan KK, Baharuddin AH (2019) an Economic Analysis of Anthropogenic Climate Change on Rice Production in Malaysia. Malaysian J Sustain Agric 4:01–04. https://doi.org/10.26480/mjsa.01.2020.01.04

Li W, Chien F, Hsu CC et al (2021) Nexus between energy poverty and energy efficiency: Estimating the long-run dynamics. Resour Policy. https://doi.org/10.1016/j.resourpol.2021.102063

Lokhandwala S, Gautam P (2020) Indirect impact of COVID-19 on environment: A brief study in Indian context. Environ Res 188:109807

Molla MB, Ikporukpo CO, Olatubara CO (2019) Evaluating Policy and Legal Frameworks of Urban Green Infrastructure Development in Ethiopia. J Environ Assess Policy Manag. https://doi.org/10.1142/S1464333219500169

Mugableh MI (2017) World oil price volatility and stock returns fluctuations: evidence from Southeast Asian equity markets. Sci Int 29:759–762

Mukanjari S, Sterner T (2020) Charting a "Green Path" for Recovery from COVID-19. Environ Resour Econ. https://doi.org/10.1007/s10640-020-00479-0

National B, Stewardship E (2005) 2005 Environmental Sustainability Index Law and collaboration with : with : 1–4

Nwanna IO, Eyedayi AM (2016) Impact of Crude Oil Price Volatility on Economic Growth in Nigeria (1980-2014). J Bus Manag

Ozoike-Dennis P, Spaling H, Sinclair AJ, Walker HM (2019) SEA, Urban Plans and Solid Waste Management in Kenya: Participation and Learning for Sustainable Cities. J Environ Assess Policy Manag. https://doi.org/10.1142/S1464333219500182

Pedauga L, Sáez F, Delgado-Márquez BL (2021) Macroeconomic lockdown and SMEs: the impact of the COVID-19 pandemic in Spain. Small Bus Econ. https://doi.org/10.1007/s11187-021-00476-7

Pinto E, Morrison-Saunders A, Bond A et al (2019) Distilling and Applying Criteria for Best Practice EIA Follow-Up. J Environ Assess Policy Manag. https://doi.org/10.1142/S146433321950008X

Raza SA, Shahbaz M, Amir-ud-Din R et al (2018) Testing for wavelet based time-frequency relationship between oil prices and US economic activity. Energy. https://doi.org/10.1016/j.energy.2018.02.037

Renardy M, Eisenberg M, Kirschner D (2020) Predicting the second wave of COVID-19 in Washtenaw County. MI. J Theor Biol 507:110461. https://doi.org/10.1016/j.jtbi.2020.110461

Sachs JD, Karim SA, Aknin L et al (2021) Priorities for the COVID-19 pandemic at the start of 2021: statement of the Lancet COVID-19 Commission. Lancet 397:947–950

Sun HP, Tariq G, Haris M, Mohsin M (2019) Evaluating the environmental effects of economic openness: evidence from SAARC countries. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-05750-6

Sun H, Pofoura AK, Adjei Mensah I et al (2020a) The role of environmental entrepreneurship for sustainable development: Evidence from 35 countries in Sub-Saharan Africa. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.140132

Sun L, Cao X, Alharthi M et al (2020b) Carbon emission transfer strategies in supply chain with lag time of emission reduction technologies and low-carbon preference of consumers. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.121664

Sun L, Qin L, Taghizadeh-Hesary F et al (2020c) Analyzing carbon emission transfer network structure among provinces in China: new evidence from social network analysis. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-08911-0

Tanveer A, Zeng S, Irfan M (2021) Do Perceived Risk, Perception of Self-Efficacy, and Openness to Technology Matter for Solar PV Adoption ? An Application of the Extended Theory of Planned Behavior. Energies 14:5008. https://doi.org/10.3390/en14165008

Tiep NC, Wang M, Mohsin M et al (2021) An assessment of power sector reforms and utility performance to strengthen consumer self-confidence towards private investment. Econ Anal Policy. https://doi.org/10.1016/j.eap.2021.01.005

Wang X, van't Veld K, Marcy P et al (2018) Economic co-optimization of oil recovery and CO 2 sequestration. Appl Energy 222:132–147

Wen F, Gong X, Cai S (2016) Forecasting the volatility of crude oil futures using HAR-type models with structural breaks. Energy Econ 59:400–413

Wen D, Wang G-J, Ma C, Wang Y (2019) Risk spillovers between oil and stock markets: A VAR for VaR analysis. Energy Econ 80:524–535

Wen C, Akram R, Irfan M et al (2022) The asymmetric nexus between air pollution and COVID-19: Evidence from a non-linear panel autoregressive distributed lag model. Environ Res 209:112848. https://doi.org/10.1016/j.envres.2022.112848

Wu Chien-Ming, Hui-Chi, Tseng Po-Chou, Chan Sue-Fen, Huang Wei-Wei, Chu Yung-Fu, Chen (2012) Evaluation of stock trading performance of students using a web-based virtual stock trading system. Computers & Mathematics with Applications 64(5):1495–1505. https://doi.org/10.1016/j.camwa.2012.03.097

Yang C, Hao Y, Muhammad I (2021) Energy consumption structural adjustment and carbon neutrality in the post-COVID-19 era. Struct Chang Econ Dyn 59:442–453. https://doi.org/10.1016/j.strueco.2021.06.017

Yarovaya L, Elsayed AH, Hammoudeh S (2021) Determinants of Spillovers between Islamic and Conventional Financial Markets: Exploring the Safe Haven Assets during the COVID-19 Pandemic. Financ Res Lett 43:101979. https://doi.org/10.1016/j.frl.2021.101979

Yu L, Zha R, Stafylas D et al (2020) Dependences and volatility spillovers between the oil and stock markets: New evidence from the copula and VAR-BEKK-GARCH models. Int Rev Financ Anal 68:101280

Zhang D, Mohsin M, Rasheed AK et al (2021) Public spending and green economic growth in BRI region: Mediating role of green finance. Energy Policy. https://doi.org/10.1016/j.enpol.2021.112256

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