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Does COVID-19 pandemic cause natural resources commodity prices volatility? Empirical evidence from China

Shanwen Guo, Ph.D\textsuperscript{a}, Qibin Wang, Ph.D\textsuperscript{a,}\textsuperscript{*}, Tolassa Temesgen Hordofa, Ph.D\textsuperscript{b}, Prabjot Kaur, Dr\textsuperscript{c}, Ngoc Quynh Nguyen\textsuperscript{d}, Apichit Maneengam\textsuperscript{e}

\textsuperscript{a} Institute of Political Economy, Taiwan ChengKung University, Tainan, Taiwan
\textsuperscript{b} School of Economics and Finance, Xi’an Jiaotong University, China
\textsuperscript{c} Department of Mathematics, Birla Institute of Technology Mesra, Ranchi, Jharkhand, India
\textsuperscript{d} Department of Economics, Thuongmai University, Vietnam
\textsuperscript{e} Department of Mechanical Engineering Technology, College of Industrial Technology, King Mongkut’s University of Technology North Bangkok, Wongsawang, Bangsue, Bangkok 10800, Thailand

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ABSTRACT

COVID-19 pandemic caused havoc around the globe in both economic and non-economic sectors. This paper, unlike previous studies, evaluates the role of COVID-19 on the volatility in natural resources. The volatility of natural resources commodity prices has been the center of discussion, especially during the pandemic. Unlike previous studies, this study aims to evaluate the role of the pandemic, i.e., Covid-19 and its possible impact on volatility in natural resources commodity prices for China. China has been the center of this epidemic disease and is considered one of the major economies affected by the Covid-19; therefore, it is better to conduct this study for China. This study uses data from January 2020 till September 2021 to capture the peak time of Covid-19. Moreover, this study employs the novel wavelet power spectrum and wavelet coherence approach to better capture volatility within commodity prices volatility and Covid-19 and evaluate the association between both variables. The empirical results reveal that only natural resources commodity prices are volatile and only short. While Covid-19 positive cases and Covid-19 deaths are not vulnerable during the study period. Moreover, the wavelet coherence conforms that both Covid-19 positive cases and Covid-19 deaths significantly cause volatility in natural resources commodity prices. Although, volatility is found at different periods; still, volatility is observed only in the short-run. The study also provides relevant policy implications to ensure a relevant and timely solution for the existing issue. Moreover, future research guidelines and the study’s limitations are also provided.

1. Introduction

In the shape of COVID-19, the world has experienced another major shock to the global economy after the global financial crisis. The world has changed dramatically during the previous three decades as a result of many economic and non-economic events or crises. Specifically, the Gulf War (1990s), Asian financial crisis (1997), oil price spike (2004), global financial crisis (2007), European sovereign debt crisis (2010–2012), oil supply glut (2015–2016), and the recent Covid-19 pandemic outbreak are among the events attributed for global and regional economic issues (Lyu et al., 2021; Maitra et al., 2021). These events influence industrial/production activities and economic development and create uncertainty in natural resources and their prices (Sun and Wang, 2021; Guan et al., 2021). The Covid-19 pandemic causes severe illness and death, making the people fear this novel disease led economies to recession. In China, this novel pandemic is identified at first, which reached out to most nations. The said economy is affected the most in employment, services, production, tourism, and others. However, the primary sources of economic growth of Chinese economy are considered as the industrial or production sector. Which is severely affected as a result of the lock-down environment in the country. This postponement in the industrial sector reduces production and

\begin{itemize}
  \item [a] Corresponding author.
  \item E-mail addresses: Shanwen.Guo.123@gmail.com, u18053023@ncku.edu.tw (S. Guo), qibin.wang123@gmail.com, u18083028@ncku.edu.tw (Q. Wang), tmhurtree@gmail.com (T.T. Hordofa), M.prabjot.kaur@bitmsra.ac.in, prabjotkaur@bitmesra.ac.in (P. Kaur), quynh.nn@tmu.edu.vn (N.Q. Nguyen), apichit.m@cit.kmutnb.ac.th (A. Maneengam).
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consequently leads to a decline in the natural resources demand. As a result, the overall supply and demand chain of natural resources like crude oil, coal, natural resources are disturbed. Hence, the prices of such natural resources are not stable in this pandemic period. Therefore, it is important to analyze the association of natural resources volatility and the Covid-19 pandemic in the region affected the most in the world (see Table 1).

Since the last three decades, scholars and policy-makers have been involved in a contradictory debate, where the earlier claimed that natural resources abundance weakens economic growth (Gelb, 1988; Sachs and Warner, 2001). However, the latter studies oppose these claims by revealing the conditional positive impact of natural resources on economic growth by enhancing human capital and institutional quality product diversification (Rahim et al., 2021; Joya, 2015; Expo and Nochi Faha, 2020). However, whether a blessing or a curse, natural resources have long been discussed. Currently, volatility in natural resources attracted the attention of policy-makers and the academic world.

The Covid-19 epidemic caused damage to the global economy, which also caused fear in financial markets throughout the world (Li et al., 2021). Since the recent outbreak, most economic sectors have been closed down due to the lockdown environment in most parts of the world. Likewise, in China, the spread of the Covid-19 pandemic postponed production, manufacturing, and the pharmaceutical industry, which causes uncertainty in the global supply chain and causes a severe shortage of life-saving drugs (Gupta et al., 2020). This postponement in economic and industrial sectors reduces the demand for natural resources such as oil, which dramatically reduces the prices of raw materials and natural resources in China and the rest of the world. Additionally, the Covid-19 pandemic severity, where the positive cases and death ratio are increases fear in public and consequently increases volatility in natural resources (Devour and Narayan, 2020).

Given the significance of crude oil price volatility, it’s essential to consider its progress, especially at a time when it reached its lowermost point in history. That is, f or the first time in its history, crude oil prices fell below zero. The price of West Texas Intermediate crude fell to US$37 per barrel on April 20, 2020, representing an exceptional 300 percent decline in price (Devour and Narayan, 2020). The pricing war between Saudi Arabia and Russia and the Covid-19 outbreak might be to blame for this drop. Global economic activity was suspended as a result of the epidemic. Regardless of price recovery, the post-April 2020 era marks one of the most volatile natural resources commodity market periods. The hypothesis of current study is that the outbreak of the Covid-19 pandemic coincided with the oil market’s most volatile time, with Covid-19 active or positive cases and deaths contributing to this volatility. We contend that Covid-19 and oil market activity, including price and volatility, are inextricably linked. The rationale is straightforward.

The novel Covid-19 pandemic triggered three particular governmental reactions: firstly, the lockdown; secondly, the travel ban, and thirdly, the stimulus package (see Phan and Narayan, 2020). Two of these three governmental reactions (i.e., lockdown and travel restriction) effectively suspended economic activity, including foreign travel, lowering oil demand and consumption. According to the World Trade Organization (WTO), as a consequence of Covid-19, trade in 2020 is predicted to drop by 13–32 percent. In summary, global oil demand has decreased, affecting both the price of oil and its uncertainties, which current study expect to be evident in oil price volatility.

The primary objective of this study is to analyze volatility in natural resources commodity prices and Covid-19 pandemic. Specifically, the Covid-19 pandemic is represented by the Covid-19 positive cases and the deaths caused by Covid-19. Nonetheless, many studies in the existing literature examined the influence of Covid-19 pandemic on oil prices. However, these studies ignore volatility in natural resources commodity prices and primarily focus on the economic impact of oil prices. Secondly, this study aims to analyze the causal association Covid-19 positive cases and natural resources commodity prices during the peak period of pandemic. Although the studies of Ma et al. (2021), and Sun

| Author          | Country (Period) | Methodology          | Findings                                                                 |
|-----------------|------------------|----------------------|--------------------------------------------------------------------------|
| Ma et al.       | China (January 1, | Wavelet methods,     | More volatility in natural resources in Covid-19. Bidirectional causality exists between natural resources and economic performance. |
| (2021)          | 2019-April 01,   | Frequency domain causality |                                                                        |
|                 | 2021)            |                      |                                                                          |
| Sun and Wang    | Global Data (January 01, 2019-July 01, 2021) | Wavelet methods | Natural resources are volatile. No causality between natural resources and economic performance. |
| (2021)          |                  |                      |                                                                          |
| Gil-Alana and   | Global Data (May 04, 2010-May 04, 2020) | Long memory techniques | Covid-19 has a significant impact on oil prices.                        |
| Monge (2020)    |                  |                      |                                                                          |
| Apergis and     | USA (January 21, 2020-April 30, 2020) | Mixed Data Sampling modeling | Covid-19 and oil prices help reduce the US political polarization. The pandemic causes volatility in natural resources. |
| Apergis (2020)  |                  |                      |                                                                          |
| Gupta et al.    | China            | Review               |                                                                          |
| (2020)          |                  |                      |                                                                          |
| Bildirici et al. | WTI, Brent, Dubai crude oil (May 29, 2006-March 31, 2020) | LSTARGARCH | Covid-19 and Russia-Saudi conflict is responsible for chaotic behavior of natural resources. |
| (2020)          |                  |                      |                                                                          |
| Sharif et al.   | USA January 21,  | Wavelet methods      | Covid-19 significantly affects economic uncertainty.                     |
| (2020)          | 2020-March 30, 2020 |                      |                                                                          |
| Kartal (2021)   | Turkey (July 25, 2019-October 30, 2020) | Multivariate Adaptive Regression | Covid-19 influence oil prices.                                           |
| Narayan (2020)  | Global sample    | Statistical Analysis | Covid-19 promote oil price volatility.                                   |
| (2020)          | (February 01, 1995-May 05, 2020) |                      |                                                                          |
| Meni et al.     | Global Data (April 23, 2018-April 24, 2020) | Asymmetric Multifractal Detrended Fluctuation Analysis | Covid-19 causes volatility in natural resources commodity prices. |
| (2020)          |                  | ARDL, PMG           |                                                                          |
| Guan et al.     | Natural Resource Dependent Countries (2000–2020) |                      | Natural resources volatility is harmful for economic growth.            |
| (2021)          |                  |                      |                                                                          |
| Li et al.       | Panel (December 16, 2019-December 16, 2020) | GARCH(1, 1) | Current pandemic declines stock market returns and economic growth.     |
| Zhao et al.     | Developed countries | Panel Regression | Covid-19 enhances volatility in stock market returns.                    |
| (2021)          |                  |                      |                                                                          |
| Khan et al.     | China (1987-2017) | Generalized Least Square | Natural resources have adverse impact of financial development.       |
| (2020)          |                  |                      |                                                                          |
| Umar et al.     | 12 Oil producing countries (2001Q1-2019Q4) | Panel Regression | Resource curse surges the possibility of banks default. Bubbles are identified in the oil market in various periods. In Covid-19, the Bitcoin is a safe haven. (continued on next page) |
| (2021a)         |                  |                      |                                                                          |
| Umar et al.     | Brent Crude Oil  | Probability-based bubble detection mechanism | Wavelet Methods | wavelet methods, Frequency domain causality | Natural resources are volatile. No causality between natural resources and economic performance. |
| (2021b)         | (January 2000-December 2020) |                      |                                                                          |
| Goodell and Goutte (2021) | December 31, 2019-April 29, 2020 | Wavelet Methods |                                                                          |
and Wang (2021) provide empirical evidence regarding volatility in natural resources commodity prices while considering the Covid-19 pandemic period, yet they ignored the specific causal nexus of mentioned variable and are more oriented to economic performance. Lastly, this study examines the causal association between deaths caused by the Covid-19 pandemic and natural resources commodity prices volatility. The deaths caused by Covid-19 pandemic cause fear among the general public in China, which leads to the postponement of various economic activities. Thus, demand for natural resources has fallen down drastically, which could play a substantial role in natural resources commodity price volatility. Therefore, this study is substantial and could provide relevant policy implications to tackle the issue.

This study is novel and contributes to the existing literature in three ways. Firstly, it is one of the pioneering efforts empirically investigating volatility in Covid-19 positive cases, Covid-19 deaths, and natural resources commodity prices. Although, the literature consists of empirical studies for the influence of Covid-19 cases and deaths on oil prices. Still, volatility in the Covid-19 pandemic remained unexplored. However, this is an emerging topic of interest for the policy-makers as it is relevant to a country’s economic system. Secondly, this study provides empirical evidence of the causal linkage between Covid-19 positive cases, Covid-19 deaths, and natural resources commodity prices volatility. There are numerous factors and indicators influencing natural resources commodity prices volatility. However, the Covid-19 pandemic is considered the leading cause of volatility in natural resources for which the literature is not extensive. Therefore, current study provides empirical evidence as contribution to the literature. Moreover, this study used extended dataset that covers Covid-19 pandemic period extensively. Unlike other studies, this study provides comprehensive empirical estimates for volatility and causal nexus using wavelet specifications, which are considered relatively better than the existing methodologies (as discussed in Section-3). Since the Covid-19 pandemic is a threat to human lives and economic systems. Also, China stood the first to experience this fatal pandemic. Therefore, this study’s findings and policy implications could help the scholars view and tackle the issue in a more appropriate way.

The rest of the paper is organized as following: Section-2 provides relevant literature review; Section-3 presents data and methodology; Section-4 represents results and discussion of the empirical findings; Section-5 provides conclusion and policy implications along with the limitations and future research guidelines.

2. Literature review

Since the last three decades, there is a growing literature regarding the influence of natural resources and various economic and non-economic factors and indicators. However, after the emergence of Covid-19 pandemic, the scholars focused more on volatility in natural resources commodity prices. Specifically, Ma et al. (2021) investigated the pre and post-Covid-19 pandemic periods in case of China by using the wavelet power spectrum, wavelet coherence, and the frequency domain causality tests. The estimated results asserted that natural resources commodity prices are more volatile in Covid-19 pandemic period. Also, the results reveal bidirectional causal association between natural resources commodity price volatility and economic performance. Regarding global economic performance and natural resources commodity price volatility, Sun and Wang (2021) investigated the period of January 01, 2019, to July 01, 2021, by employing the wavelet specifications. The study found that natural resources commodity prices are volatile at different frequencies across different periods, while economic performance is stable. In contrast to Ma et al. (2021), this study found no causal association between the variables. In addition, the recent study of Umar et al. (2021b) used the Probability-based bubble detection mechanism to detect bubbles in the Brent Crude Oil during the period January 2000–December 2020. The study’s examined results reveal that bubbles exist in the oil market in various periods.

Besides total natural resources volatility, the recent studies are more tending towards volatility in oil prices. Specifically, Gil-Alana and Monge (2020) examined the influence of Covid-19 pandemic on crude oil prices via employing the long memory techniques. The empirical results reveal that the crude oil market was efficient before the outbreak and became efficient after the Covid-19 pandemic. Also, the results unveil that oil prices incorporate mean reverting behavior, indicating that the Covid-19 pandemic shock will be transitory while having long-lasting effect. Using the MIDAS methods, Apergis and Apergis (2020) found that both oil prices and Covid-19 pandemic help in mitigation of the US political polarization. Specifically, the authors claimed that the political leaders minimize their aim for partisan gains particularly in the stressful times. The Covid-19 pandemic, which originated from Wuhan, affects most countries across the globe, reducing global economic growth from 2.9 to 2.4 percent. However, in China, Gupta et al. (2020) illustrate that Covid-19 pandemic spread leads to the close down the production and manufacturing sector, the pharmaceutical industry – disturbs the supply chain leads to shortage of life saving drugs. The authors argued that the reduction in China’s production leads to decreased prices of raw materials and natural resources in other parts of the world.

Bildirici et al. (2020) investigated West Texas Intermediate (WTI), Brent and Dubai crude daily oil price covering the period from May 29, 2006, to March 31, 2020. The study used Logistic Smooth Transition Autoregressive Generalized Autoregressive Conditional Heteroskedasticity (LSGARCH) and the long-short term memory specifications. The empirical findings reveal that the behavior of oil prices is chaotic across the time, where the recent trends, i.e., Covid-19 pandemic, and Russia and Saudi Arabia conflict, are the leading reasons for this behavior in oil prices. Using the wavelet specifications, Sharif et al. (2020) states that oil is the leading market in US with a lower and higher frequency during the period under observation. Additionally, the authors reveal that Covid-19 pandemic significantly affect the political and economic uncertainty of the US relative to their stock market. In addition, Kartal (2021) analyzed Turkish economy from July 25, 2019, to October 30, 2020, using multivariate adaptive regression. The study uncovers that the volatility index has the greatest impact on oil prices irrespective of sample size. Moreover, in Turkey, the COVID-19 outbreak impacts the influence of effective factors on local currency oil prices. In continuation, Narayan (2020) analyzed the impact of Covid-19 and negative oil price news on oil price volatility. The empirical findings suggest that both Covid-19 active cases and

| Author et al. (Year) | Country (Period) | Methodology | Findings |
|----------------------|------------------|-------------|----------|
| Kirkikali et al. (2021) | United Kingdom (1998–2017) | Wavelet Methods | Economic growth and nuclear energy consumption is positively correlated. |
| Raza et al. (2018) | USA (1979M1–2013M7) | Wavelet Methods | Oil prices positively affect economic activities. |
| Zhang et al. (2021) | China (1965–2019) | Granger Causality | Economic growth causes carbon emissions. |
| Wang et al. (2021) | USA (January 4, 2011–July 31, 2020) | Econometric techniques | Diversification enhances profitability but reduces volatility in portfolio. |
| Umar et al. (2020a) | China (1980–2017) | FMOLS, DOLS, CCR | Economic growth and natural resources are the factors of emissions. |
| Umar et al. (2020b) | China (1971–2018) | Wavelet methods | Enhancement in financial development lower emissions. |
negative oil price news significantly increase volatility in oil prices. However, in this panic times, Goodell and Goutte (2021) argued that Bitcoin is the safe haven for investors.

Regarding the influence of the Covid-19 pandemic on the price of the most tradable natural resources, i.e., gold and oil prices, Mensi et al. (2020) employed the Asymmetric Multifractal Detrended Fluctuation Analysis approach on 15-min interval intraday data. The empirical findings report that prior to Covid-19 pandemic, the gold market was inefficient due to downward trends, while the inefficiency of gold market was reported during the Covid-19 pandemic. Besides, the oil market is found inefficient by following upward trends before the pandemic and downward trends during the Covid-19 pandemic – which is evidence of the volatility in natural resources commodity prices. Besides volatility in natural resources commodity prices, studies provide empirical evidence regarding the influence of natural resources on various economic and non-economic factors and indicators. Specifically, Guan et al. (2021) analyzed natural resources price volatility and its influence on the economic growth of the natural resources’ dependent economies over 2000–2020. The study used autoregressive distributed lag (ARDL) model and pooled mean group (PMG) estimator for empirical analysis. The results obtained revealed that crude oil had faced a significant downturn, particularly in the 2008 global financial crisis and Covid-19 pandemic. However, gold prices are found less volatile than the crude oil prices during these periods. Moreover, volatility in these natural resources prices deteriorates economic growth in these regions in both short and long run. On the other hand, Raza et al. (2018) claim that oil prices are positively associated to economic activities in the USA during the period 1979M1–2013M7. Due to this, Wang et al. (2021) asserted that diversification is a better option to enhance profitability in the USA. However, economic activities are the leading factor of economic growth across the globe. On the other hand, economic growth and natural resources are the major cause of carbon dioxide emissions Umar et al. (2020a). In addition, the recent study of Zhang et al. (2021) also demonstrates that economic growth causes carbon emissions, which reveals that growth without considering environment is harmful to sustainable development.

In addition, Mazur et al. (2021) investigated S&P1500 in order to analyze Covid-19 pandemic and the stock market crash in March 2020. The study found that healthcare, food, natural gas, and software stocks produces high positive returns. However, the equity value in petroleum hospitality, entertainment and real estate sectors fall drastically. The authors argued that the recent pandemic outbreak triggered the stock market crash. Regarding the association between Covid-19 pandemic fear and volatility in the stock market, Li et al. (2021) employed the GARCH(1, 1) specifications and revealed that Covid-19 fear is the driving force for stock market volatility. Specifically, an increase in the Covid-19 cases significantly reduces economic growth and stock market returns. Besides, the authors claimed that the public attention to buying or selling attitude of stocks is greatly dependent on the cases of Covid-19 pandemic. Moreover, Zhao et al. (2021) studied the influence of Covid-19 containment measures on the expected stock price volatility in developed economies. Employing panel regression in the daily data, the study unveils that six-month-ahead volatility indices fell when first or re-imposed lockdowns were announced but did not fall considerably once the lockdowns were eased. For three-month-ahead predicted volatility, such patterns are weaker, and for one-month-ahead expected volatility, they are almost non-existent.

To summarize the literature, this study observed from the given literature that natural resources volatility and pandemics are greatly associated. To be more specific, the literature appeals that economic productivity or industrial production has been dropped due to pandemics. Due to this, the demand for natural resources across the globe has slowed down, which causes volatility in natural resources. However, studies have provided a safe haven for future investment instead of natural resources like oil. Such safe havens are gold, and the bitcoins. Moreover, the literature also demonstrates that the pandemic has created fear amongst the industrialists. While this fear of sickness and death leads drop the stock market participation and performance. Nonetheless, the existing literature provides a valuable insight regarding the association of pandemic and natural resources volatility. However, most of the studies have focused only on the economic aspects of the volatility. Relatively, these studies have ignored the primary reason behind natural resources volatility. Moreover, China is the first economy to experience the worst impact of Covid-19 pandemic. Also, the Chinese economy stood among the most affected region across the globe due to postponement of production and industrial sector. In addition, the reduction of production and other economic activities across the globe leads to fluctuations in the prices of natural resources. Therefore, it is important to identify whether Covid-19 is the cause of this volatility in natural resources in China.

3. Data and methodology

3.1. Variables and data

Based on the objectives and mentioned literature, this study used a total of three variables to analyze the causal association of Covid-19 pandemic and natural resources commodity price volatility. Specifically, this study used the Covid-19 positive (CP) cases – indicates the infection that spreads across the country, deaths due to Covid-19 positive (CPD) – indicates the number of deaths that is occurred due to the novel pandemic, and oil prices (OP) to represent volatility in natural resources commodity prices. The main reason behind the selection of the variables is that the Covid-19 pandemic creates fear in the economies across the globe. Two factors are responsible for this fear in the general public. Specifically, the fear of Covid-19 sickness, and the death due to this novel disease. Keeping in mind these two factors, the industrial and production sectors postponed production, severely affecting the demand and supply chain of goods and services. Also, temporary closing of the industrial and production sector reduces demand for natural resources, which disturbs imports and exports of natural resources such as oil. Therefore, reducing the demand for natural resources and particularly crude oil, its prices tend to reduce. Also, the trade war between Russia and Saudi Arabia regarding oil exports also affects the demand and supply chain of natural resources. Hence, it is important to analyze whether Covid-19 pandemic is leading in this perspective. In order to discover the results, daily data for the said variables have been obtained from various sources, particularly for China, covering the period from January 2020 to September 2021. Regarding the data sources, the oil prices data is obtained from West Texas Intermediate (WTI),1 while data for Covid-19 active cases and deaths due to Covid-19 positive is extracted from World Health Organization (WHO).2

3.2. Estimation strategy

The current study used a wavelet technique to measure the correlation of time series such as Covid-19 active cases and deaths due to Covid-19 on China’s natural resources commodity price volatility. Nonetheless, time-varying estimation methodologies such as recursive autoregressive conditional heteroscedasticity (ARCH), generalized ARCH, cointegration, or Diebold and Yilmaz’s (2009) rolling-sample spillover index methodology are available. On the other hand, the wavelet technique is regarded as more resilient since it better represents short- and long-run time series trends and causalities. The wavelet technique breaks down a time series into specific time scales instead of other short and long term conventional approaches such as cointegration and error correction. According to Kim Karlsson et al. (2018), wavelet analysis

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1 For oil price data and details, visit: https://www.investing.com/commodities/crude-oil-historical-data.
2 For Covid-19 data and details, visit: https://covid19.who.int/table/.
will validate differences in data and vital information, which might be ignored in other time-varying procedures. The wavelet technique, in other words, shows how the time series element evolves over time. This separates the time series under consideration into scaled and shifted mother wavelet time series (Aguir-Conrraria et al., 2008). In addition, wavelet transformations – in which the wavelet’s length varies independently over time - allow for natural local analysis of time-series variables. On the other hand, this approach may be compressed into a short wavelet component to examine higher frequency variations and stretched into a long wavelet function to predict the pattern of lower-frequency variations. Short wavelet functions (narrow window) are appropriate for recording fast or quick changes, but the enlarged function can be used to isolate gradual and steady fluctuations (wide window). Also, the wavelet technique leads to efficient estimates by converting non-stationary time series challenges into empirical evidence, which other approaches cannot do (Sifuzzaman et al., 2009).

Since there are numerous advantages that the wavelet method offers in empirical research, however, some of the advantages of this time-varying approach is discussed above. As a result of these benefits, the current study used a wavelet approach, which included the wavelet power spectrum and wavelet coherence, to explore vulnerabilities or volatilities and the causal relationship between Covid-19 active cases, deaths caused by Covid-19 pandemic, and the oil prices. Both of these specifications are discussed as following:

3.2.1. Continuous wavelet

The current work used a novel wavelet method, in which the wavelet coherence approach reveals time-frequency domain causalities for all variables in the short and long run. In general, a wavelet is an integral squared function having a real value and a mean of zero, denoted by $\psi$ and given as follows:

$$\psi(t) = S^{-1/2} \psi \left( \frac{t - T}{S} \right)$$

(1)

From the above equation, The unit variance held by wavelet is shown by $S^{-1/2}$, which is a normalized constant. Aside from that, the wavelet has two parameters: location/time ($T$) and frequency ($S$). Both time and frequency factors are important for detecting the specific wavelet location or position in time, which is mostly related to wavelet fluctuations, and controlling corresponding frequency variations, respectively.

The $\psi$ expression will waggle across the $t$-axis and behave in a wavileike manner. The wavelet utilized here is essentially from the Morlet wavelet family developed by Goupillaud et al. (1984), which may be expressed as

$$\psi(t) = \pi^{-1/4} \frac{1}{e^{\frac{1}{2}}} e^{\frac{1}{2} t^2}$$

(2)

From the above equation, the factor of normalization is represented by $\pi^{-1/4}$, which indicates the unit energy of wavelet. The Gaussian envelope with a one unit of standard deviation is depicted by $e^{\frac{1}{2} t^2}$. Additionally, $e^{\frac{1}{2} t^2}$ represents complex sinusoid. Moreover, the wavelet in this scenario, exclusively evaluates limited time series data $p(t) = 1, 2, …, T$. The distinction among time and scale localization is uncertain according to Heisenberg’s uncertainty principle. As a result, the Morlet wavelet $w_0 = 6$ is effective for the central frequency, according to Rua and Nunes (2009), due to its performance in optimizing the time and scale localization.

3.2.2. Continuous wavelet transform

We can compute the temporal fluctuation of the frequency of time series using the continuous wavelet transformations $W_p(T, S)$. The following equation may be used to express the continuous wavelet transform:

$$W_p(T, S) = \int_{-\infty}^{\infty} p(t) S^{-1/2} \psi \left( \frac{t - T}{S} \right) dt$$

(3)

Where the $^*$ in Eq. (3) denotes complex conjugates, and $S$ specifies whether the wavelet differentiates components of $p(t)$ at a lower or higher scale, which is feasible if the acceptability requirement is met. Furthermore, a higher scale suggests smaller wavelets or fluctuation, whereas a lower scale indicates higher wavelet fluctuations. In this case, wavelet power spectrum (WPS) is appropriate since it delivers more information and amplitude for a given time series. The WPS operated with the following squared form:

$$\text{WPS}_p(T, S) = |W_p(T, S)|^2$$

(4)

3.2.3. Wavelet coherence

This study used the wavelet coherence approach after evaluating the wavelet power spectrum. Despite the commonalities and contrasts between wavelet coherence and other existing methodologies, this method is unique in that it allows for the detection of correlations between two time variables, $p(t)$ and $q(t)$, in a unified time-frequency domain. The following is the equation for the cross-wavelet transform of both time series:

$$W_{pq}(T, S) = W_p(T, S) W_{q}^*(T, S)$$

(5)

From the above equation, $W_p(T, S)$ and $W_{q}(T, S)$ indicates the cross-wavelet transformation for $p(t)$ and $q(t)$, respectively. In addition, the bar denotes complex conjugates. $W_{pq}$ (cross-wavelet transform) on the left indicates the covariance of two time series at a certain scale. The wavelet power spectrum records contribution to the series’ variance at each time scale, whereas cross-wavelet power measures covariance contribution in time-frequency space.

The wavelet coherence, as previously stated, captures the frequency co-movement of two time series variables, $p(t)$ and $q(t)$. In this regard, Torrence and Compo (1998) suggested the squared form of wavelet coherence, which may be described in Eq. (6) below:

$$R^2(T, S) = \frac{|D(S^{-1}W_{pq}(T, S))|^2}{D(S^{-1}|W_p(T, S)|^2)D(S^{-1}|W_q(T, S)|^2)}$$

(6)

From the equation mentioned above, the time smoothing process is indicated by $D$. Regarding the right side of the equation, its values range from 0 to 1, i.e., $0 \leq R^2(T, S) \leq 1$. Specifically, if the $R^2(T, S)$ value is approaching to zero, this designates that there is no correlation between the two time series. However, if $R^2(T, S)$ value is approaching to one, this reveals that there is a strong correlation between the two time series. Colors ranging from blue to yellow-red might be used to distinguish the connection in a wavelet coherence. The colour blue denotes a lack of or weak connection, but the colour yellow-red denotes a high association between two time variables $p(t)$ and $q(t)$.

3.2.4. Phase

There is no definite distinction that indicates whether the relationship between time variables $p(t)$ and $q(t)$ is positive or negative when using the $R^2(T, S)$ analytical approach. In this case, the wavelet coherence phase difference is utilized to look for a positive or negative correlation, as well as a lag-lead relation, between the two time series in a combined time-frequency domain. As a result of Torrence and Webster’s (1999) research, the wavelet coherence phase difference may be calculated using the following equation:

$$\varphi_{pq}(T, S) = \tan^{-1} \left( \frac{L\{D(S^{-1}W_{pq}(T, S))\}}{O\{D(S^{-1}W_p(T, S))\}} \right)$$

(7)

From the above equation, the real part operator and imaginary part operators of smooth power spectrum is captured by $L$ and $O$. \newpage
respectively. Interestingly, \( \varphi_p(T, S) \) provides two-dimensional graphical representation, which can be used for the empirical findings regarding wavelet coherence technique.

The empirical findings may be interpreted as follows once the results are produced using the wavelet technique. The horizontal axis reflects time, while the vertical axis reflects frequencies in the wavelet power spectrum and wavelet coherence graphical representation. A lower frequency implies a greater size. In the time-frequency domain, wavelet coherence may be used to detect two time series that co-vary. Additionally, the colour yellow-red indicates a strong connection between series, whereas the blue colour indicates a weaker to no connection between the temporal variables under examination. If there is no link between the series, the cooler regions away from the critical region(s) imply time and frequency. Further, the lag and lead phase relationships between the examined variables are shown by arrows in the wavelet graphical displays. At a given scale, the zero phase shift represents the co-movement of two time series. Furthermore, the time series are all in phase or have a positive correlation when the arrows go to the right, but out of phase or have a negative correlation when the arrows travel to the left. Both variables flow in the same direction when two series are in phase, while they flow in the opposite direction when they are anti-phase. Moreover, an arrow moving up, left-up, or right-down on a wavelet coherence schematic graph depicts that the first variable causes the second variable. On the other hand, if the arrows are pointing down, left-down, right up, this leads to the conclusion that the second variable is causing the first variable.

After discovering volatility and causal nexus between the variables via the wavelet power spectrum and wavelet coherence, respectively, this study tested the association between these variables via employing the Quantile-on-Quantile (QQ) regression approach. This technique is more powerful in dealing the non-normality or irregularity issue of the data under consideration. Hence, the QQ regression is used as a robustness test.

4. Results and discussion

Non-stationary qualities can be seen in a variety of economic and non-economic variables. On the other hand, most estimating methodologies do not allow for empirical investigation of non-stationary series. Furthermore, these non-stationary series might contain significant periodic signals that change amplitude and frequency with time. We used the wavelet power spectrum to capture these shifting trends in Covid-19 positive (CP) cases, deaths due to Covid-19 positive, and natural resource commodity prices from January 2020 to September 2021 in China. In addition, the time-frequency dependency of these variables might raise a few problems, as stated in the study’s objectives: First, is there any evidence of time-frequency dependency for these variables? Second, what is the direction of causality between these variables, provided the hypothesis is correct? Finally, whether the relationship occurs in a certain time period (i.e., short-run and long-run) or across the overall time span? The current study used the wavelet coherence technique for empirical analysis of China to answer these questions. As a result, both wavelet methods are used in this work.

4.1. Results of the wavelet power spectrum

The graphical depiction of wavelet power spectrum in Figs. 1–3, depicts the zone of influence, which also specifies an edge. However, the wavelet power spectrum produces negligible findings below that edge and cannot be interpreted. Furthermore, Monte Carlo simulation was used to achieve such substantial estimations – demonstrated by the black contour. The black contour represents the empirical findings’ at 5% significance level. In addition, the colors of the wavelet power spectrum graph reflect vulnerabilities, with blue (colder) indicating low or no vulnerabilities and red (hot) indicating larger vulnerabilities in time series variables (Kirikkaleli, 2020).

Regarding the graphical display of wavelet power spectrum for oil prices (Fig. 1), only one significant region is found that indicates the vulnerable oil prices. Specifically, the vulnerable period is between February and May (2020). The scale is found lower, indicating that the frequency is higher in these months, reported as 0–15. Besides, other regions reported showed vulnerability in natural resources commodity prices, yet these regions are insignificant. The vulnerability in natural resources during these months is likely due to the lockdown environment in China (Gupta et al., 2020). Specifically, the lockdown due to Covid-19 pandemic leads to reduced production, trading, and other economic activities, which significantly reduces oil demand and causes fluctuations in oil prices among other natural resources. Besides, the recent conflict of Russia and Saudi Arabia leads to a substantial supply of oil at a lower price for market capturing strategy (Bildirici et al., 2020). This further contributes to the oil market volatility in China. As a result, natural resources commodity prices, i.e., oil prices, in particular, lost prices consistency due to these mentioned issues. These findings are consistent with the earlier empirical findings of Umar et al. (2021b), which demonstrate the existence of bubbles in the oil price market in different periods. Hence, it is concluded that vulnerabilities exist in the oil prices. Concerning Fig. 2 and Fig. 3, the Covid-19 positive cases and deaths are found stable during the selected period of time. Specifically, a higher fluctuation has not been observed in the Covid-19 positive cases and deaths caused by the Covid-19 pandemic. As depicted by the dark blue color, these variables are not significantly vulnerable, while a weaker vulnerability is observed as depicted by the light blue/green color, which is still insignificant. Hence, it is concluded that in the selected three variables, only natural resources commodity prices are volatile in a shorter period of time.

4.2. Results of the wavelet coherence

The wavelet coherence graphical display shown in Figs. 4 and 5 shows that the horizontal line represents time, and the vertical line represents frequency. Lower frequency indicates larger scale connection, similar to the wavelet power spectrum, whereas higher frequency indicates lower scale linkage. Wavelet coherence is a more effective method than other existing causality methodologies when considering the time-frequency domain. This method takes two time variables \( p(t) \) and \( q(t) \) at the same time, as well as their respective co-movements across the selected time period. Focusing on such advantages, the current study used the wavelet coherence approach to investigate the short- and long-term causal links between Covid-19 positive cases and deaths and natural resource commodity price volatility in China across the time period under study. The wavelet coherence graph, like the wavelet coherence schematic graph depicts that the first variable causes the second variable. On the other hand, if the arrows are pointing down, left-down, right up, this leads to the conclusion that the second variable is causing the first variable.
power spectrum, uses colors to identify the causal effect, with blue (colder) color denoting weaker or no inter-relationship and red (hot) color denoting high inter-relationship between the variables under investigation (Kirikkaleli, 2020). Furthermore, the black cone-shaped curve denotes a significant zone, and the contour denotes a 5% significant level. Moreover, arrows might be used to indicate the causal linkage: while heading to the right (left), the variables are in phase (antiphase) and traveling in the same (opposite) direction. Further, the first variable is leading when the arrows are pointed up, left-up, or right-down. In contrast, the second variable is leading when the arrows are pointing down, left-down, or right-up. This work’s wavelet coherence empirical findings might give vital policy insights for governors, policymakers, and academics.

Regarding the wavelet coherence between natural resources commodity prices and Covid-19 positive cases, Fig. 4 reveals four significant regions of causal nexus between the two in different periods. Firstly, in the period of February 2020 showed significant causal influence of Covid-19 positive cases on oil prices as the arrows are pointing towards the right-up direction. However, this causal nexus is very limited. Lastly, the period of June–July 2021 is observed significant for causal nexus between oil prices and Covid-19 positive cases. Specifically, this causal influence is of higher frequency ranging from 16 to 40. However, the arrows are found traveling towards right-up and right-down, indicating a bidirectional causal association between the discussed variables. However, the influential magnitude of Covid-19 positive cases is found greater. Also, the rightward moving arrows indicate that the association between these two variables is in phase. These findings are in line with the earlier studies of Ma et al. (2021) in case of China and Sun and Wang (2021) in a global perspective – revealing that natural resources are more volatile in the Covid-19 pandemic peak period. The reason behind the phasal movement and causal nexus between Covid-19 pandemic and natural resources commodity prices is China’s postponement of production and industrial activities (Gupta et al., 2020). Which further fuel volatility in natural resources commodity prices. However, as the empirical findings reveal that the causal influence is only for a shorter period of time, this is also consistent with the study of Gil-Alana and Monge (2020), which indicates that the Covid-19 shock exhibit mean reverting behavior and transitory.

Regarding wavelet coherence between oil prices and Covid-19 deaths, Fig. 5 reveals that significant regions hold the causal nexus of these two variables. Specifically, causality is found at various periods during the selected time span. However, these causal nexuses are observed only in the short-run, while missing in the long-run. Specifically, the periods of February 2020, August–November 2020, February 2021, and May–July 2021 are found significant for casual association between Covid-19 deaths and natural resources commodity prices. Besides, the causal association between Covid-19 deaths and oil prices is found only in the shorter run with a different scale and frequencies. From these significant regions, the arrows are pointing to the right, indicating a phasal association between these variables. Moreover, arrows pointing towards right-up, right-down, right-up, and left-down designate that there is a bidirectional causal association between the said variables. Specifically, the Covid-19 death increases fear in general public (Li et al., 2021). This fear reduces the supply of labor force that offsets production and other economic activities. As a result, demand for
natural resources has fallen down, creating volatility in natural resources commodity prices. The findings of this study are consistent with the empirical findings of Narayan (2020), Ma et al. (2021) and Guan et al. (2021), which indicates that natural resources and oil prices, in particular, are volatile during the Covid-19 pandemic, while this volatility in oil prices is driven by Covid-19 pandemic, which could lead to the deterioration of economic growth in both short and long run.

4.3. Robustness results

Nonetheless, the wavelet coherence demonstrates bidirectional causal association between OP–CP, and OP–CPD. However, to validate this association of OP and explanatory variables like CP and CPD, this study uses Quantile-on-Quantile (QQ) regression. The prime advantage of the said approach is that it tackles the irregularity or non-normality issue of data. Fig. 6 provides the empirical estimates of QQ regression for OP and CPD. As per the study of Xu et al. (2021), the darker blue color represents the lowest value of coefficient, and the darker red color indicates the higher coefficient value. While the darker red color indicates higher value of coefficient. Current findings indicate that there is a mixed effect of CP on OP across different quantiles. Specifically, in the earlier quantile (0–0.2) of OP, the influence of CP is observed positive, while in the middle quantiles (0.3–0.6) it is negative but with a lower coefficient value. However, in the higher quantiles (0.8–1) of OP, the influence of CP is found negative with a relatively higher value. This demonstrates that with the increase of Covid-19 pandemic active cases, the oil prices become more unstable and volatility increases. Hence, this study’s findings are consistent with the existing study of Sun and Wang (2021) and Ma et al. (2021), that validates the enhancement of volatility in natural resources during the pandemic period.

Similar to the earlier results of OP and CP, the estimated results of the QQ regression for OP and CPD is reported in Fig. 7. The examined results reveal a mixed association between CPD and OP. That is, the earlier (0–0.3) quantiles of OP are positive across all the quantiles of CPD with a higher coefficient value of 1–1.5. While in the medium quantiles, the coefficient value of CPD decline to the negative with a –2.5 in 0–0.2 quantiles. Whereas the higher quantiles reveal the higher coefficient values. The mixed, i.e., positive and negative values of CPD indicates that volatility of OP due to fluctuations in the deaths of patients due to Covid-19 pandemic. The current findings of Gil-Alana and Monge (2020) and Gupta et al. (2020) empirically demonstrate that Covid-19 pandemic is the major reason for volatility in natural resources commodity prices in a global and panel data, respectively.

4.4. Discussion

In recent times, the major issue considered responsible for economic recession and postponement of industrial production is the Covid-19 pandemic. Also, China remained the first country to experience the worst effect of Covid-19 in the shape of industrial postponement. Due to such shock, unemployment rises in the country and similar for the income levels of the investors, industrialists, and households. Consequently, demand for natural resources diminishes while the supply is also surging due to the Russia and Saudi Arabia conflict of capturing higher market proportion by lowering the prices of oil. Simultaneously, the spread of Covid-19 pandemic increases, which causes fear in the general public and leads to the temporary closing of the industries.
Keeping this in mind, current study analyzes whether there is any association between the Covid-19 active cases, Covid-19 deaths, and oil prices in case of China. The estimated results of wavelet power spectrum reveals that the oil prices are volatile in the month of May. This indicates that the oil prices are unstable during the Covid-19 pandemic peak period instead of volatile. On the other hand, the wavelet coherence asserted a two-way causality between oil prices and Covid-19 active cases, and similar for the oil prices and Covid-19 deaths. This demonstrates that enhancement in the Covid-19 active cases and death leads the government of China to implement strict policies regarding the health of the general public. In this sense, China found the lockdown a more suitable policy of public health instead of economic sustenance. However, the drawback of this policy is that the industrial production slowed down, which further reduces natural and energy resources demand such as crude oil in the global market. Also, the conflict between Saudi Arabia and Russia further fuels the higher supply chain for economic benefits. Due to this uncertain situation in China caused by Covid-19 pandemic, the oil prices are unstable and volatility persists. Hence, to recover from natural resources volatility, Chinese government must take substantial and appropriate initiatives.

5. Conclusion and policy implications

5.1. Conclusion

The recent trend of natural resources commodity price volatility and Covid-19 pandemic nexus motivate scholars to add more to this critical issue. Current study aims to analyze whether there is volatility in natural resources commodity prices and Covid-19? If yes, what is the causal nexus of these variables? In this regard, this study investigated China by using daily data from January 2020 to September 2021. In order to determine volatility, there are various methods available in the literature. However, the wavelet power spectrum is considered the most efficient technique since it considers both the time and frequency domain simultaneously. Besides, the causal nexus could be better analyzed with the novel wavelet coherence specifications by underlining the characteristics mentioned above. Therefore, the current study employed these approaches, which provides short-run and long-run estimates. The empirical findings reveal that oil prices are vulnerable during at only one point. Where it is observed that this vulnerability in oil prices is during the Covid-19 pandemic peak period. Specifically, in the said period, the Covid-19 pandemic was reported as highest in the selected span, which led the country’s government to stop industrial production and other economic activities for public health. Also, the causal association between the variables validates the bidirectional causal association between oil prices and Covid-19 active cases, and the oil prices and Covid-19 deaths. Since the emergence of this novel pandemic, China has faced a severe shock in the shape of the lockdown, which triggered the postponement of Chinese industrial sector. Consequently, the prices of natural resources commodity prices fall down and even reach the negative. Nonetheless, the fear of Covid-19 illness and death further leads to closing other economic activities such as trading inside or across the borders. The supply and demand chain is highly disturbed. Hence, the primary reason for fluctuations in natural resource commodity prices is Covid-19 pandemic in the shape of active cases increase and surge in Covid-19 patients deaths. These results are found robust by QQ regression approach.

5.2. Policy implications

Based on the empirical findings, this study suggests that immediate actions are required to stabilize natural resources volatility in China. Specifically, there are two appropriate policies that this study suggests: firstly, the price ceiling or price freezing policy could be adopted to regulate the prices of natural resources like crude oil. Nonetheless, the price ceiling or freezing would help the natural resources market stabilize in various crisis conditions regardless of the demand-supply chain disturbance. Secondly, natural resources hedging could be an appropriate policy in these crisis times. The hedging of natural resources will benefit the economy in the short-run and the longer run and tackle the issue of natural resources volatility. Moreover, the Covid-19 is observed as the primary reason for this conflict of natural resources volatility. In this regard, innovative policies in the health sector are required to recover from this novel pandemic for economic and natural resources markets recovery.

5.3. Limitations

Although this study provides substantial findings, it is still limited from various perspectives. Specifically, this study utilized only oil prices
to represent natural resources commodity prices volatility. However, future researchers could extend this study by investigating other natural resources commodity prices such as coal price, gold price, forest prices, metallic natural resources prices, etc. Also, this study provides empirical results only for China as it is the first country to experience a novel Covid-19 pandemic crisis. However, researchers in the future shall investigate developed, emerging, and developing economies. Moreover, both the pre and post Covid-19 pandemic periods shall be investigated for a comprehensive analysis of Covid-19 pandemic. In addition, the developed and emerging economies could be compared regarding the association of Covid-19 pandemic and natural resources volatility in future studies.

Credit author statement
Shanwen Guo: Supervision, Project management, Funding acquisition. Qibin Wang: Formal Analysis, Conceptualisation, write-up, empirical analysis. Tolaas Temesgen Hordofa: Review and Discussion. Miss Prabjot Kaur: writeup support and empirical analysis. Soufiyan Bahetta: Supervision, formal training. Apichit Maneengam: Formal Analysis, Conceptualisation.

Data availability
The data that has been used is confidential.

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