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COVID-19 impact on multifractality of energy prices: Asymmetric multifractality analysis

Khalid Khan a,*, Chi-Wei Su b, Adnan Khurshid c, Muhammad Umar b

a School of Finance, Qilu University of Technology, Jinan, China
b School of Economics, Qingdao University, Qingdao, China
c School of Economics and Management, Zhejiang Normal University, Jinhua, China

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1. Introduction

The aim of the study is to examine the multifractality of the energy prices (EPs) such as crude oil, natural gas, coal, heating oil, kerosene, propane, diesel and gasoline prices in the context of corona disease (COVID-19). The phenomenon of multifractality is extremely important because a higher (lower) multifractality shows a rapid rise (fall), which has different consequences for the international energy market. It implies that EPs may have different behaviour to the upside (downside) movements caused by the pandemic [1]. Moreover, EPs behaviour may be a time-variant variable that behaves differently in the upside and downside price movements [2]. The pandemic has proved catastrophic to the energy market which has plummeted, followed by strict restrictions and social distancing. This has restricted mobility in the aviation and transports sectors around the world and has dramatically reduced the energy demand. Furthermore, industrial production slowed down which resulted in the lowest energy demand. Moreover, the pandemic has affected the shipping industry which carries almost 80% of the international trade and disrupted the supply chains, which in turn translated into a lowering of the energy demand [3,4]. Thus, the reaction of EPs to upside and downside trends determined by the pandemic is exceedingly paramount to be probed. It reflects whether EPs have asymmetric responses equally to upside and downside trends.

Energy is the backbone of the global economy and sustainable energy supply is extremely essential for economic growth [5]. A strong association has been established between the two in the past [6]. Similarly, rising EPs boost economic growth and provide enough financial liquidity for exporting countries. On the other hand, higher EPs increase manufacturing and transportation costs for importing countries, which is reflected in the inflationary pressure [7]. Moreover, EPs fluctuations will have a significant impact on the international economy, as well as on prosumers. In this way, price movements triggered by the political and economic...
crisis are crucial and market prices swiftly reflect upward (downward) trends, which are further reflected in the economy [7]. In the event of an economic, political, or geopolitical catastrophe, international energy market prices become prominent. This behaviour is observed during the 2008 global financial crisis and the COVID-19, both of which have huge global economic consequences. Meanwhile, the outbreak of the pandemic is having a disastrous effect on global economic development. The global economy has been devastated by social distancing and lockdown, which has undermined demand. Similarly, before the pandemic, the pricing war between Saudi Arabia and Russia left the energy market uncertain and oversupplied [8]. The oversupply was eclipsed by the COVID-19 in late March 2020 and EPs have collapsed, followed by the lowest demand and even the oil prices have declined into the negative zone [2,9]. The majority of the energy demand comes from aviation and transportation sectors, which are both constrained, resulting in lower energy consumption [10,11]. The energy market mildly recovered due to the easing of restrictions and the Organization of the Petroleum Exporting Countries (OPEC) has balanced demand and supply and price stability by cutting production, which pushed the prices. Meanwhile, various economies, especially China, have resumed their economic activity, which had a positive impact on the energy market. However, the second wave of COVID-19 in August 2020 has resulted in a new wave of restrictions, that again lowered the energy demand. Consequently, the prices have indicated a decreasing trend in September 2020, due to the concern over the reappearance of the pandemic and the anticipation of oversupply. However, the largest decline in prices is observed between March and November 2020, driven by the new wave of the pandemic. Moreover, gasoline, kerosene, diesel, propane, natural gas and heating oil prices have recovered in 2021, because of the economic recovery and rising demand [12]. Meanwhile, the overall pace of the pandemic has been receding, which resulted in a rise in the energy demand. EPs have continued to rise since the first quarter of 2021, caused by rising demand and reached the highest level in the last quarter of 2021. As countries recover from the pandemic, energy demand grows, pushing EPs to new highs on the worldwide market. The analysis of EPs is extremely important because their integration with the global economy and volatility remains a major concern for both exporting and importing countries [13]. Therefore, EPs behaviour during upward and downward movements is extremely important because of the COVID-19 and therefore it requires further investigation.

The main contribution of this study is listed as follows. The study considers the impact of the COVID-19 on the asymmetric multifractality on the different EPs on the international market. The contemporary literature lacks studies on the COVID-19 effects on the asymmetric multifractality of EPs. Consequently, the study may be the first endeavor to assess the multifractality of EPs in downward and upward trends. The international energy market has experienced several upward and downward movements in the pre-pandemic and during the COVID-19, making it necessary to determine these patterns, as well as the multifractality. The study uses the daily rate of returns of EPs to examine the asymmetric multifractality in different periods of the pandemic. The behaviour may be different in the pre-pandemic and during the COVID-19 because of the different factors and events. This can be helpful as to offer a conclusive outlook on EPs for the stakeholders in the market. Moreover, EPs are extremely vulnerable to the uncertainty caused by the pandemic which has a significant effect on the supply chains, commodity pricing, and economic growth. Moreover, the reaction of the various stakeholders is exclusive to upside (downside) trends and shows the significance of detecting the multifractality performance of time series [14,33]. As a result, market efficiency evaluation in an upward (downward) trend is critical for investors and market development [15,16]. The study uses the recently proposed technique, asymmetric multifractality detrended fluctuation analysis (A-MFDFA) to ascertain the results. The Detrended fluctuations analysis approach notices mono-fractal scaling properties. It is the transformed form of the symmetric MFDFA technique, which recognizes the multifractality and presumes that the impact of the downward trend is the same as that of the upward trends on price dynamics. However, EPs behave differently during upward and downside trends, which have a different impact on EPs variations and returns. Therefore, A-MFDFA is flexible in capturing asymmetric upward and downward movements with asymmetry in the scaling performance on EPs. The results show that major EPs have asymmetric multifractality which increases equally with the fractality scale. EPs exhibit the asymmetric multifractality which increases as the fractal scale increases. The strong multifractality is detected in the downward movements for crude oil, heating oil, diesel, gasoline, propane and kerosene oil returns. The upside multifractality is greater than the downside in both periods for coal prices and natural gas returns. Furthermore, the access asymmetry is more pronounced during COVID-19 which implies greater market inefficiency. The outcomes display that EPs are inefficient during the pandemic. A special attention is required in order to observe such unexpected fluctuations in the price dynamic and guidelines are vital. The level of efficiency can be improved by a greater transparency in information while the government must play its role in regulations.

We structure the paper as follows. We review the previous literature in section 2, then follows the methodology in section 3. After that, we present the data in section 4, which is followed by an empirical analysis in section 5. We summarize this study in section 6.

2. Literature review

Nyga-Łukaszewska and Aruga [10] examine the oil and gas market during COVID-19 and conclude that the pandemic has an adverse impact on oil and gas prices. Moreover, the pandemic has a negative impact on oil prices in Japan and the U.S. while affecting positively the gas prices. Aruga et al. [17] investigate the Indian energy consumption response to the COVID-19 and the findings display that the pandemic has drastically reduced the energy demand and consumption. Mensi et al. [2] review the oil prices response to upside (downside) movements caused by the COVID-19. The outcome exhibits that the pandemic has resulted in upward (downward) movements which have strong repercussions on oil prices. Moreover, the oil prices are more inefficient in the downside trends and the impact is more pronounced. Aloui et al. [18] explore that the COVID-19 has increased the vulnerability of EPs and prices have declined dramatically. Yılmazkuday [19] shows that the COVID-19 does not affect oil prices, while the oil prices are driven by the disagreement between OPEC member countries. Maijama’a et al. [20] assess the global energy demand response to the pandemic and confirm the negative correlation between oil prices and COVID-19. Sharif et al. [21] estimate the COVID-19 impact on EPs in the U.S. The results reveal that COVID-19 has caused unprecedented uncertainty which is extremely detrimental to oil prices. Devpura and Narayan [22] conclude that oil prices are extremely volatile because of COVID-19. Amadi et al. [23] show that COVID-19 has disrupted the global economic activity and supply chains which has drastically declined transportation and ultimately translates into the lowest level in oil prices. Mzoughi et al. [24] show the negative impact of COVID-19 on oil prices due to a reduction in demand which leads oil prices to a negative zone for the first time in history. Kingsly and Henri [25] evaluate EPs behaviour during the COVID-19 in Europe and North America. They
conclude that industrial production slowdown plummets the oil prices.

Oulbusoye et al. [26] evaluate EPs during the COVID-19 and find that EPs have responded significantly to the uncertainty created by the pandemic. Novan et al. [27] discuss how the energy sectors reacted to the COVID-19 uncertainty. The findings state that the pandemic generated severe restrictions which have squeezed the transport industry and the lower energy demand is reflected in the low oil prices. Algamdi et al. [28] examine the Saudi Arabian oil price behaviour during COVID-19 and confirm that the severity of the pandemic has a substantial impact on oil prices. Shahzad et al. [29] investigate the COVID-19 impact on the different EPs and the outcome displays the highest variance in oil prices, which has adversely affected oil prices. Tang et al. [30] assess the international and Chinese energy markets during the COVID-19 and conclude that the pandemic does not affect these energy markets. Gao et al. [12] consider the U.S. and China financial markets behaviour during COVID-19 and confirm a drastic decline in the two markets during the pandemic. Khan et al. [4] study the behaviour of EPs during the pandemic and conclude that EPs are vulnerable to the pandemic, which has a negative impact on different EPs. Furthermore, COVID-19 has a higher impact on oil prices as compared to natural gas and heating oil prices. Rizvi and Itani [31] find that the oil market has experienced huge fluctuations during the COVID-19, making the international energy market uncertain.

The existing literature focuses on crude oil and to some extent natural gas and seeks to determine the changing behaviour caused by COVID-19, while ignoring the other energy resources such as diesel, kerosene, heating oil, propane and gasoline prices which cover a different segment of the economy and play an important role in the international energy market. Hence, the current study attempts to analyze EPs considering the crude oil, diesel, propane, kerosene, gasoline, heating oil, and coal returns in different periods in the context of COVID-19. The results indicate that these EPs returns have responded differently to the uncertainty caused by the COVID-19 [6,34]. Furthermore, most of the studies have concentrated on one period, which may not provide comprehensive information for the policy formulations. On the other hand, our study analyzes the period before and during the pandemic, which offers a comparative analysis and helps to identify the determinants and specific time period of sudden changes. The findings display that EPs returns are greatly vulnerable to economic uncertainty during the pandemic [35]. Moreover, the preceding literature fails to evaluate EPs returns response to downward (upward) moments, which may be different in different periods. The phenomenon of multifractality is extremely important because the higher (lower) multifractality shows a rapid rise (fall). This implies that EPs may have different behaviour to the upside (downside) movements [1]. Lastly, the paper employs a novel approach, namely asymmetric multifractality detrended fluctuation analysis, which identifies the multifractality and presumes that the impact of downward trends is the same as that of the upward trends on price dynamics. However, EPs behave differently during upside and downside trends, which has a different impact on EPs variations and returns. The results mention that major EPs have multifractality, which increases equally with the fractality scale. A greater multifractality is observed in the downward (upward) movements to the uncertainty caused by the pandemic.

3. Methodology

The existing literature lists the methods used to explore the impact of various events on energy prices. In this regard, quantile on quantile, wavelet-based approach, VAR Model, Detrended Fluctuation Analysis (DFA), the Generalized Supremum Augmented Dickey-Fuller (GSADF), multifractal Detrended Fluctuation Analysis (MF-DFA) and Multivariate Adaptive Regression Spline (MARS) are the most widely used methods. These approaches are used to evaluate the impact of different pandemic events effects on different EPs and the findings reveal that different events and COVID-19 have a drastic impact on EPs. Meanwhile, EPs are vulnerable to COVID-19 uncertainty which has reduced the energy demand. The global energy market has a different response to upward and downward movements, which needs to be analyzed. The A-MFDFA is an appropriate method to test the market efficiency as well as the response of different EPs to downside and upside price movements [1,2]. Moreover, the approach is suitable to analyze asymmetric multifractality in a complex system and allows for scaling properties of EPs [2].

The time series A is divided and its profile B into nonoverlapping sub-time series of interval n that are designated from 5 to N/4, established on the suggestions of Pierdzioch et al. [32] to detect the asymmetrical multifractal scaling behaviour. The length of the last part may be smaller than n. Since N may not be a multiple of n. We split up by beginning from the other end of A to study the rest of A. 2Nn = (Nn = N/n) sub-time series {Al}Nn−1 for A [1]. The sub-time series can be reached for B {Bl}Nn−1. The ith sub-time series of A is symbolized by Aiy = (fiyi)m−1 where qi-p specifies the qth component of Ai. For Ai and Bi, we examine the linear fit

\[ A_i(m) = x_0 + y_0m \]

where \( x_0 \) is the intercept and \( y_0 \) is the slope of the trend line. For Ai, the trend line is used to detrend Bi [1]. We then measure the variations functions as follow:

\[ F_q(n) = \frac{1}{n} \sum_{p=1}^{n} (b_{q,p} - F_q(p))^2 \] (1)

The directional q-order average fluctuations functions are computed by

\[ F_q^+(n) = \left( \frac{1}{M^+} \sum_{l=1}^{2Nn} \frac{1}{2} \sum_{i=1}^{n} \text{sign}(y_{il}) + 1 \right) \left( \frac{M^+}{2} \right)^{1/q} \]

\[ M^+ = \frac{2Nn}{2} \sum_{l=1}^{2Nn} \frac{1}{2} \] (2)

\[ F_q^-(n) = \left( \frac{1}{M^-} \sum_{l=1}^{2Nn} \frac{1}{2} \sum_{i=1}^{n} \text{sign}(y_{il}) - 1 \right) \left( \frac{M^-}{2} \right)^{1/q} \]

\[ M^- = \frac{2Nn}{2} \sum_{l=1}^{2Nn} \frac{1}{2} \] (3)

where \( F_q^+(n) \) and \( F_q^-(n) \) means the upside and downside q-order average fluctuations functions, respectively. Supposing that \( y_{il} \neq 0 \) for all \( l = 1, \ldots, 2Nn \), then \( M^+ + M^- = 2Nn \).

Equations (1)–(3) of the fluctuations are used to compute the scaling association, which is distinct as:

\[ F_q(n) \sim n^{H(q)}; F_q^+(n) \sim n^{H^+(q)}; F_q^-(n) \sim n^{H^-(q)} \] (4)

where \( H(q) \), \( H^+(q) \) and \( H^-(q) \) stands for the whole, upside and downside scaling exponents, respectively. The scaling behaviour of the variations in Equation (4) is measured by evaluating the log-log plots of \( F_q(n) \), \( F_q^+(n) \) and \( F_q^-(n) \) versus \( n \) for each value \( q \). \( H(q) \), \( H^+(q) \) and \( H^-(q) \) can be assessed by the least-squares approach formed on
the logarithmic form. Moreover, when $H(2) > 0.5$ the correlation in the time series is persistent or long memory while the interaction is anti-persistent when $H(2) < 0.5$. If $H(2) = 0.5$, the time series reflects the random walk process. Likewise, if $H^+(q) = H^-(q)$, the interaction in the time series is symmetric, however, if $H^+(q) \neq H^-(q)$, the interaction in the time series are asymmetric. A-MFDFA technique is superior to the fractional Brownian motion and GARCH to detect the stylized facts witnessed in a time series. The asymmetric scaling performance shows that the correlation in the time series is different in upside and downside movements. A-MFDFA technique is the changed form of the symmetric MFDFA method, which detects the multifractality and assumes that the influence of downward trends is the same as the upward trends on price dynamics. However, the price behaves differently during upside and downside trends, which has a different impact on EPs rates fluctuations and returns. Thus, A-MFDFA is flexible to capture asymmetric upward and downward movements. The steps involved in performing empirical research are given as follows. The energy price returns are used for analyzing the asymmetric multifractality before and during the COVID-19. For this purpose, the daily returns of energy prices are estimated. In the next step, the direction of the movement is established, followed by measuring the variations functions. Moreover, the directional fluctuations functions specify the upside and downside movements. The Hurst exponent for the full period, upward and downward period is illustrated, followed by the estimation of the asymmetric multifractal spectrum.

4. Data

The daily returns of the different EPs, such as crude oil, diesel, coal, kerosene, heating, natural gas and propane from September 2018 to December 2021 are used to examine the asymmetric multifractality in the different phases of COVID-19. The pre-pandemic period spawns from September 2018 to December 2019. However, the pandemic period spawns from January 2020 to December 2021. The studied period is extremely important due to numerous events that have changed the global economic outlook. Before the pandemic, EPs are affected by the Sino-U.S. trade tension, the price war between Russia and Saudi Arabia, the geopolitical crisis in Venezuela and the sanctions on Iran. This price war between the two largest oil producers has caused excessive oil supply to the market. However, the breakout of the COVID-19 has paralyzed the global economic system and EPs have reached new lows. The pandemic has triggered a stringent lockdown, placing strain on the world economy and driving EPs to collapse. The oil price falls into the negative zone, caused by the lowest level of energy demand [11–36]. This requires a thorough examination of EPs’ behaviour in both downward and upward trends. For this purpose, the oil price is retrieved from the U.S. Energy Information Administration, namely the spot price [6]. Likewise, coal price is the average price per metric ton in dollars, while the natural gas price is the spot price. Similarly, propane, diesel, kerosene and gasoline prices are the dollar value per gallon and all data is obtained from the Federal Reserve Economic Data (FRED). The returns of the series are computed $r_t = \ln\left(\frac{EP_t}{EP_{t-1}}\right)$ where $EP_t$ is the energy prices at time $t$.

Fig. 1 exhibits energy returns behaviour. The energy market has tightened due to the possibility of reimposing sanctions on Iran who has reduced the supply in 2018. Moreover, the oil production from the major oil producing countries declined, which put pressure on the EPs. In 2019, oil prices have declined as a result of the U.S. petroleum production, and production cut announcements of OPEC. Similarly, trade tensions between the Sino-U.S. hampered global economic growth and the energy demand and returns remain low. The volatility is detected from January 2020 to June 2020, driven by the collapse of energy demand in wake of COVID-19. However, the trend is to rebound from June 2020 onward because of the mild recovery around the world which has pushed the energy demand. Meanwhile, the reappearance of the pandemic in September 2020 has led the energy demand to decline which is reflected in the price returns of the EPs. The remaining EPs such as gasoline, kerosene, diesel, propane, natural gas and heating oil show the lowest price level in the first quarter of 2020 mainly caused by the contracted economic activity around the world. However, these EPs returns have rebounded in the last quarter of 2020, followed by the resumption of the economies, which has increased the energy prices. The returns have shown an upward trend in 2021 because of the huge economic recovery which put pressure on the energy prices.

5. Empirical analysis

5.1. Asymmetric multifractality analysis

This section covers summary statistics and the results of the asymmetric multifractality analysis for EPs returns. It will comprise four forms for every EP. First, the asymmetric multifractality is evaluated, measuring the multifractality during upside and downside trends. Second, the access asymmetry is examined during the upside and downside moments. Third, the Hurst exponent for the entire $H(q)$, upward $H^+(q)$ and downward $H^-(q)$ are revealed. Last, the asymmetric multifractal spectrum is explored. Table 1 explains EPs descriptive statistics. In the pre-pandemic
period, negative rates of returns are recorded for EPs. On the contrary, the mean values of EPs returns are positive during the pandemic, suggesting that EPs have witnessed a declining trend in a brief period followed by an increasing trend. Moreover, the standard deviations show that EPs returns had a greater volatility during the COVID-19 as compared to the period before the pandemic. The skewness value of the majority of EPs is negative, except for natural gas. Similarly, the platykurtic distributions are confirmed by the kurtosis values for EPs returns because the values are greater than 3. Last, the Jarque-Bera test confirms that EPs returns are non-normally distributed.

Fig. 2 illustrates the A-MFDFA functions $F_2 (n)$ versus the time scale $n$ of crude oil returns. It describes different multifractality during upside and downside trends in the panel (a-e), which increases with the fractality scale. The downward multifractality is greater than the upward in both periods, which shows the asymmetric multifractality. It implies that oil returns are extremely vulnerable to downward movements. The results are similar to Mensi et al. [2] and suggest that multifractality is higher in the downside trend for crude oil, which shows that oil is more inefficient because of pandemic uncertainty.

The access asymmetry in multifractality is assessed as below:

$$\Delta h(q) = h^+(q) + h^-(q)$$  \hspace{1cm} (5)

The negative values are observed for access asymmetry and illustrated in panels (b-f). The outcomes exhibit that the downward movement is greater than the upward in most periods. It shows that asymmetric multifractality is stronger in downward movements. However, the access asymmetry is more pronounced during the COVID-19, which suggests that the energy market is inefficient during the pandemic. Mensi et al. [2] find that access asymmetry is prominent and robust during the pandemic. The Hurst exponent for the entire $H (q)$, upward $H^+ (q)$ and downward $H^- (q)$ are revealed in panel (c-g). The outcomes illustrate the market trends before and during the COVID-19. Furthermore, they display the two different outcomes and show that the upside value is greater than the downside exponent for negative scales, which reverses for positive scales. The results exhibit that the market efficiency declines. Panel (d-h) shows the asymmetric multifractal spectrum and indicate a larger width for upward trends in the pre-pandemic period and downward trends during the COVID-19. The results show oil returns are unpredictable during the pandemic, which is confirmed by the frequent fluctuation during the pandemic.

The A-MFDFA outcomes of heating oil returns are highlighted in Fig. 3. Panel (a-e) depicts different multifractality in downside and upside trends. The downward multifractality is greater than the upward in both periods. Thus, the findings show the asymmetric multifractality of heating oil returns. The access asymmetry is highlighted in panel (b-f) and detects that downward movement is greater than the upward trends. However, the access asymmetry is stronger during COVID-19 which suggests that the market is inefficient. The Hurst exponent for the entire $H (q)$, upward $H^+ (q)$ and downward $H^- (q)$ are provided in panel (c-g). It acclaims that the downside value is greater than the upside, implying that the market is inefficient in both periods. Panel (d-h) illustrates the asymmetric multifractal spectrum and finds a larger width for downward trends which suggests that heating oil is uncertain and unstable.

Fig. 4 depicts the results of the A-MFDFA for the natural gas returns in panel (a-e). The upside multifractality is greater than the downside in the pre-pandemic. Moreover, the multifractality is greater than the upward multifractality during the pandemic. Meanwhile, the positive values are observed for access asymmetry and are explained in panel (b-f). The outcomes detect that upward movement is greater than the downward before the pandemic and vice versa during COVID-19. This might be explained by the fact that natural gas has already been low before the pandemic and the prices remained low. Moreover, the gas prices responded differently in the different periods [10]. The Hurst exponent for the entire $H (q)$, upward $H^+ (q)$ and downward $H^- (q)$ are established in panel (c-g). It shows two different results for pre-pandemic periods as the upside value is greater than the downside exponent for negative scales, which reverses for positive scales. The market efficiency declines before COVID-19. Panel (d-h) shows the asymmetric multifractal spectrum. It exhibits a larger width for upward trends and vice versa during COVID-19 which highlights the higher uncertainty. Natural gas is decreased by COVID-19 as demand declines in the short run. Moreover, the gas industry is in a crisis in the pre-COVID-19 period which is furthered by the emergence of the pandemic [12].

Fig. 5 explains the A-MFDFA results of coal price returns. Panel (a-e) illustrates different multifractality in downside (upside)
Fig. 2. (a) A-MFDA functions (b) Excess asymmetry in multifractality (c) Hurst exponents for crude oil returns. (d) Asymmetric multifractal spectrum.
Fig. 3. A-MF DFA functions of heating oil.
Fig. 4. A-MFDFA functions of natural gas returns.
Fig. 5. A-MFDDA functions of coal price returns.
trends. The upside multifractality is greater than the downside in both periods, which implies that the coal market response to COVID-19 uncertainty is not huge as compared to other energy sources. Moreover, coal price has faced a rising trend in the second quarter of 2020 because of higher oil returns. The access asymmetry results are illustrated in panel (b-f). It displays the positive values because the upward movement is greater than the downward, which suggests a weaker response of coal price to COVID-19 uncertainty. The Hurst exponent for the entire $H(q)$, upward $H^+(q)$ and downward $H^-(q)$ are shown in panel (c-g). The results indicate that exponent values fluctuate across all periods. It ascertains that the upward value is greater than the downside exponent, which implies that the market efficiency improves. Panel (d-h) confirms the asymmetric multifractal spectrum and illustrates a larger width for downward trends for both periods.

Fig. 6 exemplifies the A-MFDFA results of diesel price returns. It depicts results in panel (a-e). The downward multifractality is greater than the upward in both periods, suggesting strong asymmetric multifractality in diesel returns. The negative values are observed for access asymmetry and explained in panel (b-f). The findings explore that the downward movement is greater than the upward. Furthermore, the access asymmetry is more pronounced during COVID-19. The Hurst exponent for the entire $H(q)$, upward $H^+(q)$ and downward $H^-(q)$ are exhibited in panel (c-g). The results show that the downside value is greater than the upside, which implies greater market inefficiency. Panel (d-h) displays the asymmetric multifractal spectrum and explores a larger width for downward trends for both periods.

The A-MFDFA results of gasoline price returns are highlighted in Fig. 7. Panel (a-e) illustrates that the downward multifractality is greater than upward, suggesting that the asymmetric multifractality. The negative values are detected for access asymmetry and exhibited in the panel (b-f). The outcomes suggest that the downward movement is greater than the upward which is more pronounced during the pandemic, which leads to the conclusion that GOP is inefficient in the COVID-19. The Hurst exponent for the entire $H(q)$, upward $H^+(q)$ and downward $H^-(q)$ are recognized in panel (c-g). The results reveal that the downside value is greater than the upside which implies that during the pandemic and pre-period. Panel (d-h) illustrates the asymmetric multifractal which suggests a larger width for downward trends in which the gasoline returns are unpredictable in both periods.

Fig. 8 shows the A-MFDFA outcomes of propane price returns. The different multifractality is illustrated in panel (a-e). The downward multifractality is greater than the upward in both periods which denotes the asymmetric multifractality attributes. Panel (b-f) exhibits the access asymmetry and detects the negative values for access asymmetry. As per the outcomes, the downward movement is greater than the upward in most periods. Panel (c-g) highlights the Hurst exponent for the entire $H(q)$, upward $H^+(q)$ and downward $H^-(q)$. The results indicate two different outcomes before the pandemic. They reveal that the upward value is greater than the downside exponent for negative scales, which reverses for positive scales, implying that efficiency declines. However, the downward trend is greater than the upward trend during the pandemic. Panel (d-h) displays the asymmetric multifractal spectrum and suggests a larger width for upward trends in pre-periods and vice versa for downward trends during the pandemic.

Fig. 9 explains the A-MFDFA results of kerosene price returns. It describes different multifractality in panel (a-e). The downward multifractality is greater than the upward in both periods. The negative values are observed for access asymmetry and shown in panel (b-f). For example, the results exhibit that downward movement is greater than the upward. Moreover, the access asymmetric is stronger during COVID-19. Similarly, the Hurst exponent for the entire $H(q)$, upward $H^+(q)$ and downward $H^-(q)$ are recognized in panel (c-g). The results show that the downward trend is greater than the upward which implies that the market efficiency declines during the periods. Panel (d-h) shows the asymmetric multifractal spectrum and shows a larger width for upward trends in the pre-pandemic period, while the larger width is observed for downward trends during the pandemic and show that kerosene price is unstable.

The market inefficiency is measured by market deficiency measures (MDM) following the Wang et al. [37] and explained below:

$$M_{DM} = \frac{1}{2} \left[ (H(-10) - 0.5) + h(10) - 0.5 \right] = \frac{1}{2} \sum h$$

where $H(-10)$ is a small fluctuation and $H(10)$ represents a large fluctuation. A market is efficient and follows a random walk process if all fluctuations including small $q = -10$ and large $q = 10$. Moreover, the market is considered efficient if the MDM values are close to zero. Table 2 highlights the overall fluctuations $H(q)$, while $H^+(q)$ upward and $H^-(q)$ downward movements. According to the results, the crude oil return is more inefficient during the COVID-19 in the downward trend. However, the heating oil price is inefficient before the pandemic. Similarly, natural gas, diesel, propane, gasoline and kerosene returns are more inefficient during the pandemic in the downward. The inefficiency is more visible during the downward trends as multifractality is higher on the downside (upside) in the pre-pandemic period. Furthermore, coal price returns are inefficient during the pandemic in upward. However, the upwards trend is more than the downward trend which implies that efficiency improves in the pre-pandemic period. It is concluded that the highest inefficiency is observed in the energy market during the COVID-19 in downward movement.

5.2. Robustness test

The multifractal detrended fluctuation analysis (MF-DFA) developed by Kantelhardt et al. [38] approach is applied to check the robustness of results which estimate the Hurst exponent and Magnitude of Long Memory (MLM). The higher (lower) values of MLM show higher (lower) memory level in EPs returns.

$$MLM = (|h(-10) - 0.5| + h(10) - 0.5)$$

where $H(-10)$ is small fluctuation and $H(10)$ represents large fluctuation. If the MLM values are near to zero, the market is called efficient [39]. The results are highlighted in Table 3. According to the results, crude oil and coal returns are highly inefficient during the pandemic period. However, natural gas and diesel returns are highly efficient during the COVID-19. Similarly, before the pandemic coal, heating and propane price returns are most inefficient. Moreover, natural gas, gasoline and kerosene returns are highly efficient.

The Hurst exponent results are illustrated in Table 4. It shows the effects of small and large fluctuations. Similarly, the existence of multifractality is confirmed in the series. Furthermore, the findings suggest that energy market fractality increases and becomes more inefficient.
Fig. 6. A-MFDFA functions of diesel price returns.
Fig. 7. A-MFDFA functions of gasoline price returns.
Fig. 8. A-MF DFA of propane.
Fig. 9. A-MFDFA functions of kerosene oil returns.
6. Conclusion

The paper unveils the COVID-19 impact on the asymmetric multifractality of EPs returns in two different periods. It assesses the response of different EPs returns to the downward (upward) movements caused by COVID-19. This purpose is achieved through the asymmetric multifractality detrended fluctuation analysis. The results exhibit that EPs returns show different multifractality in the downside (upside) trends. Moreover, the multifractality of EPs returns increases with fractal scale increase. The downward multifractality is greater than the upward in both periods for the crude oil price, heating oil, diesel, gasoline, propane and kerosene price returns, suggesting the strong asymmetric multifractality in the downward movement. The negative values are observed for access asymmetry and the findings display that the downward movement is greater than the upward. Furthermore, the access asymmetry is more pronounced during COVID-19. The Hurst exponent shows greater downside value which implies greater market inefficiency. The asymmetric multifractal spectrum implies a larger width for downward trends for both periods, which explains that gasoline price is unpredictable in both periods. The upside multifractality is greater than the downside in both periods for coal and natural gas returns. The access asymmetry results detect the positive values because the upward movement is greater than the downward. The Hurst exponent finds out greater upward value than the downside exponent, which infers that the market efficiency improves. The asymmetric multifractal spectrum explores a larger width for downward trends for both periods.

The study concludes with the following policy implications for the concerned stakeholders. First, the findings suggest that EPs are inefficient during COVID-19, which may be harmful to probability

| Energy price returns | Overall | Upward | Downward |
|----------------------|---------|--------|----------|
| Crude oil Before COVID | 0.231   | 0.085  | 0.130    |
| Heating oil Before COVID | 0.428   | 0.051  | 0.405    |
| Natural gas Before COVID | 0.122   | 0.101  | 0.299    |
| Coal Before COVID | 0.122   | 0.083  | 0.073    |
| Diesel Before COVID | 0.225   | 0.085  | 0.307    |
| Propane Before COVID | 0.058   | 0.112  | 0.065    |
| Gasoline Before COVID | 0.240   | 0.455  | 0.250    |
| Kerosene Before COVID | 0.100   | 0.035  | 0.280    |

Table 2
Market deficiency measures (MDM).

Table 3
Multifractality before and during COVID-19.

| EPs returns | Period | Δα | ΔHq | Hurst average | LML | Ranking |
|-------------|--------|----|-----|---------------|-----|---------|
| Crude oil   | Before | 0.657 0.875 0.6087 | 0.1046 4 |
| Heating oil | Before | 0.664 0.934 0.6166 | 0.3366 7 |
| Natural gas | Before | 0.534 0.688 0.4998 | 0.0284 1 |
| Coal        | Before | 0.778 0.945 0.6256 | 0.2929 8 |
| Diesel      | Before | 0.595 0.778 0.6257 | 0.1758 5 |
| Propane     | Before | 0.641 0.989 0.6610 | 0.2024 7 |
| Gasoline    | Before | 0.741 0.973 0.6083 | 0.1006 2 |
| Kerosene    | Before | 0.558 0.775 0.5948 | 0.0998 3 |

Table 4
Hurst exponent for EPs before and during COVID-19.

| EPs | Period | Q           |
|-----|--------|-------------|
|     |        | -10         |
| Crude oil | Before | 0.875 0.843 0.792 0.749 0.687 0.614 0.544 0.461 0.422 0.384 0.325 |
| Heating oil | Before | 0.934 0.871 0.801 0.705 0.676 0.601 0.572 0.482 0.436 0.383 0.322 |
| Natural gas | Before | 0.901 0.876 0.828 0.776 0.681 0.614 0.543 0.488 0.415 0.388 0.332 |
| Coal | Before | 0.771 0.772 0.722 0.685 0.643 0.582 0.492 0.385 0.302 0.284 0.242 |
| Diesel | Before | 0.688 0.711 0.5487 0.0318 1 |
| Propane | Before | 0.685 0.689 0.6999 0.2312 6 |
| Gasoline | Before | 0.698 0.678 0.5563 0.1919 5 |
| Kerosene | Before | 0.558 0.775 0.5948 0.0998 3 |
|     |        | 8           |
| Crude oil | Before | 0.934 0.875 0.843 0.792 0.749 0.687 0.614 0.544 0.461 0.422 0.384 0.325 |
| Heating oil | Before | 0.901 0.876 0.828 0.776 0.681 0.614 0.543 0.488 0.415 0.388 0.332 |
| Natural gas | Before | 0.934 0.871 0.801 0.705 0.676 0.601 0.572 0.482 0.436 0.383 0.322 |
| Coal | Before | 0.688 0.711 0.5487 0.0318 1 |
| Diesel | Before | 0.685 0.689 0.6999 0.2312 6 |
| Propane | Before | 0.698 0.678 0.5563 0.1919 5 |
| Gasoline | Before | 0.558 0.775 0.5948 0.0998 3 |
| Kerosene | Before | 0.558 0.775 0.5948 0.0998 3 |

The Hurst exponent finds out greater upward value than the downside exponent, which infers that the market efficiency improves. The asymmetric multifractal spectrum explores a larger width for downward trends for both periods.

The study concludes with the following policy implications for the concerned stakeholders. First, the findings suggest that EPs are inefficient during COVID-19, which may be harmful to probability
forecasting, as the prediction is based on the previous data. As a result, EPs are not based on the assumption that price moves in a geometric Brownian motion. Specific regulations are needed to overcome the unpredictability during the pandemic and obtain reliable forecasts. Second, a greater downward deviation than the upward deviation is detected for most of these EPs which show different trends before the pandemic. This indicates the sudden upward deviation is detected for most of these EPs which show reliable forecasts.

Second, a greater downward deviation than the upward trend which requires portfolio optimization strategies of mixing equities with EPs to reduce the portfolio risk [40]. Last, the economic uncertainty drives the market instability and inefficiency, which are observed in the rate of returns of the energy prices. Therefore, the level of efficiency can be improved by the greater transference in information, while the government must play its role in regulations. This can increase stability and decrease the expected risks and price movements. As energy is the lifeblood of global economic growth and trade, its price fluctuations have considerable consequences for international economic health. The hedging capabilities of EPs are more effective before the pandemic and vice versa. Thus, the correlation between the different EPs and their determinants in the different time periods are extremely critical [41]. It might be helpful that future research examines the correlation in the context of COVID-19 because such a relationship may help to understand the specific mechanism of the switching process from one energy source to another. Moreover, the study can be extended to evaluate the connectedness between these EPs. Similarly, the research can be expanded to determine who is the influencer and who is being influenced.

Credit author statement

Khalid Khan: Conceptualization, Methodology, Software. Writing original draft. Chi Wei Su: Visualization, Data curation. Writing original draft preparation. Adnan Khurshid: Writing, review and editing. Muhammad Umar: Writing, Reviewing and Editing.

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