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Research Article

Do Volatilities Matter in the Interconnectedness between World Energy Commodities and Stock Markets of BRICS?

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Financial markets integration has resulted in high interconnectedness among the BRICS stock markets, which minimizes diversification potentials. This has increased investors' interest in the financialization of commodities to minimize their portfolio risks. However, the comovements between these assets do not operate in a vacuum, which requires that the role of volatilities be considered in tandem. The purpose of this study is to explore the interdependencies between energy commodities and stock markets of BRICS in the midst of relevant volatilities. For this reason, the wavelet techniques, biwavelet and partial wavelet, are employed. We find that positive comovements between energy commodities and stock markets of BRICS become stronger in the long-term. Furthermore, volatility has a long-term impact on the correlations between energy commodities and the BRICS stock market. We argue that the US Volatility Index, which measures investor anxiety and volatility in stock markets, has the biggest impact on the relationship between energy commodities and BRICS stock markets. Surprisingly, the correlations between energy commodities and Russian stock markets were strong enough to withstand the effects of volatilities. Hence, investors can use volatilities to hedge portfolio risks in energy commodities and stock markets in Brazil, India, China, and South Africa.

1. Introduction

The emergence of BRICS economies has become one of the significant developments in global politics. Governments from these economies have set high aims for this regional bloc since 2011 [1]. For instance, the Chinese government describes the BRICS as a significant force to extend South-South cooperation, whereas the Russian government argued that international relations with BRICS are a polycentric system [2]. It is important that the factors on which international relations are critically examined with respect to their role and importance to world economies over time. Most attribute the importance of BRICS to their increasing economic size. On the other hand, a common claim to their international relations can be attributed to their extensive natural resource wealth. Energy is abundant in the BRICS economies, which are heavily reliant on the production and export of these commodities [1].

The energy sectors of the BRICS economies supply over 40% of the world's energy, as they are both net energy imports (China and India) and net energy exporters (Russia, Brazil, and South Africa). Russia is a net exporter of energy resources, save uranium, according to the BRICS Energy Report [3], and consistently ranks first in worldwide gas exports. Russia ranks second in oil exports and third in coal exports. In 2017, China's crude oil imports surpassed those of the United States for the first time, making China the world's largest oil importer. China further surpassed Japan in 2018 to become the largest natural gas importer. After the USA and China, India is considered the third largest energy consumer in the world with about 6% of

global demand [3]. South Africa consumes the second most energy on the African continent. Because South Africa's oil and natural gas production is limited, the majority of these energy products are imported. South Africa, on the other hand, exports more than 45 million tons of coal to international markets each year.

Aside from the resource endowment of BRICS economies, most of their governments employ "resource diplomacy" in their foreign policy strategies. Resource wealth is argued to be one of the factors contributing to the unification of BRICS economies [4] and therefore is considered as "resource powers." However, there is arguably a significant distinction between the status of an energy resource power and a mere possession of energy resources. Dating from the resource curse, particularly in Africa, endowment with resources does not automatically translate into economic development, or even financial development. As argued by Stulberg [5], the ability for a state to utilize natural resources depends on its domestic institutional capacity to control economic activity within that sector. Consequently, the policy dimensions instituted by these economies are relevant in determining the translation of resource wealth into economic or financial benefits [1].

Although attempts to achieve sustainable development goals by many developing and emerging markets have been initiated based on policies and measures for energy conservation and emissions reduction, the increasing demands of energy within these regions require that dependence on fossil fuels cannot be disregarded over a short period [6]. As a result, fossil fuels have become irresistible and important commodity in the international trade market. The rapid rate of energy consumption unavoidably leads to an increase in resource trade [7]. Energy trade relations between economies are of great importance to ensure that energy supports economic activities [8], with high probability of supporting the development of stock markets [9–13].

The lower diversification potentials of the BRICS markets have induced empirical studies to inculcate other financial assets [11, 12, 14–16]. The broad consensus from these empirical studies has been the higher likelihoods of portfolio diversification, safe haven, or hedge benefits depending on the markets outcome.

A nascent and fledgling body of literature has considered the financialization in commodities [17–19] which has maximized interconnectedness and volatility spillover to minimize diversification potentials among commodities [20, 21] to rather provide diversification benefits for distinct asset classes such as stocks and bonds [19, 22]. The interesting dynamics of BRICS stock markets [14, 23] may provide a greater reference for portfolio diversification with commodities.

Despite the unflinching interest in BRICS stock markets, current literature still requires empirical evidence on their interconnectedness with world energy markets [11]. From the behavioural intentions of investors, diverse investors may choose to diversify risks in BRICS stock markets through the energy markets which have faced rapid ramifications over time. This has brought about recent empirical studies to examine the interdependence structure between energy markets and stock markets of BRICS [9–12, 24, 25]. Regardless of the interesting results obtained by these studies, Sadraoui et al. [11] posit that the global energy sector works under heightened uncertainties caused by significant variations in demand and prices. It is argued that fluctuations in international energy prices may be a path against which world uncertainties are diffused to all stock markets through contagion [11].

Similarly, BRICS markets are susceptible to fluctuations in macroeconomic and global market settings [22, 26]. It is worthy of note that the role of domestic factors in shaping the financial and economic dynamics of BRICS nations cannot be ignored; likewise, the influence of external factors on their economies is not overemphasised [22, 27]. This can be seen from series of global economic crises such as the 2008 global financial crisis and the COVID-19 pandemic which led to volatile capital flows and stock performance of BRICS. It is an undeniable fact beyond any reasonable doubt that strong and robust economic outcomes of world leading economies such as the US are advantageous for BRICS (even though the bloc was able to withstand capital flight due to tapering by the US federal reserve) whose (BRICS) economies share massive and economic trade links. To some extent, less robust economic outcomes in developed nations would plunge exports by BRICS to the developed economics, which eventually dwindles capital flows and investments to BRICS nations [11, 14, 22].

With the high integration between BRICS economies and the developed economies, shocks from the developed economies including the US can have ravaging effects on BRICS stock returns [26] whose energy is abundant and are heavily reliant on the production and export of these commodities [1]. Similar to the adverse relationship between the US VIX and that of the returns [28], there is high expectation that the former's relationship with stock market returns of BRICS would exhibit more ravaging outcomes. Likewise, the sensitivity of BRICS economies to the high integration within emerging economies and their significant role in energy production and consumption demand that the impact of volatilities within emerging markets and energy sector be investigated in detail. Moreover, to account for the impact of volatilities from the largest nonfinancial securities, the NASDAQ-100 volatility index is further employed. The NASDAQ-100 index is home to some of the innovative companies around the globe, and as such, a proxy for the world's preeminent large-capitalisation growth index. As a result, its volatility is regarded as the newest entrant in a trading space dominated by a single "fear gauge" known as the CBOE Volatility Index (VIX). Its VIX includes a large and variable number of money options (in, at, and out) that forms a quantity of annualised variance. Accordingly, global volatilities or uncertainties have a role to play within the interconnectedness between world energy markets and stock markets of BRICS. This is lacking in empirical literature in finance as most studies ignore the partial influence of volatilities on the comovements between world energy markets and stock markets of BRICS across frequency and time.

It becomes pertinent to quantify the extent to which uncertainties distort or meander the comovements between world energy markets and stock markets of BRICS. A recent

study by Junior et al. [14] examined the extent to which investor fear influences the interconnectedness between BRICS stock markets, and the impact was found to be significant. However, despite the exorbitant finance studies on the comovements between energy and stock markets, little is known about the impact of relevant volatilities or uncertainties within these markets in a time and frequency domain.

The contributions of this study to empirical literature are in two main folds. First, we examine the comovements between five important world energy markets and stock markets of BRICS in a time and frequency perspective using the biwavelet technique. The world energy commodities employed are global energy index (Aenergy), Brent crude oil, heating oil (Hoil), gasoline, and WTI crude oil. Second, we assess the impact of four relevant volatilities or uncertainties between the comovements of the world energy markets and BRICS stock markets through the partial wavelet. With the influence of volatilities on other financial assets regarding empirical literature, the Chicago Board Exchange Volatility Index of the US (VIX), Global Volatility Index (GV), Emerging Markets Volatility Index (EM), and Volatility in Energy Markets (VEnergy) were employed as relevant volatilities in the energy and BRICS markets. These volatilities are forward-looking other than historical to gauge uncertainties/fear within the interactions between the energy markets and BRICS stocks. Consequently, through the partial wavelet, the impact of a common interdependence can be investigated while assessing the comovements between the variables in a time and frequency dimension.

We found positive comovements between world energy commodities and stock markets of BRICS, especially in the long-term. In addition, volatilities have a significant long-term impact on the comovements between the energy commodities and the BRICS stock market. Specifically, we found that the US Volatility Index as a measure of investor fear and volatility in energy markets has the most impact on the nexus between stock commodities and the stock markets of the BRICS.

The rest of the article is organized as follows: the literature review is provided in Section 2; methodology is given in Section 3; Section 4 contains empirical results; and Section 5 concludes the study and contains guidance for further research.

2. Literature Review

The empirical discourse on the interdependencies among BRICS stock markets is blatant with a strong consensus of high integration [29–31]. However, the high integration within the BRIC markets has the potential of minimizing diversification benefits across time-frequencies. As averred by Kannadhasan and Das [32], strong comovements in BRICS economies entail a state near to perfect integration and may limit the benefits of arbitrage and portfolio diversification. But, due to the resistance of BRICS stocks to most uncertainty shocks, it becomes practically impossible for uncertainties to distort their high level of integration relative to being disintegrated regarding market bloc [14], revealing their synergistic properties to shocks. Accordingly, attention has been driven to forming portfolios with other assets, such as commodities to seek safe haven benefits [33]. Similarly, there are high similarities among commodities [34] which demands that an extension of assets classes for portfolio diversification be made.

The theoretical link between energy commodities and stock markets can emanate from the stock valuation model or monetary channel [35]. The stock valuation model assesses a stock by discounting all estimated future cash flows leading to either escalation in cost of production (for energy-consuming firms) that minimizes net present value or increases future profitability (for energy-producing firms) [13, 36–38]. That is, the impact of fluctuation in energy prices on stock prices largely depends on net-consumer or producer [39]. On the other hand, the monetary channel originates from higher discount rates due to surges in energy prices (regarding high inflationary pressures coupled with an upsurge in interest rates). A growing body of literature also accounts for this linkage based on speculative dynamics and contagion effects, concerning delayed responses to information, market over-reaction, mean reversion, investor sentiments, attention to extreme price changes, etc. [27, 35].

This is necessary for BRICS economies whose energy sector is huge and they are heavily reliant on the production and export of these commodities [1]. The energy sectors of the BRICS economies supply over 40% of the world's energy, as they are both net energy imports (China and India) and net energy exporters (Russia, Brazil, and South Africa). It becomes relevant that the nexus between energy markets and BRIC stock markets in light of uncertainties be adequately investigated, because the persistent plummeting of stock market performance or portfolios declines investors' trusts and confidence in the financial system [40].

As a result, the wavelet techniques have become a common instrument for investigating limited variations of power within time series to determine both prevailing modes of variability and how the modes change over time through decomposition due to the time and frequency dynamics of financial assets [13, 23, 41–43]. In comparison to other methods such as quantile regression [34, 38, 44, 45], GARCH models [46–48], entropy techniques [49–52], and wavelet multiple [14, 23, 43], do not account for both time and frequency dimensions simultaneously, wherein serious economic events in addition to investment horizons are necessary to clearly understanding financial and economic phenomenon.

Specifically, the biwavelet technique is adequate in revealing the lead/lag relationships between financial time series in both calendar and intrinsic times. Similar to the biwavelet, the partial wavelet divulges the impact of a common interdependence on the nexus or interconnectedness between two financial time series across time and frequency. The finance and economic relevance of the partial wavelet technique is the extent to which a third variable can transmit shocks to the level of interdependencies between two financial time series. This induces the extent of diversification, hedge, or safe haven power of a third variable

(which are volatility indices in the study's context) depending on market outcomes.

Thus, the biwavelet and partial wavelet techniques adequately respond to the heterogeneous market hypothesis (HMH) [53] (Müller et al., 1997) and adaptive market hypothesis (AMH) [54]. The time and frequency domain provided by the wavelets show stock market participants' various investing horizons, which is consistent with Müller et al.'s [53] HMH. Also, the adaptive market hypothesis (AMH) developed by Lo [54] proposes that markets evolve and market efficiency differs in degree at separate periods as a result of events and structural transformations.

Given the several projections [55–58] into the development of the BRIC market, coupled with the fact that news items are more contagious in the few decades than ever [59], resulting from financial market turbulence, there is the need to assess the degree of interconnectedness between energy commodities and stock markets of BRICS while integrating the partial impact of volatilities in line with the modern portfolio theory of Markowitz [60]. This would disclose the linkages between the markets across time and frequencies, making it easier to examine the operability of fundamental market dynamics. Investors, portfolio managers, and fund managers might make valid assessments of safe haven, hedges, and diversification chances based on the revealed relationships and market dynamics of world energy markets and BRIC markets. It would also give insights to governments on the extent of resource diplomacy in their foreign policy strategies towards enhancing financial development in light of uncertainties. As advocated by Junior et al. [14], investors can modify their risk choices by investigating volatilities, and it is hoped that world energy markets and regional bloc analyses can help relevant stakeholders such as investors, portfolio managers, risk managers, and others better appreciate the global and regional structure of volatility in financial assets.

3. Methodology

The biwavelet and partial wavelet techniques are specifically employed in this study.

3.1. Biwavelet. The biwavelet showed the nexus between energy commodities and stock markets of BRICS economies from time-frequency perspective. Their results are shown in a pictorial form using arrows that are pointing right and left as well as upward or downward. The first variable is designated by right arrows pointing upwards and left arrows pointing downwards and vice versa for left arrows pointing upwards and right arrows pointing downwards. A color palette and a surface color represent the nexus between the linked variables.

3.1.1. Continuous Wavelet Transform (CWT). Wavelet has two transformation techniques, namely, discrete wavelet transforms (DWTs) and continuous wavelet transform (CWTs). The paper focused on CWT because it does a better extraction advantage. CWT ensures decomposition in time series into elementary functions. Because every frequency is used in operation and the shifting of the wavelet function is a continuous process, CWT results are easier to interpret. (1) is presented depicting the mother wavelet as

$$\psi_{i,s}(t) = \sqrt{s^{-1}}\,\psi(t - i)\left(s^{-1}\right),\ \psi(\bullet) \in L^2(R), \tag{1}$$

where $\sqrt{s^{-1}}$ is the normalization factor, pledging the mother wavelet to have a variance that is equal to one. Mathematically, it can be represented by $(\psi_{i,s}(t))^2 = 1$; i and s have been explained earlier. The Morlet wavelet equation is shown in the following equation:

$$\varphi^M(t) = \pi^{-1/4} e^{i\omega_o t} e^{-t^2/2}, \tag{2}$$

where ω_o represents the main frequency of the wavelet of a value set at 6 [61, 62].

A mother wavelet decomposition for a time series $x(t)$ can be represented in (3) following the study of Li et al. [63] as

$$w_x(i, s) = \int_{-\infty}^{\infty} x(t)\,\sqrt{s^{-1}}\,\psi\left(\frac{t - i}{s}\right)\mathrm{d}t, \tag{3}$$

where ψ is known to be complex conjugate in the mother wavelet function. Based on the chosen time-series factors and limiting it to the specific features of $\psi(\bullet)$, our end is $w_s(i, s)$. As previously stated, the fundamental advantage of a CWT is the ability to dismantle and recreate the function $x(t) \in L^2(R)$

$$x(t) = \frac{1}{C_\varphi}\int_0^\infty \left[\int_0^\infty W_x(i, s)\psi_{i,s}(t)di\right]\frac{ds}{s^2}, s > 0. \tag{4}$$

3.1.2. Wavelet Transform Coherence (WTC). Wavelet transformation coherence that is WTC is explained by Torrence and Compo [64] as a cross-absolute spectrum's squared value normalization to a single wavelet power spectrum. The equation of the squared wavelet coefficient is denoted in the following equation:

$$R^2(x, y) = \frac{\left|\rho\left(s^{-1}W_{xy}(i, s)\right)\right|^2}{\rho\left(s^{-1}\left|W_x(i, s)\right|^2\right)\rho\left(s^{-1}\left|W_y(i, s)\right|^2\right)}, \tag{5}$$

where ρ is a smoothing factor used to stabilities resolution as well as significance, and squared wavelet coefficient ranges between 0 and 1; $0 \le R^2_{xy}(i, s) \le 1$. A value close to 0 denotes a shaky link, whereas a number close to 1 denotes a strong link. WT illustrates a comprehensive nexus amid the time series variables in the time-frequency domain. To achieve stronger comovements, a brighter color is shown. The Monte Carlo procedure was issued to test the statistical significance of this nexus since cross wavelet transform coefficient theoretical distribution is difficult to tell [64].

3.1.3. WTC Phase Difference. The WTC phase difference shows in a specific time series the interruptions in the oscillation. Taking insight from Bloomfield et al. [65], the

difference in phase between $x(t)$ and $y(t)$ is shown in the following equation:

$$\varnothing_{xy}(\mathrm{i}, s) = \tan^{-1}\left(\frac{\mathfrak{I}\{S(s^{-1}W_{xy}(\mathrm{i}, s))\}}{\mathfrak{R}\{S(s^{-1}W_{xy}(\mathrm{i}, s))\}}\right), \quad (6)$$

where $\mathfrak{I}$ and $\mathfrak{R}$ used in (6) show imaginary operators and real operators individually.

3.2. Partial Wavelet Coherence (PWc). The PWc is used in literature to minimize the issue of "pure" correlation between time-series variables as well as control the effect of time series variable *z(t)* on the wavelet coherence between other two-time series variables $x(t)$ and $y(t)$ [14]. PWc is depicted in a similar equation to the partial correlation squared, as shown in the following equation:

$$R_p^2(x, y, z) = \frac{\left|R(x, y) - R(x, z)\bullet R(x, y)^*\right|^2}{[1 - R(x, z)]^2[[1 - R(y, z)]]^2}, \quad (7)$$

where $R_p^2(x, y, z)$ is between 0 and 1. The paper, x, and y denote world energy commodity returns and BRICS stock returns while z denotes relevant volatilities. PWc uses Monte Carlo methods in estimation.

3.3. Data Sources and Description. The daily data in support of this study included five relevant energy commodities which are NASDAQ Commodity Energy as a measure of global energy index (Aenergy), Brent crude oil, heating oil (Hoil), gasoline, and WTI crude oil, in addition to four volatilities, Chicago Board Exchange Volatility Index of the US (VIX), DWS NASDAQ-100 Volatility (includes 100 of the largest nonfinancial securities listed on the NASDAQ Stock Market based on market capitalisation) which we proxy as Global Volatility Index for nonfinancial securities (GV), CBOE Emerging Markets ETF Volatility (EM), and CBOE Energy Sector ETF Volatility (VEnergy). Particularly, the GV is an improved measure of implied volatility of equity indices on the NASDAQ-10 Index, whereas the VEnergy measures the market's expectation of 30-day volatility implicit in the prices of near term energy-stocks options. Moreover, we employed daily stock prices of BRICS countries which are made up of Brazil (Ibovespa Index), Russia (Moscow Exchange Russia Index), India (NIFTY 500 Index), China (Shanghai Stock Exchange Composite Index), and South Africa (JSE/FTSE All Share Index). The daily data span was 26th April, 2012, to 31st March, 2021. The suggested period was selected where the beginning and end-points are primarily driven by consistent data availability. Notwithstanding, this period spans serious economic events such as the aftermath of the 2008 GFC, the Eurozone crisis, Brexit, crude oil price crashes, and the COVID-19 pandemic. The data on BRICS were gleaned from EquityRT, whereas energy commodities and volatility indices were obtained from investing.com. We utilized daily returns as $r_t = \ln P_t/P_{t-1}$, where r_t is the logarithmic returns, P_t is the current index), and P_{t-1} is the previous index.

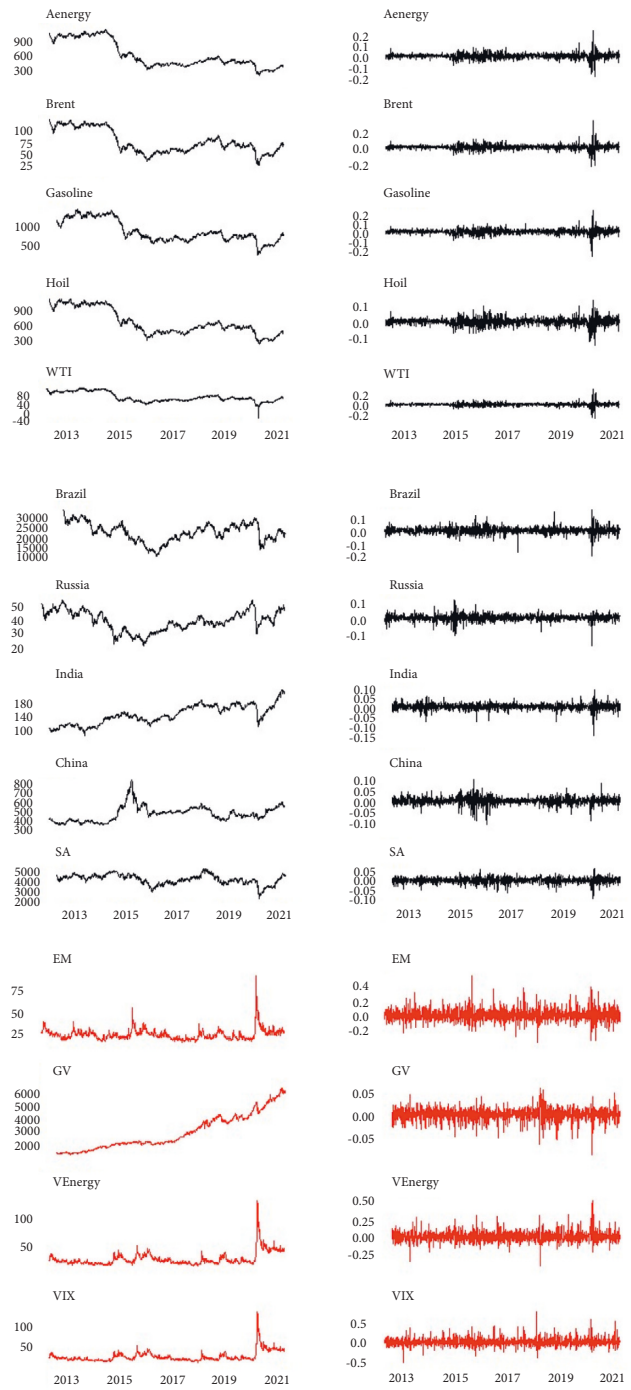

Figure 1: Plots of raw and returns series.

Figure 1 provides the time-varying prices and returns of energy commodities, volatilities, and stock markets of BRICS. We notice upwards and downwards movements in the variables. The sharp decline in most assets prices around 2015 may be attributable to the delayed effect of financial assets responds to the turbulence of the Eurozone crisis. Furthermore, the volatility indices show inverse relationships with the energy commodities and stock markets of BRICS, especially the GV. This may provide a useful signal for portfolio diversification. The rise in GV is not surprising because its VIX includes a large and variable number of

Table 1: Descriptive statistics.

	Mean	Std. Dev.	Skewness	Kurtosis	Jarque–Bera
Aenergy	−0.00062	0.02259	−0.21889	17.06987	14869.73000***
Brent	−0.00035	0.02665	0.19331	24.17586	33661.16000***
Gasoline	−0.00023	0.02557	−1.22407	23.19561	31056.45000***
Hoil	−0.00052	0.02139	−0.28973	8.83366	2578.98600***
WTI	−0.00010	0.03114	0.20020	28.54743	48989.56000***
Brazil	−0.00026	0.02408	−0.64188	13.40565	8248.99800***
China	0.00018	0.01563	−0.67740	10.22979	4060.15200***
India	0.00041	0.01465	−1.06232	14.12231	9621.84100***
Russia	−0.00003	0.01785	−0.77477	12.15640	6471.64500***
SA	0.00001	0.01777	−0.73518	7.82979	1912.72500***
EM	−0.00007	0.07089	0.73956	7.71178	1830.16500***
GV	0.00082	0.01217	−0.75476	7.68888	1820.82700***
VEnergy	0.00028	0.06424	0.92790	10.00211	3937.70300***
VIX	0.00008	0.08816	1.16758	10.87065	5057.80800***

Note. *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

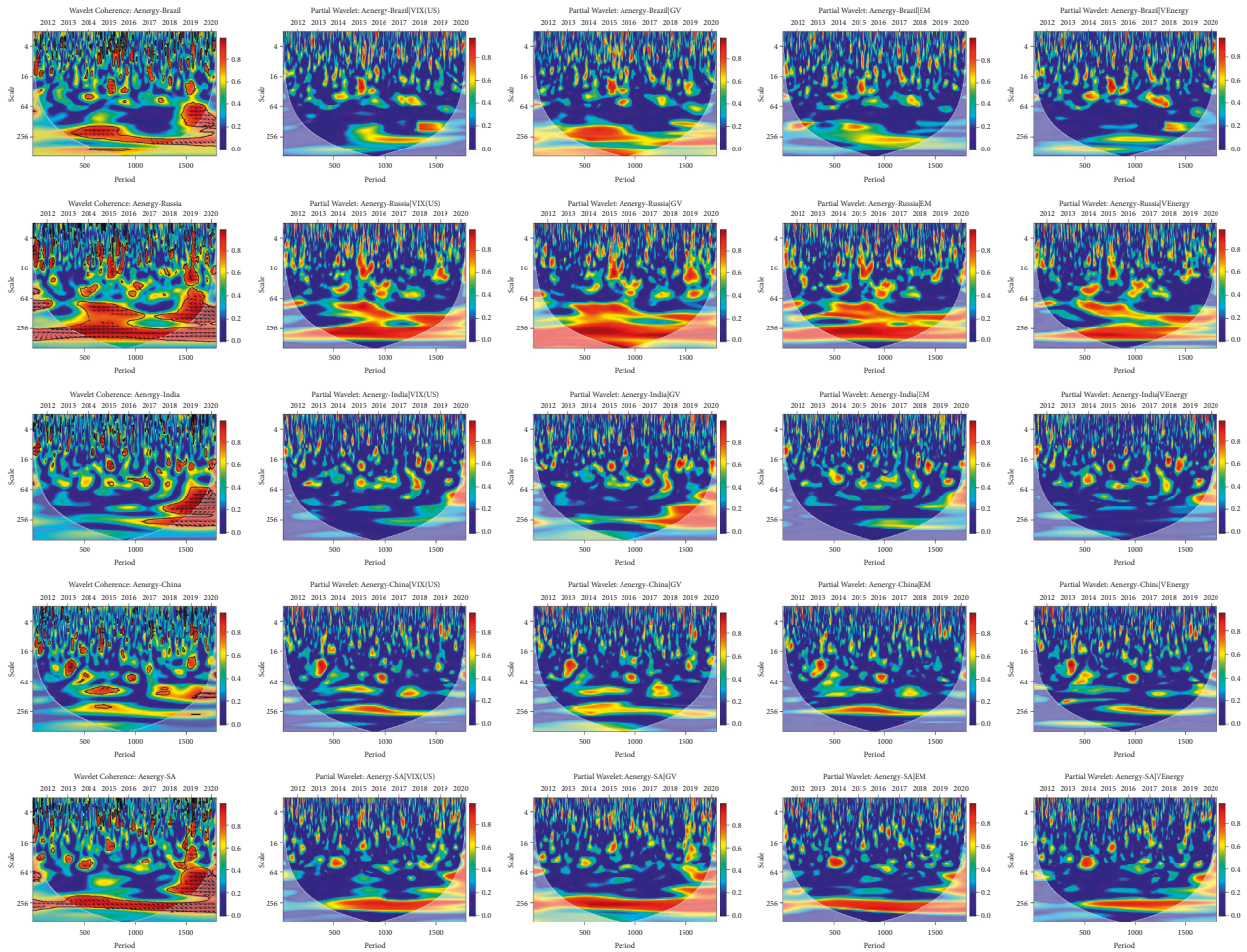

Figure 2: Comovements among global energy, BRICS, and volatility indices.

money options (in, at, and out) that forms a quantity of annualised variance, and thereby surging its value due to statistical noise from any of the three option types, and this impact is aggravating even during the COVID-19 pandemic. The sharp rise (fall) and fall (rise) of the other volatility indices (commodities and BRICS stocks) beyond 2019 suggest high likelihoods of markets rebound. The log-return plots demonstrate volatility clustering as expected due to the stylised facts of financial time series.

Table 1 shows the initial statistical analysis for the series of returns. The negative mean returns indicate the poor performance of financial assets over time whilst the positive

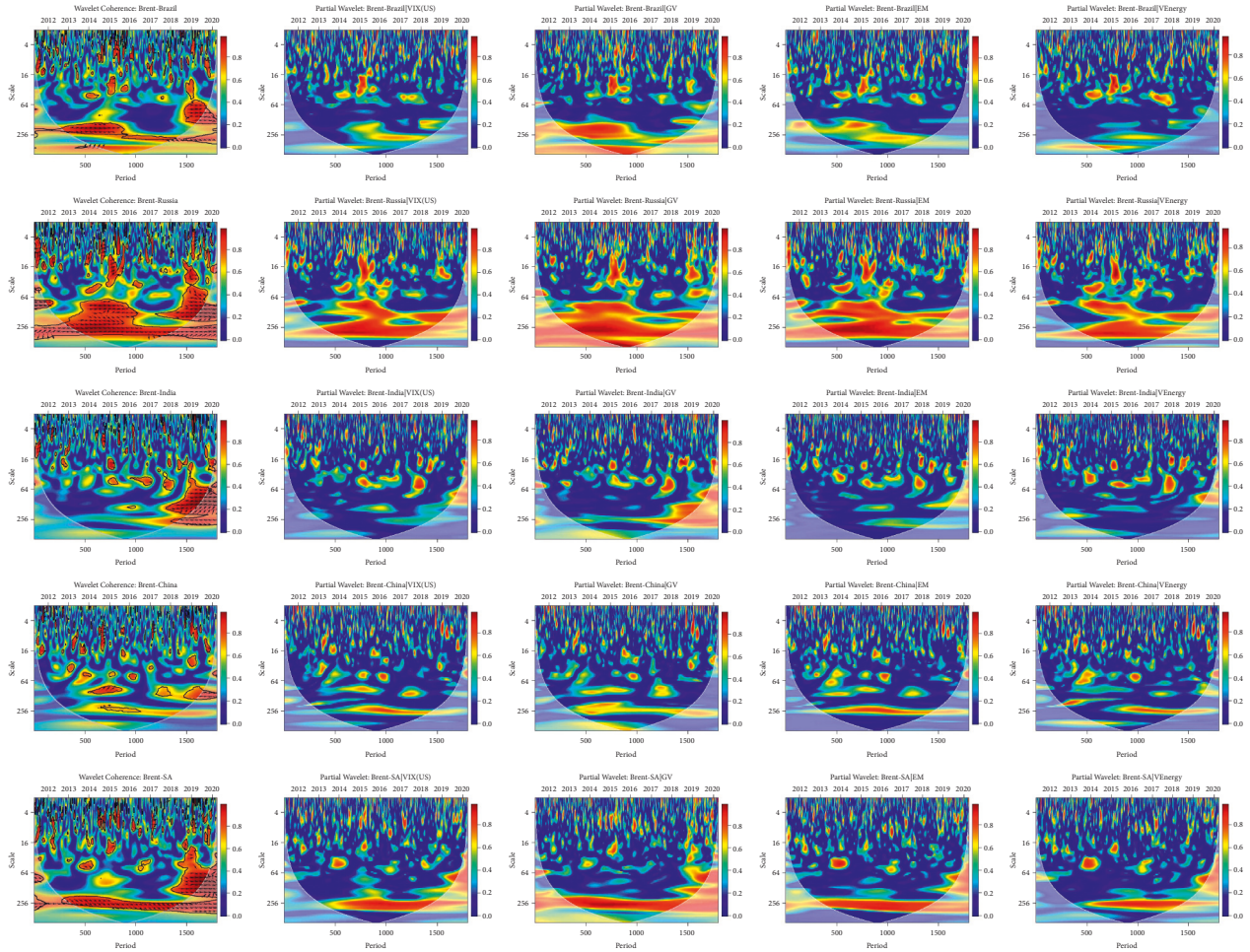

Figure 3: Comovements among Brent crude oil, BRICS, and volatility indices.

returns depict the tendency for markets to withstand shocks. The negative skewness specifically suggests that investments in these assets should be done with caution since there is a prospect for lower returns in a foreseeable period. Also, it can be observed from the Jarque–Bera statistic that all the series are not normally distributed.

4. Results and Discussion

The biwavelet and partial wavelets techniques are specifically presented in this section. We seek to assess the lead and lag relationships between energy commodities and BRICS stocks using the biwavelet technique. In addition, the partial impact of volatilities (as a common interdependence) on the comovements between energy commodities and BRICS stocks is investigated through the partial wavelet. Analyses are therefore mainly conducted on a time and frequency perspective.

4.1. Time-Frequency. The following section presents the time-frequency domain analysis of energy commodities and BRICS stock markets, as well as the partial impact of volatilities between the nexus. Right-pointing arrows and left-pointing arrows indicate whether the variables are moving in the same direction or in the opposite direction, respectively. The first variable is shown by right-pointing arrows upwards and left-pointing arrows downwards. Left-pointing arrows upwards and right-pointing arrows downwards, on the other hand, imply that the second variable leads. The surface color represents the degree of comovement between the matched series. The warm color denotes parts with a lot of interactions, whereas the cool color denotes regions with less interactions [14]. The region outside the cone of influence is insignificant. This is because they are beyond the 95% confidence level. Analyses are displayed for the short-, medium-, and long-terms at various calendar times in Figures 2–6.

From the biwavelet technique, we notice long-term significant positive comovements between the selected energy commodities and stock markets of BRICS. The positive comovements suggest high integration in the long-term dynamics which minimizes portfolio diversification. This is partly in line with the financialisation hypothesis as also found between gold and bitcoin in the study of Derbali et al. [66]. That is, both the energy and stock markets of BRICS move in the same direction with similar dynamics. The high integration between energy commodities and BRICS stock

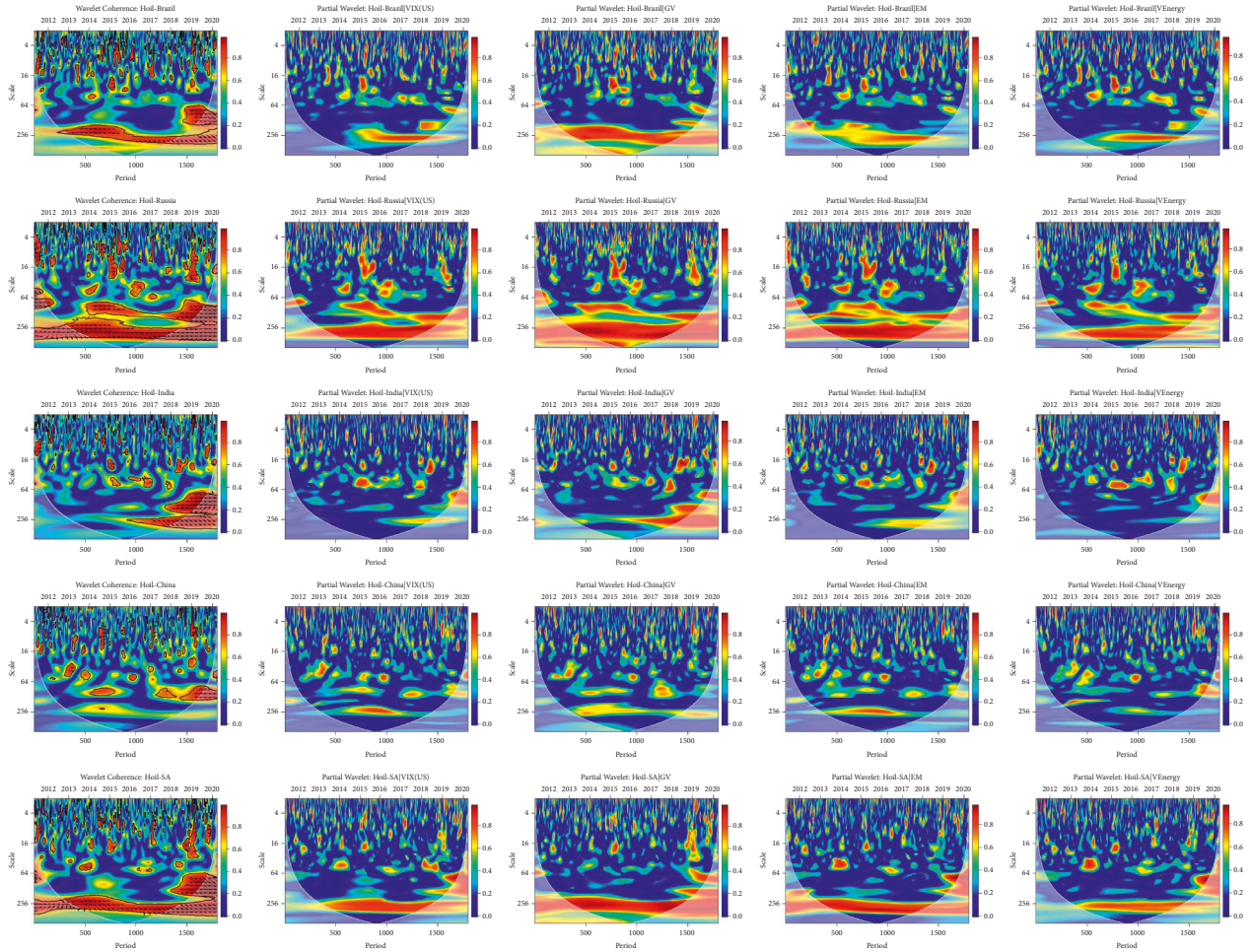

Figure 4: Comovements among heating oil, BRICS, and volatility indices.

markets highlights the assertion made by Abramova and Fituni [4] that resource wealth is one of the factors contributing to the unification of BRICS economies to enhance financial development, which makes those nations resource powers. Particularly, the Russian stock market demonstrates the most significant positive integration with all energy commodities relative to other constituents of BRICS. This is not daunting, because Russia is a net exporter of energy resources and has consistently ranked 1st in gas exports internationally. Furthermore, Russia is second to none in terms of oil exports and third in coal exports according to BRICS Energy Report [3].

In most cases, between 2012 and 2018, we find that the BRICS stock markets drive energy commodities in the long-term. This implies that, in the long-term, the BRICS stock markets act as a first mover or leader to predict the behaviour of energy commodities. It also suggests that the BRICS stock markets are the first variables to respond to shocks before the energy commodities. This highlights the degree of vulnerability of stock markets of BRICS to most uncertainties across time-frequency domain. Beyond 2018, there are traces of interdependencies between energy commodities and stock markets of BRICS in the medium- and long-terms where all markets have the potentials to either lead or lag. At this point, the markets have become saturated, and portfolio rebalancing becomes a relevant course of action to undertake. Yet, the level of integration between the markets is high which hinders portfolio diversification. Specifically, the strong long-term comovements between crude oil products (Brent and WTI) and the BRICS stock markets corroborate the outcome of Mensi et al. [25] and Mensi et al. [12]. Nonetheless, comovements of the energy commodities with India and China stocks (net energy imports) is less integrated as found in the study of Shahzad et al. [35] suggesting high diversification potentials.

The high positive comovements between energy commodities and BRICS stocks beyond 2018 span the COVID-19 pandemic period. At this point, investors assumed major losses which tumbled financial markets regarding strong uncertainty connected with the pandemic [33]. Moreover, it can be noticed from the biwavelet plots that high-rise in the spillover effects during the COVID-19 pandemic occurs mostly in the medium- and long-terms suggesting contagion effects during this investment horizon. In most cases, we find bidirectional relationship between energy commodities and BRICS stocks suggesting high degree of interconnectedness during the pandemic. Indeed, despite the rampant development of BRICS stock markets, resource wealth also

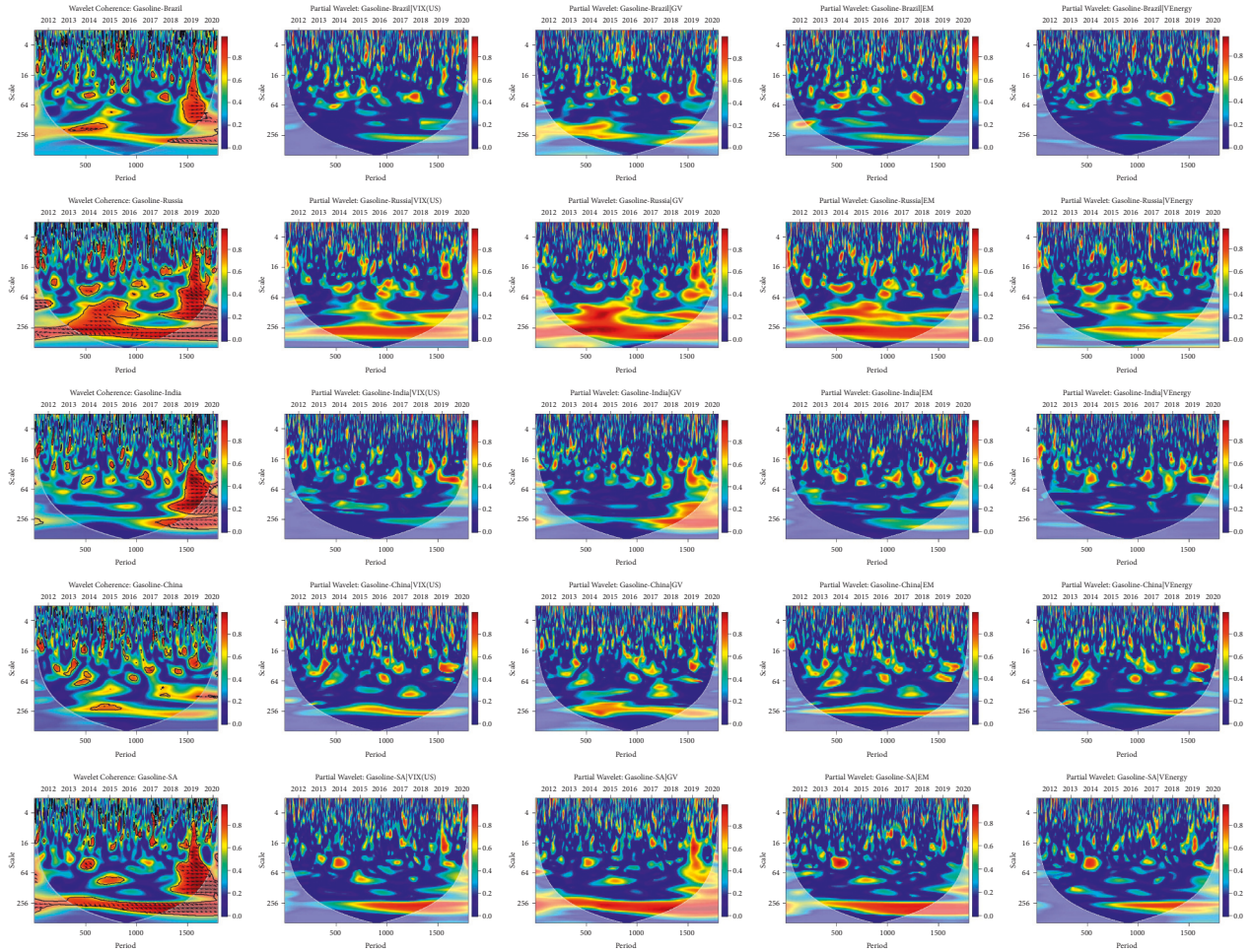

Figure 5: Comovements among gasoline, BRICS, and volatility indices.

strongly contributes to the unification of BRICS economies, to be touted as "resource powers" without overemphasis [4]. In this manner, our study supports the evidence that highlights the prevalent panic occasioned quick sell-outs and havoc in financial markets around the globe [33, 45, 49, 50, 67, 68]. It is the expectation of every investor and policymaker for the markets to recover and rebound quickly due to the ravaging impact of the pandemic.

However, since nations can enjoy the long-term sustainability of highly integrated economies, BRICS countries can shield themselves against uncertainties by hedging with relevant volatility indices. This can be inferred from the significant adverse impact of the volatility indices on the positive nexus between energy commodities and BRICS through the partial wavelet.

Throughout Figures 2–6, the US volatility index and volatility in energy markets have the most significant impact on the positive comovements between energy commodities and stock markets of BRICS. This indicates that in the midst of the volatility index of the United States and energy commodities, there is a distortion of the highly integrated energy commodities and BRICS stock markets both in time and frequency which increases the effectiveness of portfolio diversification. The adverse impact of the US VIX on the integration of BRICS stock markets can be observed from most empirical studies [14, 69, 70]. A second volatility of concern is the volatility in the energy markets. This is followed by emerging markets volatility which also has the tendency to distort the positive and significant comovements between energy commodities and stock markets of BRICS. In this sense, the implied volatility of equity indices on the NASDAQ-10 index (GV) has the least impact on the interconnectedness. However, the GV surges across time as found in the preliminary statistics; it has less relative direct link (as a common interdependence) on the comovements between energy commodities and BRICS stocks. It is required that future studies assess the impact of the GV on either energy commodities or BRICS stocks to adequately divulge its empirical properties. Notwithstanding, indeed, the impact of external shocks on the interconnectedness between energy commodities and BRICS stocks is eminent as indicated by Bouri et al. [22] and Bouri et al. [27].

The strong comovements in the long-term reiterate the heterogeneous [53] and adaptive behaviours of the markets [54] due to the changing dynamics of the markets across time and frequency. The comovements are also greater beyond 2019 in the medium- and long-terms when most economic activities were distorted due to the adverse impact

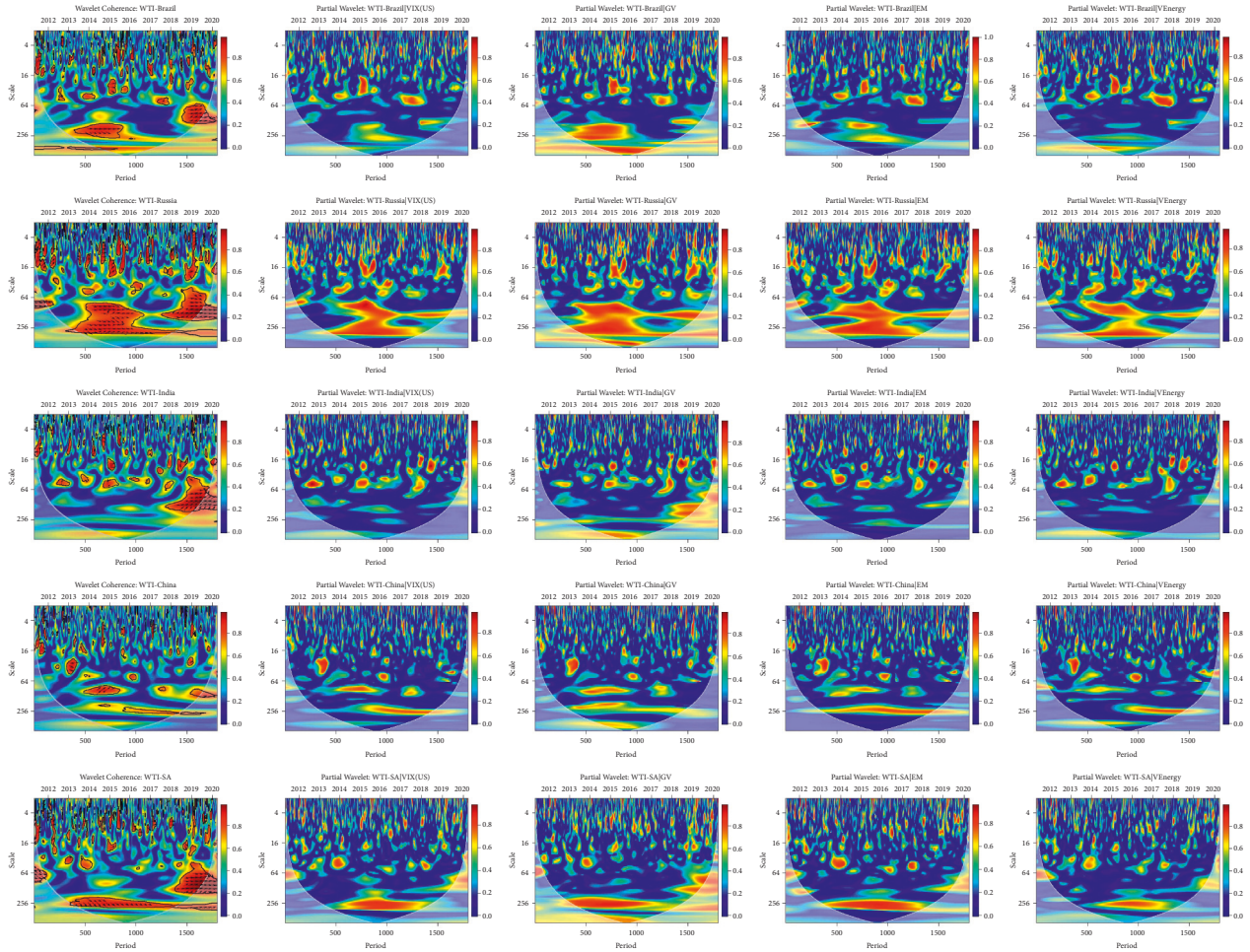

Figure 6: Comovements among WTI crude oil, BRICS, and volatility indices.

of the pandemic, requiring effective portfolio rebalancing. The high interdependencies between the markets suggest that financial markets begin to learn from each other coupled with similar spillover dynamics. That is, each market relies on each other which induces one market to react accordingly in times of shocks or contagion effect on the other market to influence investors' confidence. This hinders diversification potentials between markets, requiring portfolio rebalancing or redeployment of portfolios, especially in the long-term holdings of these assets. However, investors can gain by hedging against fluctuations in the high interdependencies between energy commodities and BRICS markets using relevant volatilities, such as the US VIX, as well as the US VIX and volatility in the energy markets can act as relevant safe haven instruments during the COVID-19 pandemic.

5. Conclusions

We employ wavelet techniques to examine the interconnectedness amid energy commodities returns and BRICS stocks returns, while considering the role that relevant volatilities play in tandem. Specifically, the biwavelet is employed to assess the comovements amid energy commodities returns and BRICS stocks returns. In addition, the partial wavelet is utilized to assess the impact of volatilities in the nexus between energy commodities returns and BRICS stock returns. We perform the analysis in a time-frequency perspective to reveal the heterogeneous and adaptive dynamics of the markets.

We found from the biwavelet technique that positive significant comovements exist among energy commodities and most of the stock markets of BRICS in the long-term and highlight the degree to which BRICS economies are touted as "energy resource powers." This implies that the energy markets and stock markets of BRICS are highly integrated, but mostly in the long-term. Specifically, the comovements between energy commodities and the Russian stock market were the strongest in the long-term, revealing the dominance of Russia in world energy commodities [3]. On the other hand, the integration of China's stock market is low, even in times of the COVID-19 pandemic, relative to its comovements with some selected international stock market indices in the pandemic [71]. Similar dynamics can be said of India. We assert that interconnectedness between energy commodities and stock markets of net energy importers (China and India) is low relative to that of net exporters (Russia, Brazil, and South Africa). This accentuates the fact that stock

markets of net exporters of energy commodities are more susceptible to fluctuations in the international energy market relative to net importers [35].

The result of the partial wavelet discloses that volatilities have a significant long-term impact on the comovements between the energy commodities and the stock market of BRICS. Specifically, we found that VIX (a measure of investor fear and volatility in stock markets) has the most impact on the nexus between energy commodities and the stock markets of the BRICS. Interestingly, the comovements between energy commodities and stock markets of Russia were strong enough to resist the adverse impact of volatilities. Hence, investors can hedge against portfolio risks within energy commodities and Brazil, India, China, and South Africa stocks using volatilities.

Findings from the study imply that diversification potentials vary between the world's energy markets and BRICS stock markets from the short-, medium-, and long-terms across calendar times, espousing the HMH [53] and AMH [54]. Moreover, the results offer indication on the predictableness of implied volatility indices on the connectedness between world energy markets and BRICS stock markets. We advocate that the US VIX is the dominant predictor of shocks in the energy-stock nexus. This is not surprising because the US stock market is huge with high tendency for its implied volatility to impact emerging stock markets [22]. We add that its impact on emerging stock markets has an analogous effect on world energy markets. This makes it effective to act as a common interdependence predictor of shocks rendering the notion that local investors worry more about other local and regional stock market uncertainties than the US market uncertainty, a potential inconclusive discourse. It is commendable that the US VIX has a transitioning effect on different classes of financial assets. Investors can therefore pay exceptional attention on the ravaging impact of the US VIX in meandering the nexus between energy and BRICS stock markets in times of portfolios formation and management. The results from this study do not only induce policymakers to secure stock markets against extreme world energy price movements in the future, but to effectively do so in light of several other volatilities, with the US VIX ablaze.

We recommend that investors, portfolio managers, and risk managers, among others should be wary of the heterogeneous and adaptive behaviour of the interconnectedness between word energy markets and BRIC stock markets at diverse market outcomes for appropriate rebalancing of portfolios. In addition, governments of BRICS should fine-tune their foreign policy strategies on the extent of resource diplomacy toward enhancing financial development with uncertainties in tandem.

The study covers energy commodities, whereas commodities markets exhibit heterogeneous dynamics. Similarly, the heightening interests in emerging markets render investigations of a broad spectrum of economies within this region prodigious. Other regional blocs and commodities from other sectors can be incorporated to examine their comovements in tandem with volatility indices. The impact of relevant uncertainty indices, including local volatilities on the nexus between country specific commodities can also be examined to respond to the high connectedness phenomenon among commodities. Subsequent studies can quantify the flow of information between the variables via multi-frequencies [50, 51, 72–75] (to add up to the spillover connectedness.

Data Availability

Data used in support of this study are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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