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Wavelet Coherence and Continuous Wavelet Transform - Implementation and Application to the Relationship between Exchange Rate and Oil Price for Importing and Exporting Countries

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ABSTRACT

The purpose of this study is to analyses the time - frequency relationship between exchange rate and the oil price for exporting and importing countries by using measures of continuous wavelet transform (CWT) and Wavelet coherence (WCT). The findings of wavelet coherence (WCT) analysis indicates that the high coherency between exchange rates and oil price is witnessed in Brazil, Singapore, and Taiwan in medium and long term for importing countries while in Kuwait, Russia, and Canada for exporting countries. In addition, there is no co-movement between the exchange rates and oil price for Angola, Venezuela, Iraq, and Iran for exporting countries while in Egypt for importing countries in short, medium, and long term. In addition, in most of the period studied, exchange rate for importing and exporting countries was leading and passing anti-cycle effects on oil price (OPEC, BRENT, and WTI) shocks which are the major contribution of our study.

Keywords: Continuous Wavelet Approach, Wavelet Coherency, Oil Price, Exchange Rate, Import Countries, Export Countries
JEL Classifications: E0, E3, E320, E32

1. INTRODUCTION

The relationship between the exchange rate and oil price is still inconclusive and ambiguous, so study the relationship between these variables is hazardous endeavour, but indulging in this exercise is invertible for financial and economic decision making in this era of globalisation. The significance of examine the relationship between oil prices and exchange rates of major importing and exporting countries, as difficult as it is, stems from the fact that the result of a financial and economic decision taken today is contingent, among other things, the value of the underlying oil price and exchange rate that will prevail in the upcoming. This is a reason why the study the relationship between oil prices and exchange rates is important for international financial operation, including policymakers, speculation, capital budget, economic decision, traders, and institutional investor's perspective.

From a theoretical perspective, according to the Bodenstein et al. (2011) the oil prices shocks can be transmitted to the exchange rate through two main channels. First channel, in the terms of trade, a rise in oil prices for an exporter (say, a positive terms of trade shock) drives up the price of non-traded products in the domestic economy to increases and then the real exchange rate (RER), which is defined as the relative price of a basket of non-traded and traded products between the foreign and domestic economies. As we know, the non-traded products prices could be sticky; in this case, the adjustment of the real exchange rate (RER) could require nominal exchange rate (NER) appreciation as well. In the second channel, in the term of wealth effects, the study conducted by Kilian (2006) argued that the negative in oil prices shock would transfer wealth from countries oil exporters to importers, resulting to large shifts in portfolio reallocation and in current account balances.

Both fundamental channels in above derived from theories inter-temporal models tend to indicate that a rise in oil prices must be accompanied by real appreciation of oil countries exporters. Though, things could be somewhat different in real practice.

This paper differs from the previous empirical evidence in many ways. Firstly, the earlier studies used different methodology such as linear Granger-causality (which were based on approach of the time domain) to test the causal relationship between oil prices and exchange rate. Usually used Granger (1969) causality test, is based on unable to take into anti-cyclical and cyclical account relationship between microeconomics variables (such as exchange rate and oil price) while our approach in present paper is very advantageous to answer this question. Secondly, we presented time-series concept with frequency domain, therefore, we presented the "time-frequency" concept which is time-series concept with frequency domain, therefore, we analyzed time-frequency relationship as in the frequency domain framework time information is lost. Thus, in this paper we used continuous wavelet transform (CWT) and wavelet coherency (WTC) to examine and analyse the impact of exchange rate changes on oil price and vice-versa.

The rest of paper is organized as following: Section (2) provides literature reviews; following sections explains methodology and data collection. Empirical findings are interpreted in section (5) and conclusions.

2. LITERATURE REVIEW

The literature review deals with two issues: (i) Measure the relationship between exchange rates and oil prices by using general approach, and (ii) Measure the relationship between exchange rates and oil prices by using wavelet analysis. These issues will be dealt with in turn.

2.1. Measure the Relationship between Exchange Rates and Oil Prices by Using General Approach

The relationship between the oil price and exchange rate increases ambiguous during the last period in the economics and policymakers. Previous studies examine the relationship between these variables such as Beckmann and Czudaj, 2013a; Jiang, 2016; Kohlscheen et al., 2016b; Pershin et al., 2016; Jawadi et al., 2016; and Delgado et al., 2018. The empirical evidence from these studies indicate that USD exchange rate depreciation when the oil prices in importing major countries arise while the increase in price of crude oil leads to appreciates local (domestic) currency against USD.

Furthermore, the study conducted by Abubakar (2019) examined the relationship between oil price and exchange rate in Nigeria and found that they were interrelated. Anjum also explored this relationship in 2019 and concluded that it was bidirectional. Singhal et al. (2019) discovered that oil prices negatively impacted stock prices and exchange rates in Mexico, while Malik and Umar highlighted the significant effect of oil prices on the exchange rate. In 2020, Mukhtarov revealed that the impact of oil price shocks on stock prices depended on the sources of shocks. Adekunle et al. (2020) confirmed the predictability of stock returns from oil price shocks. Aloui and Ben (2013) suggested the necessity of considering oil prices, exchange rate, and stock prices together to avoid omitted variable bias, and Delgado et al. supported that these three variables improved the fit of the model. Polat confirmed the existence of a time-varying effect of oil price shocks on stock prices in Turkey, while Tiwari et al. concluded that there was risk spillover between oil prices and stock markets in the G7 countries. The literature also supported an asymmetrical relationship between oil prices and other economic variables, and in 2021, Unch and Lionel reported an asymmetric relationship in the dynamic interactions of oil price, exchange rate, and stock prices in Nigeria. In addition, Delgado et al. (2018) conducted a study on the correlation between oil prices, exchange rates, and stock market indices in Mexico, using data from 1992 to 2017. They utilized a VAR model and concluded that oil prices have a significant impact on exchange rates, indicating that an increase in oil prices leads to a stronger exchange rate. Similarly, Turhan et al. (2014) explored the connection between oil prices and exchange rates in emerging markets, using daily time series data from 2003 to 2010. They also used a VAR model and found that higher oil prices increase the value of emerging countries' currencies against the US dollar. Additionally, their research discovered that the relationship between oil prices and exchange rates became more pronounced after the 2008 financial crisis. These results suggest that oil price variations have a substantial influence on exchange rates.

Mukhtarov et al. (2019) conducted a study on Azerbaijan, examining the effects of oil prices on inflation. They utilized data from 1995 to 2017 and applied a VECM model. Their findings showed that both oil prices and exchange rates exerted a positive, statistically significant effect on inflation in the long term. Additionally, they discovered that the decrease in oil prices in 2014 led to the devaluation of the national currency. Narayan et al. (2019) investigated the connection between oil prices and Indonesia's exchange rate from 1986 to 2017 employing an ARDL model. Their study revealed that the long-term cointegration relationship between oil prices and the actual exchange rate was sensitive to various exchange rate regimes in Indonesia. Abraham (2016) examined the impact of exchange rate policy and falling crude oil prices on the Nigerian stock market. By utilizing an ARDL model, the researcher found that crude oil prices were positively linked to the performance of the Nigerian stock market and could negatively affect its performance during periods of turmoil. The study also emphasized that the devaluation of the Naira was an effective strategy to mitigate the negative influence of falling crude oil prices on the stock market. Another study conducted by Duna et al. (2021) explored how geopolitical risk placed pressure on Venezuela's exchange rate and oil prices using wavelet-based analysis. The research found bidirectional causality between oil prices and the exchange rate.

Several studies indicated that an inverse relationship exists between the value of oil price and exchange rate, including a research study carried out by Anjum (2019) investigated the dynamics of volatility in oil prices and the US dollar exchange rate using GARCH models on data from 2000 to 2015. The study found that there is no evidence of volatility transmission between the two if structural breaks are not considered, but there is significant transmission when structural breaks are accounted for. Kumar et al. (2019) employed an ARDL model on data from 2006 to 2018 and found that oil prices have a negative long-term influence on the exchange rate in Mexico. Mukhtarov et al. (2020) studied the effect of oil prices on macroeconomic variables in Azerbaijan from 2005 to 2022 using a VECM model. The results indicate that oil prices negatively impact the exchange rate, and they suggest that researchers and policymakers understand the impact of oil price shocks on the economy of developing oil-rich countries like Villarreal-Samaniego (2020) also used an ARDL model to reveal an inverse relationship between the exchange rate and oil price movements.

2.2. The Relationship between Exchange Rates and oil Prices by Using Wavelet Analysis

Ji et al. (2019) examined the dynamic relationship between WTI crude oil and the exchange rate of the United States and China, applying 6 time-varying copula models to account for changes in dependence structures. They found that the dependence between crude oil and the RMB exchange rate is weakly positive with lower tail dependence, while the dependence between crude oil and the US dollar index is significantly negative with lower-upper and upper-lower tail dependence. The study also identified asymmetric risk spillovers from crude oil to the Chinese and US exchange rate markets using CoVaRs results. Balcilar et al. (2015) used a Bayesian Markov-Switching Vector Error Correction model to analyze the information transmission dynamics between oil prices, precious metal prices, and exchange rates. The study found asymmetrical relationships between oil prices and exchange rate volatility. Saenong et al. (2020) explored the symmetric and asymmetric effects of crude oil prices and exchange rates on bond yields in Indonesia using ARDL and NARDL models. The study revealed no symmetric long-run relationships between oil prices or exchange rates and bond yields but found asymmetric short-run relationships. Zhu and Chen (2019) investigated the symmetric effects of oil prices and exchange rates on China's industrial prices using an NARDL model. They discovered inconsistencies between the practice of oil price and exchange rate transmissions in China and the importance of China's oil product mechanism and exchange rate policy reforms in mitigating transmission distortions.

According to the study conducted by Jammazi, along with their collaborators (2015), utilized a wavelet-based nonlinear autoregressive distributed lag (NARDL) model to examine the exchange rate pass-through to crude oil prices across 18 countries. The results indicated a significant and asymmetric pass-through of exchange rates to oil prices in both the short and long term. The study highlights that filtering the crude oil and exchange rate data is crucial for analyzing their interactions efficiently. In another investigation by Aloui et al. (2013), they employed a copula-GARCH model to analyze the conditional dependence structure between crude oil prices and US dollar exchange rates by using data from 2000 to 2011. This study provided evidence of significant and symmetric dependence for most oil-exchange rate pairs, showing that the appreciation of oil prices is related to the depreciation of the US dollar. Chou and Tseng (2016) investigated the link between oil prices, exchange rates, and price asymmetry in the Taiwanese retail gasoline market using the NARDL model. Their findings revealed that oil prices had slow, complicated responses to exchange rate shocks and exhibited reverse adjustments during the period of initial exchange rate depreciation. Lastly, Mohammadi and Jahan-Parvar (2012) conducted a study on the oil prices and exchange rates in oil-exporting nations using TAR and M-TAR models. The results indicated that there is no evidence of short-term causality, but exchange rates adapt more quickly to positive deviations from equilibrium, indicating that oil prices have a long-term impact on exchange rates. In Kumar's (2019) study, he investigates how oil prices affect exchange rates and stock prices using data from January 1994 to December 2015. By using nonlinear Granger causality and NARDL models, he discovered that positive and negative shocks in oil prices from the previous month have both positive and negative significant impacts on exchange rate and stock prices. Meanwhile, Augustin et al. (2020) analyze the effects of oil prices on exchange rates in Asisa countries from 1970 to 2016. They found that crude oil prices might also have an indirect effect on exchange rates through sovereign credit risk. In relation to sub-Saharan Africa, Baek and Kim (2020) perform an NARDL model to establish a connection between crude oil prices and exchange rates. The result indicates that changes in oil prices have an asymmetric impact on real exchange rates in the long run, reflecting greater responsiveness towards oil price increase compared to a decrease. Lastly, Xu et al. (2019) utilizes a bivariate normal mixture model to understand the nonlinear relationship between crude oil prices and exchange rates both quantitatively and structurally. Their research identifies that there is a structural heterogeneity during economic expansion, although there is little evidence of heterogeneity during a recession. In the study conducted by Khraief et al. (2021), the authors analyzed the motion of oil prices and exchange rates in China and India in a nonlinear manner. Through the use of an NARLD model, it was determined that only the long-term effects of oil prices on exchange rates in both countries were asymmetric. However, after removing any time-series noise, the asymmetry in the long-term effect became symmetric in India. Similarly, Fasanya et al. (2021b) explored the correlation between oil prices and exchange rates for Nigeria by utilizing ARDL and NARDL models with monthly data from 1997 M1 to 2019 M12. The researchers concluded that an increase in oil prices results in the depreciation of the Naira relative to the US dollar, and oil price asymmetries appear to play a role in both short-term and long-term periods. In contrast, Oreste et al. (2019) examined the long-term linkage between interest rates and exchange rates in Mexico using a nonlinear ARDL model spanning from 1996 to 2017. The findings indicate that there is a positive relationship between interest rates and exchange rates in Mexico.

2.3. Study Contributes to the Literature

Wavelet analysis in this study allows us to examine and measure the co-movements between oil prices and exchange rate time-series. Using wavelets tools both short and long run movements are captured relative to the time as well as the frequency span of time. We study the relationship between the benchmark oil prices with exchange rates of oil exporting and importing major countries in the world in the time and frequency space. Previous empirical evidence either frequency or time domain does not provide the complete dynamics in co-movements relationship. The main different between the traditional time-series and wavelets approach is that traditional (standard) time-series models only focus into the time scale while the wavelet analysis focus on both frequency domain and time into consideration. Consequently, using wavelets approach can help the economists to eliminate the limitations of the standard variables time-series model.

Numerous of the studies on the relationship between the exchange rate and oil prices have been conducted for industrial as well as developed economies. There is a few studies on the relationship between the exchange rate and oil prices for importing and exporting countries for emerging and developed economies (Basher and Sadorsky, 2006; Hammoudeh and Aleisa, 2004; Hammoudeh and Huimin, 2005). Therefore, this research examines the relationship between oil prices benchmark with stock indices and exchange rate based on the data for top 15 oil importing major countries such as Japan, Spain, Turkey, Belgium, Taiwan, France, India, Italy, US, Singapore, Germany, Netherland, and Indonesia. But this study is neglected the emerging economies and exporting oil countries. In this study we examine the relationship between the oil prices and exchange rate by using wavelet analysis, also this study can contribute to the literature review through three ways:

1. Earlier literature review extensively emphases on time-series methodologies to measure and examine co-movements, whereas this study focuses to measure the relationship between exchange rates and crude oil prices by using wavelet transform coherence (WTC). Investigating the co-movements at time and frequency span of time to explain the co-movements of exchange rate and crude oil for importing and exporting countries including the emerging and developed countries is the main contribution of the paper.
2. In this study we focus on the different crude oil benchmarks: Organization of Petroleum Exporting Countries (OPEC) basket crude oil prices are applied for Emerging countries in Asia; West Texas Intermediate (WTI) crude oil price is applied for US and Brent crude oil price is applied for Europe countries.
3. In this paper we used real crude oil price which is nominal value adjusted for inflation instead used the nominal oil prices. The real crude oil price is adjusted for general price level changes over time such as deflation and inflation. This adjustment gives us full picture of oil prices for various years as if the value of the dollar were constant.

3. METHODOLOGY AND DATA

The methodologies deal with four approach analysis: (i) The Continuous Wavelet Transform (CWT) and (ii) Wavelet Transform Coherence (WTC). These issues will be dealt with in turn.

3.1. The Continuous Wavelet Transform (CWT)

The continuous wavelet transform technique (CWT) is contained to both frequency and time-series having 0 averages. The main characteristics because to use the CWT is that characterised by localising continuous wavelet transform in frequency (Δω) and time (Δt) or in both. Also, another advantage to use the CWT is to remove the nose in the time-series. CWT is exposed by Heisenberg's indeterminacy principle (also known as uncertainty principle) that tradeoff exists between localisation in frequency and time. It is most important to define the frequency (Δω) and time (Δ*t*), this is because there is a minimum limit for the uncertainty product between frequency and time (Δω.Δ*t*). From the previous empirical of Morlet wavelet, which is usually used in studies, is defined as following:

$$\psi_0(\eta) = \frac{1}{\pi^{0.25}} e^{i\omega_0\eta}\, e^{0.5\eta^2} \quad (1)$$

Where the η and ω_0 is the dimensionless of the time and frequency respectively. In the Morlet wavelet approach used the frequency ω_0 is almost equal 6. This is because it is an appropriate option for feature extraction which leads to provide a good balance between the time and frequency localisation. The Morlet wavelet approach is applied to the wavelet as band pass filter to the variables time-series. The wavelet approach is stretched in time by varying its scale which is donated by (s) in this paper, consequently that η = t multiply by s (*s*.*t*) and normalising it to have energy unit. In the Morlat wavelet (with frequency ω_0 equal 6) the Fourier period (denoted by λ_{wt}) which is often equal to the scale 1.03s. The continuous wavelet transforms of a time-series X_n where n = 1., N with uniform time steps γt which is defined as the convolution of X_n with the normalised and scale wavelet, we defined as

$$W_n^X(s) = \sqrt{\frac{\gamma t}{s}} \sum_{n'=1}^{n} X_{n'} \vartheta 0\left[\left(n' - n\right)\frac{\gamma t}{s}\right] \quad (2)$$

Where $\left|W_n^X(s)\right|^2$ is defined as the wavelet power, on the other side, the complex argument of $W_n^X(s)$ can be used to interpret as the local phase. The continuous wavelet transform (CWT) approach has edge artifacts. This is because the wavelet is not totally localised in time, which must address by introducing Cone of Influence (COI). We noted that the introducing Cone of Influence (COI) as the area in which the $\left|W_n^X(s)\right|^2$ (which is a wavelet power) caused by a discontinuity at the edge dropped to e^{-2} of the value at the edge artifacts. The statistically significant of the $\left|W_n^X(s)\right|^2$ is assessed through to the null hypotheses H_0 whereas the power spectrum (P_K) background is usually used to generate statistical stationary process (Shahbaz and Rahamam, 2010).

According to the Torrence and Compo (1999) estimated the red noise as well as white noise wavelet power spectra. White and red noise estimated have been derived from the corresponding distribution following the spectrum of wavelet power at each scale (s) and time (n), so the corresponding distribution of wavelet power spectrum can be defined as:

$$D\left(\frac{\left|W_n^X(s)\right|^2}{\sigma_X{}^2} < P\right) = 0.50 * P_k \chi_v^2(p) \quad (3)$$

Where, *v* is usually equal to one for real and two for complex wavelet approach.

3.2. Wavelet Transform Coherence (WTC)

Following Fourier spectral method, we move to define Wavelet Transform Coherency (WTC). The WTC is a ratio of the cross-spectrum to the product of the spectrum of each time series. This approach suggests local correlation between two variables (exchange rate and oil prices) time series within frequency bands and time intervals. WTC shows a high resemblance if coherence is closed to one otherwise there is no relationship between the two variables time series. In addition, The Wavelet power spectrum also displays the variance of the time series. If Wavelet power spectrum has a large power this indicates there is a large power. The covariance between the two variables (exchange rate and oil price) time series are represented by another approach such as Cross Wavelet (CWT) power following all scales or frequencies.

According to Aguiar-Conraria et al. (2008) defines Wavelet Coherency as *"the ratio of the cross-spectrum to the product of the spectrum of each series and can be thought of as the local (both in time and frequency) correlation between 2 time-series."*

Therefore, Torrence and Webster (1999) defined the Wavelet Coherence (WTC) of two variables (exchange rate and oil price) time series as following:

$$R_n^2(s) = \frac{\left|S\left(s^{-1}W_n^{XY}(s)\right)\right|^2}{S\left(s^{-1}\left|W_n^X(s)\right|^2\right).S\left(s^{-1}\left|W_n^Y(s)\right|^2\right)} \quad (4)$$

Where, $R_n^2(s)$ is the value of wavelet squared coherency and (s) stands for a smoothing operator. It is a traditional coefficient of the correlation definition that is helpful in thinking of the WTC as a localised coefficient of the correlation following series time frequency-space.

We rearrange the equation (3) once smoothing operator is equalant to one and smoothing operator (s) as a convolution in scale and time:

$$S(W) = S_{scale}\left(S_{time}\left(W_n(s)\right)\right) \quad (5)$$

Where, and S_{time} denotes smoothing in time and the S_{scale} indicates smoothing along the wavelet scale axis. The scale convolution is done by regular window and time of convolution is specified by using Gaussian (Torrence and Compo, 1999). The functional form of smoothing spectrum power following Morlet wavelet is articulated as following:

$$S_{scale}(W)I_n = \left(W_n(s) * c_2 \Pi(0.6s)\right)I_n \quad (6)$$

And

$$S_{time}(W)I_s = \left(W_n(s) * c_1^{\frac{-t^2}{2s^2}}\right)I_s \quad (7)$$

Where, c_1 and c_2 are normalised constants whereas Π stands for the rectangle function. The scale decorrelation length for Morlet wavelet approach is empirical specified by 0.6. In practice, we define the normalised coefficients indirectly and coevolutions directly. The Monte Carlo simulation method is applied to assess the theoretical distributors of WTC. To examine the wavelet coherency (WTC) approach, we follow Aguiar et al. (1999) rather than Wavelet Cross Spectrum. Aguiar-Conraria et al. (1999, p. 648-49) provides two arguments for this: *"(1) the wavelet coherency has the advantage of being normalized by the power spectrum of the 2 time-series, and (2) that the wavelets cross spectrum can show strong peaks even for the realization of independent processes suggesting the possibility of spurious significance tests.*"

3.3. Data

This paper uses monthly time series data of several benchmark crude oil prices such as OPEC basket crude oil spot price for Asia-pacific and Middle East countries, Brent crude oil spot price for European, and WTI crude oil spot price for the U.S. Exchange rates time-series of oil importing countries such as Italy (USD/EUR), Spain (USD/EUR), France (USD/EUR), Germany (USD/EUR), Australia (USD/AUD), China (USD/CNY), Japan (USD/JPY), UK (USD/GBP), Thailand (USD/THB), Egypt (USD/EGP), India (USD/INR), Switzerland (USD/CHF), Brazil (USD/BRL), Turkey (USD/TRY), South Korea (USD/KRW), New Zealand (USD/NZD), Philippines (USD/PHP), Singapore (USD/SGD), Taiwan (USD/TWD), Belgium (USD/BEF), South Africa (USD/ZAR), Indonesia (USD/IDR), and Israel (USD/ILS). On the other hand, the exchange rates time-series of oil exporting countries such as Kuwait (USD/KWD), KSA (USD/SAR), Iraq (USD/IQD), UAE (USD/AED), Nigeria (USD/NAIRA), Russia (USD/RUB), Iran (USD/IRR), Venezuela (USD/VEF), Angola (USD/AON), Norway (USD/NOK), Kazakhstan (USD/KZT), Mexico (USD/MXN), and Canada (USD/CAD). The monthly data for the period starting from 1th January 2000 to 30th April 2020 has been considered. All the exchange rate data are obtained from "DataStream" and international financial statistics while the OPEC, BRENT, and WTI oil prices data were obtained from Bloomberg, Energy Information Administration, and OPEC website respectively.

4. EMPIRICAL RESULTS

In this study, we converted the exchange rates and oil prices time series into logarithm to obtain the efficient and unbiased findings. The results of descriptive statistics of monthly exchange rates and oil prices series, both variables are measured in log level are reported in Table 1. As we can see from the Table 1, the sample means of exchange rates are positive except in Kuwait exchange rate (USD/KWD), UK exchange rate (USD/GBP), and Turkey exchange rate (USD/TRY) and the sample mean of the oil prices (OPEC, BRENT, and WTI) are also positive. The values of standard deviations indicate that the exchange rates time series and oil prices time series have low volatile except Angola exchange rate (USD/AON), Iran exchange rate (USD/IRR), Venezuela exchange rate (USD/VEB), and Kazakhstan exchange rate (USD/KZT) have 86%, 75.6%, 79.6%, 26.2% respectively.

The measure of skewness suggests that the oil prices (OPEC, BRENT, and WTI) are negatively skewed while the some of the exchange rates series are positively skewed and other exchange rates series are negative. On the other hand, the measure of Kurtosis indicates that oil prices (OPEC, BRENT, and WTI) and

Table 1: Descriptive statistics of level and returns series

Exchange rate	Mean	Median	Maximum	Minimum	SD	Kurtosis	Skewness
Δ (USD/KWD)	−1.2311	−1.2298	−1.1768	−1.3216	0.0375	−0.6937	−0.3675
Δ (USD/SAR)	1.3223	1.3220	1.3248	1.3180	0.0006	10.1641	−0.4957
Δ (USD/AED)	1.3012	1.3012	1.3015	1.3004	0.0001	11.3529	−1.9757
Δ (USD/IQD)	7.3310	7.0948	8.0961	7.0421	0.3788	−0.0278	1.2770
Δ (USD/NAIJ)	4.9948	4.9212	5.7864	4.6043	0.2370	2.8876	1.4780
Δ (USD/RUB)	3.4907	3.4075	4.3470	3.1507	0.2800	1.8077	1.7198
Δ (USD/IRR)	9.1864	9.1822	10.3885	7.4702	0.7959	0.4900	−0.7398
Δ (USD/VEB)	7.8957	7.6741	9.2130	6.4804	0.7563	−0.7735	−0.1544
Δ (USD/CAD)	0.1865	0.1641	0.4706	−0.0444	0.1545	−1.1691	0.3200
Δ (USD/AON)	4.1430	4.4647	5.1164	1.7478	0.8596	2.6369	−1.8509
Δ (USD/NOK)	1.9145	1.8702	2.2365	1.6215	0.1667	−1.0482	0.4054
Δ (USD/KZT)	5.0645	5.0073	5.8979	4.8003	0.2617	3.5324	2.0657
Δ (USD/MXN)	2.4920	2.4448	3.0610	2.2065	0.1924	0.4293	0.8436
Δ (USD/EUR)	0.0962	0.0993	0.1584	−0.0122	0.0444	0.1479	−0.6390
Δ (USD/AUD)	0.6034	0.6352	0.6890	0.4205	0.0774	−0.3742	−0.8272
Δ (USD/CHN)	2.1139	2.1137	2.1147	2.1136	0.0004	1.2411	1.6168
Δ (USD/JPY)	4.7461	4.7554	4.8873	4.6550	0.0697	−1.3026	0.2431
Δ (USD/GBP)	−0.3889	−0.3734	−0.3386	−0.4929	0.0413	0.7062	−1.2566
Δ (USD/THB)	3.7457	3.7670	3.8202	3.6217	0.0674	−0.9647	−0.7355
Δ (USD/EGP)	1.3403	1.3519	1.5320	1.2324	0.0902	−0.7697	0.4415
Δ (USD/BRZ)	0.7385	0.6752	1.0390	0.5559	0.1564	−1.2495	0.5110
Δ (USD/IND)	3.8319	3.8426	3.8786	3.7741	0.0342	−0.9134	−0.6124
Δ (USD/CHF)	0.5225	0.5116	0.5795	0.4642	0.0320	−0.8150	0.4119
Δ (USD/TRY)	−0.1286	−0.3790	0.4923	−0.6051	0.3978	−1.7255	0.3589
Δ (USD/KRW)	7.1004	7.1331	7.1916	7.0118	0.0713	−1.9678	−0.1535
Δ (USD/NZD)	0.8275	0.8577	0.9200	0.6653	0.0728	−0.4279	−0.8491
Δ (USD/PHP)	3.8649	3.9135	3.9754	3.7025	0.0939	−1.1580	−0.6735
Δ (USD/SGD)	0.5658	0.5582	0.6097	0.5160	0.0268	−1.0349	0.2704
Δ (USD/TWD)	3.4865	3.4847	3.5696	3.4187	0.0522	−1.5079	0.2036
Δ (USD/BEF)	3.7936	3.7967	3.8557	3.6852	0.0444	0.1478	−0.6389
Δ (USD/ZAR)	2.0571	2.0504	2.4557	1.8136	0.1639	1.1434	1.0088
Δ (USD/ILS)	1.4259	1.4217	1.5092	1.3892	0.0267	2.7035	1.4048
Δ (USD/IDR)	9.1396	9.1444	9.3349	8.8930	0.1323	−0.7535	−0.3010
ΔOPEC*	4.0212	4.0805	4.8969	2.9648	0.4865	−1.1154	−0.2687
ΔBRENT*	4.0320	4.0659	4.8882	2.9291	0.5393	−1.1781	−0.2148
ΔWTI*	3.9985	4.0252	4.9129	2.9189	0.5385	−1.2338	−0.1487

*OPEC: Oil crude for Asia and Middle East, BRENT: Crude Oil Price for Euro, WTI: Crude Oil Price for US, SD: Standard deviation

exchange rates series have more platykurtic distribution relative to normal distribution except Saudi exchange rate (USD/SAR), United Arab Emirates exchange rate (USD/AED), and Kazakhstan exchange rate (USD/KZT) have demonstrated excess kurtpsis which suggests that that distributions of those exchange rates series are leptokurtic compare to a normal distribution.

To examine the stationarity of the exchange rates and oil price time-series, we use in this paper the standard procedure of testing for unit root-that is, the ADF test, such that the lag length is selected based on the AIC. The Tables 2-4 results show that all the exchange rates series and oil price series are non-stationary in levels. But in first differences, all variables are stationary at the 1% level except the Egypt exchange rate (USD/EGP) in second differences.

Wavelet coherence (WTC) approach is applied to measure coherence and phase lag between exchange rates and oil prices (OPEC, Brent, and WTI) series in both frequency and time (Chang and Glover, 2010). Cause-effect analysis can be performed by using WTC approach. The phase differences are measured by using the introducing Cone of Influence (COI) test between the components of the both variables time series. In addition, the wavelet transform coherence (WTS) approach is also considered as localised correlation. Figures 1 and 2 show the wavelet coherence (WTC) plot, the vertical and horizontal axis indicates time and frequency domain respectively. In this paper, we use the Monte Carlo simulations to estimate the 5% significance level. The Figures follow a color code for coherency measure from dark blue (which means is near to 0) refers to low coherency to yellow (which means near to 1) refers to high coherency.

Table 2: Unit root test results

Oil price	ADF test H_0: Variable is non-stationary	Probability
Oil crude prices		
OPEC	−2.095234	0.2469
ΔOPEC	−10.03119***	0.0000
BRENT	−2.055674	0.2631
ΔBRENT	−9.682688***	0.0000
WTI	−2.321425	0.1662
ΔWTI	−9.518902***	0.0000
Test critical values		
Level 1%	−3.462095	
Level 5%	−2.875398	
Level 10%	−2.574234	

***Means significant at 1% level. Δ: First difference

Table 3: Unit root test results

Exchange rate	ADF test H_0: Variable is non-stationary	Probability
Exporting major countries		
(USD/KWD)	−1.905143	0.3295
Δ (USD/KWD)	−8.233743***	0.0000
(USD/SAR)	−3.883592***	0.0026
Δ (USD/SAR)	-	-
(USD/AED)	−5.111824***	0.0000
Δ (USD/AED)	-	-
(USD/IQD)	−1.279263	0.6393
Δ (USD/IQD)	−12.51104***	0.0000
(USD/NAIJ)	1.399626	0.9990
Δ (USD/NAIJ)	−9.894366***	0.0000
(USD/RUB)	−0.442164	0.8982
Δ (USD/RUB)	−10.41061***	0.0000
(USD/IRR)	0.106369	0.9656
Δ (USD/IRR)	−10.40076***	0.0000
(USD/VEB)	0.774869	0.9934
Δ (USD/VEB)	−12.99519***	0.0000
(USD/CAD)	−1.427954	0.5680
Δ (USD/CAD)	−9.756496***	0.0000
(USD/AON)	−0.368859	0.9107
Δ (USD/AON)	−9.436571***	0.0000
(USD/NOK)	−1.516851	0.5233
Δ (USD/NOK)	−9.835023***	0.0000
(USD/KZT)	−0.234620	0.9306
Δ (USD/KZT)	−8.138919***	0.0000
(USD/MXN)	−0.406364	0.9045
Δ (USD/MXN)	−10.58144***	0.0000
Test critical values		
Level 1%	−3.462095	
Level 5%	−2.875398	
Level 10%	−2.574234	

***Means significant at 1% level. Δ: First difference

Table 4: Unit root test results

Exchange rate	ADF test H_0: Variable is non-stationary	Probability
Importing major countries		
(USD/AUD)	−1.650444	0.4550
Δ (USD/AUD)	−9.969796***	0.0000
(USD/EUR)	−1.760145	0.3996
Δ (USD/EUR)	−10.34663***	0.0000
(USD/CHN)	−1.292846	0.6330
Δ (USD/CHN)	−3.041393**	0.0328
(USD/GRM)	−1.806789	0.3765
Δ (USD/GRM)	−10.34619***	0.0000
(USD/JPY)	−1.589632	0.4861
Δ (USD/JPY)	−11.44630***	0.0000
(USD/FRA)	−1.806797	0.3765
Δ (USD/FRA)	−10.34610***	0.0000
(USD/GBP)	−1.289912	0.6344
Δ (USD/GBP)	−10.92309***	0.0000
(USD/ITA)	−1.806796	0.3765
Δ (USD/ITA)	−10.34612***	0.0000
(USD/SPN)	−1.806794	0.3765
Δ (USD/SPN)	−10.34612***	0.0000
(USD/THB)	−1.249601	0.6528
Δ (USD/THB)	−9.855038***	0.0000
(USD/EGP)	2.187747	0.9999
Δ (USD/EGP)	4.123257	1.0000
ΔΔ (USD/EGP)	−4.629728***	0.0002
(USD/BRL)	−1.703320	0.4281
Δ (USD/BRL)	−9.871144***	0.0000
(USD/INR)	−0.571816	0.8728
Δ (USD/INR)	−11.12083***	0.0000
(USD/CHF)	−1.727596	0.4159
Δ (USD/CHF)	−11.81429***	0.0000
(USD/PHP)	−1.937754	0.3145
Δ (USD/PHP)	−10.31914***	0.0000
(USD/IDR)	−1.264846	0.6458
Δ (USD/IDR)	−10.40186***	0.0000
(USD/BEF)	−1.760127	0.3996
Δ (USD/BEF)	−10.34636***	0.0000
(USD/NZD)	−1.757506	0.4009
Δ (USD/NZD)	−10.43488***	0.0000
(USD/TWD)	−2.489318	0.1195
Δ (USD/TWD)	−9.469717***	0.0000
(USD/KRW)	−2.222612	0.1990
Δ (USD/KRW)	−10.37276***	0.0000
(USD/TRY)	0.846528	0.9946
Δ (USD/TRY)	−9.819358***	0.0000
(USD/TRY)	−1.741705	0.4088
Exchange rate	ADF test H_0: Variable is non-stationary	Probability
Δ (USD/TRY)	−10.37332***	0.0000
(USD/ZAR)	−0.933036	0.7762
Δ (USD/ZAR)	−10.41218***	0.0000
Test critical values		
Level 1%	−3.462095	
Level 5%	−2.875398	
Level 10%	−2.574234	

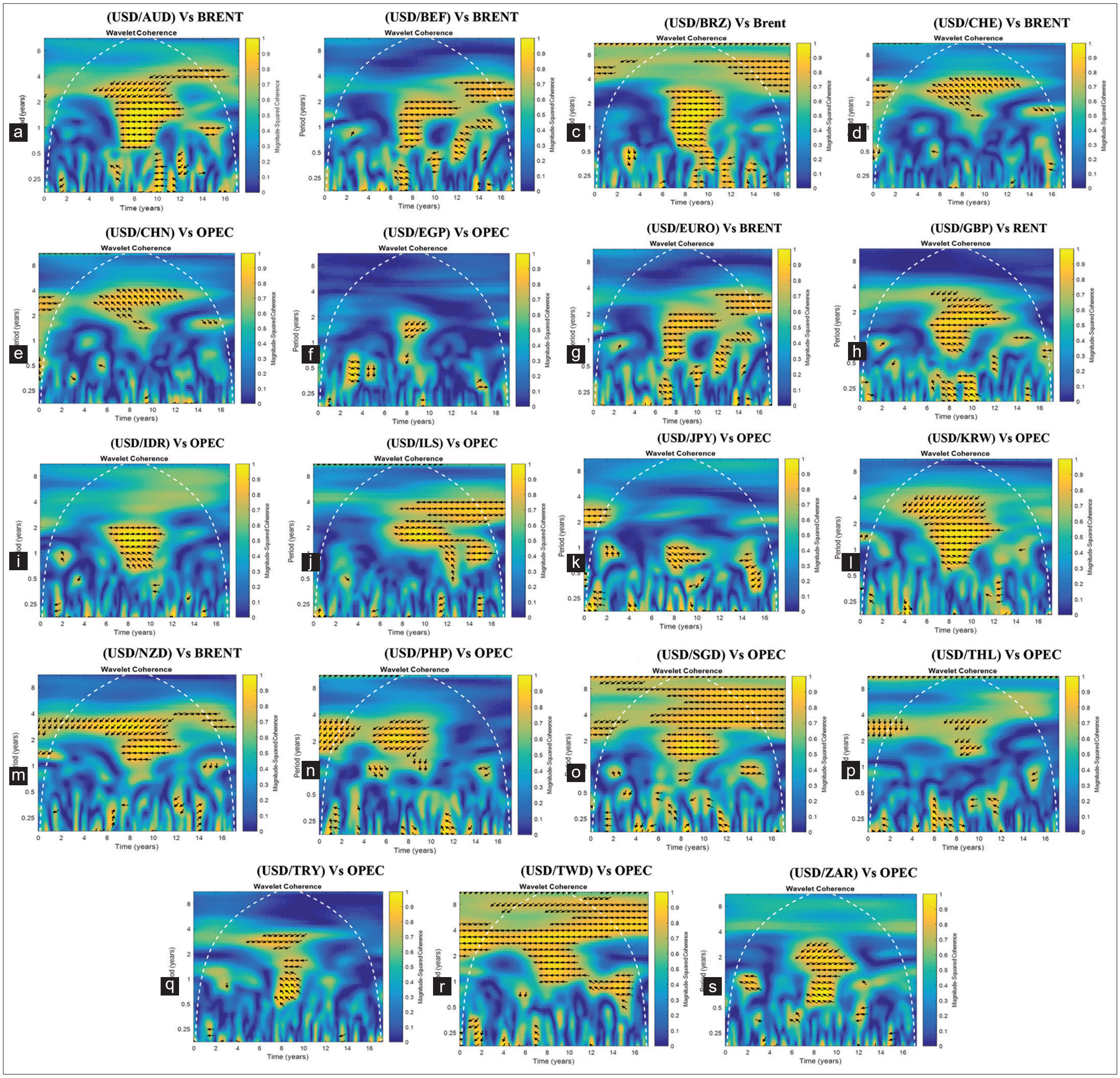
***Means significant at 1% level. Δ: First difference

In the plot of the Wavelet coherence approach, the vertical axis represents time scales in monthly as frequencies while the horizontal axis shows time. Time scale (1) represents 2-5 months; Time scale (2) represents 5-10 months, Time scale (3) represents 10-20 months and so on. Usually, the time scales are described as low, medium, and high frequency, where low denotes long term dynamics, medium denotes the medium term, and high denotes the short term dynamics of the both time series, such as exchange rates and oil prices series.

Generally, "In the phase cyclical," such as arrows indicate to the right side, this means that variable time series have a positive effect and an increase in oil prices (OPEC, BRENT, and WTI) causes an rise of exchange rate. On the other hand, "Out of the phase cyclical", such as arrows indicate to the left side, this means that variable time series have a negative effect and an increase in oil prices causes a reduction of exchange rate. About the arrows direction e.g. (down or up) points whether it's lagging or leading the other time series. When the arrows are right and up direction which indicates that the exchange rates are lagging; when the arrows right and down direction indicate that exchange rates are leading. Similarly, when the arrows left and up direction indicate that the exchange rates are leading; and when the arrows left and down direction indicate that the exchange rates are lagging.

The empirical evidence presented in Figure 1, all graphs indicate the level of wavelet coherency (WTC), cyclical effect and lead-lag pattern between the exchange rates and oil price. As we can see from the Figure 2 the relationship (co-movements) was observed during the medium term as well as in the long term for most of the

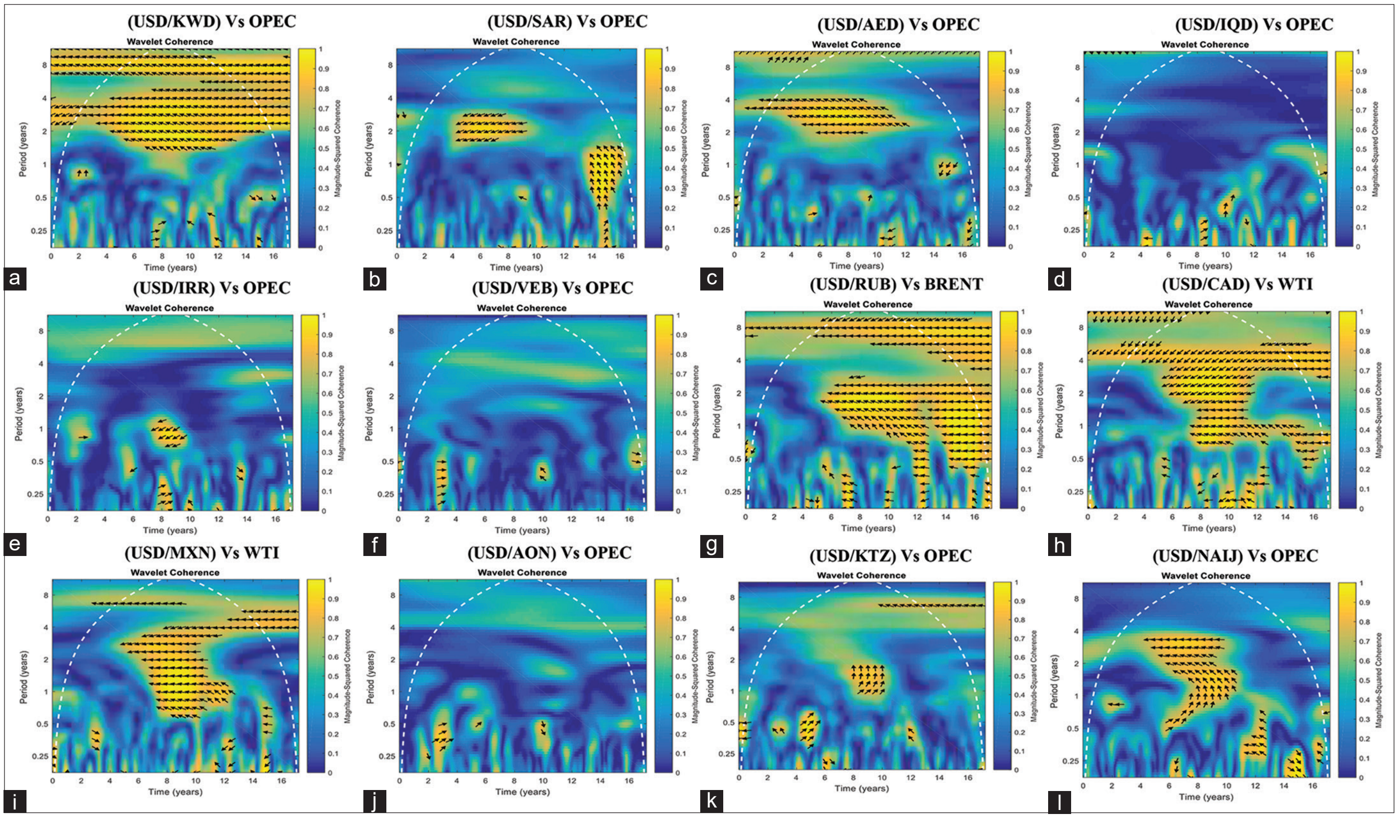
Figure 1: Exchange Rates and Oil Price for Exporting Countries– Wavelet Coherence (WTC). (a) (USD/AUD) versus BRENT, (b) (USD/BEF) versus BRENT, (c) (USD/BRZ) versus Brent, (d) (USD/CHE) versus BRENT, (e) (USD/CHN) versus OPEC, (f) (USD/EGP) versus OPEC, (g) (USD/EURO) versus BRENT, (h) (USD/GBP) versus RENT, (i) (USD/IDR) versus OPEC, (j) (USD/ILS) versus OPEC, (k) (USD/JPY) versus OPEC, (l) (USD/KRW) versus OPEC, (m) (USD/NZD) versus BRENT, (n) (USD/PHP) versus OPEC, (o) (USD/SGD) versus OPEC, (p) (USD/THL) versus OPEC, (q) (USD/TRY) versus OPEC, (r) (USD/TWD) versus OPEC, (s) (USD/ZAR) versus OPEC



importing countries. The plots of the wavelet coherence (WTC) of the oil prices and exchange rates display that, there is little or no relationship in higher frequencies or in the short term while there are possible co-movements that are found in medium term as well as in the long term.

The association between oil price and exchange rates for Brazil, Singapore, and Taiwan as observed from the Figure 1- Panel (c), (o), and (r) respectively is found to be high in both medium and long term. As we can see, the correlation is found to be high from 2000:01 to 2016:04. It is also observed from the graph that during 2006 to 2010 including the financial crisis period the oil price is leading to exchange rate of those countries in the medium and long term, whereas in the short term, exchange rate is lagging the oil price in those countries. Anti-cyclical effect is observed in all the three frequencies (short, medium and long term). The relation between oil price (OPEC) and Egypt Pound against USD is represented in Figure 1. – Panel (f). No, a significant negative relationship between Egypt Pound against USD (USD/EGP) and oil price is found during period of this study in both medium and long term. It is noteworthy

Figure 2: Exchange Rates and Oil Price for Exporting Countries– Wavelet Coherence (WTC). (a) (USD/KWD) versus OPEC, (b) (USD/SAR) versus OPEC, (c) (USD/AED) versus OPEC, (d) (USD/IQD) versus OPEC, (e) (USD/IRR) versus OPEC, (f) (USD/VEB) versus OPEC, (g) (USD/RUB) versus BRENT, (h) (USD/CAD) versus WTI, (i) (USD/MXN) versus WTI, (j) (USD/AON) versus OPEC, (k) (USD/KTZ) versus OPEC, (l) (USD/NAIJ) versus OPEC



that the period of high coherency was from 2008 to 2010. It is also observed from the figure that during the financial crisis period, the oil price is leading the exchange rate (USD/EGP) in the short term.

The rest panels on the Figure 1 depict the correlation between the exchange rates and oil price. The high correlation is observed in medium term in different period for each country. For example, between Turkey's exchange rate (USD/TRY) and oil price during the period from 2008 to 2011, South African exchange rate (USD/ZAR) and oil price during the period from 2006 to 2012, and between Euro countries exchange rates (USD/EURO) and oil price during the period from 2006 to 04:2018. In addition, it is observed from the above figures that in the medium term the exchange rates is lagging the oil price as well as a positive cyclical effect is also observed in the medium term.

In Figure 2, the plots wavelet coherence of the oil crude price and exchange rates for major importing countries, we can see the weak relationship between the oil crude price and exchange rates at higher frequencies with possible co-movements and discontinuities are found in both periods run medium as well as long run for Venezuela (USD/VEB), Iran (USD/IRR), and Iraq (USD/IQD) only.

The association between oil crude price and KWD against USD, between RUB against USD and oil price, and between oil price and CAD against USD as observed from the Figure 2 (a), (g), and (h) respectively is revealed to be high correlation in both in medium and long run. The correlation is revealed to be high from 2000 to 04:2020. Furthermore, we can see from the Figure 2 (a), (g), and (h), during the period of this study the exchange rates are leading the oil price in the medium and long run in Kuwait perspective only. In Russia and Canada case, we found that there is directional between the exchange rates and oil price in long term, while that there is bidirectional between the exchange rate and oil price from 2006 to 04:2014 in medium term in Russia, whereas, that there is bidirectional between the exchange rate and oil price in medium term from 2005 to 2012 in Canada perspective. Anti-cyclical effect is observed in all the three frequencies (short, medium and long run).

From Figure 2 (c) shows the association between UAE exchange rate against USD (USD/AED) and oil crude price. The high correlation is found during long term only. Cyclical effect and high coherency is observed from 2000 to 2012. It is also observed from the same figure that, during the period from 2000 to 2012, the UAE exchange rate (USD/AED) is lagging the oil price in the medium term as well as in the long term.

From Figure 2 (i), the correlation between Mexican peso against US Dollar (USD/MXN) and oil price is revealed to be high in the medium term. Cyclical effect and high coherency is observed from 2004 to 2012. It is also found from Figure 2 (e) that during the same period the exchange rate (USD/MXN) is leading the oil price. In addition, the relationship between exchange rate and oil price is inconclusive in long term.

5. CONCLUSION

In this study, we contribute to the literature through analysing the co-movement between exchange rates and oil price (OPEC, BRENT, and WTI) for major importing and exporting countries in the time and frequency domain by using continuous wavelet transform (CWT) and wavelet coherence (WTC) analysis from period 01:2000 to 04:2020. The ADF unit root test shows that that exchange rates and oil price time - series are non-stationary in level form and stationary in log first difference form except Egypt exchange rate in log second difference. We concluded that this paper has three significant results. Firstly, there is a weak or no co-movement between the exchange rates and oil price (OPEC, BRENT, and WTI) in the short term, but there is high frequency, and the visible co-movement is found in medium term as well as long term. Secondly, Dis-continuity in the co-relationship at both frequency scales as well as time is observed during period in this study. Finally, the lead-lag relationship changes across time and frequencies.

In importing countries, the high coherency between exchange rates and oil price is witnessed in Brazil, Singapore, and Taiwan in medium and long term while in Kuwait, Russia, and Canada for exporting countries. In addition, there is no co-movement between the exchange rates and oil price for Angola, Venezuela, Iraq, and Iran for exporting countries while in Egypt for importing countries in short, medium, and long term. It is noteworthy that high coherency between exchange rates and oil price (OPEC, BRENT, WTI) is witnessed across all the importing and exporting countries (except Angola, Venezuela, and Iraq) during financial crisis.

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