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Volatility Transmission between Oil Price and Exchange Rate

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ABSTRACT

This article presents a study on the transmission of oil price volatility to the exchange rates of 14 countries (net oil exporters and importers) during the period from January 02, 2000 to November 31, 2022. The aim is to compare the effect of oil price fluctuations on exchange rate volatility based on the country's nature. Using ARCH, GARCH, and GARCH-BEKK models, our results reveal that the real effective exchange rate is significantly linked to fluctuations in the real oil price for both categories of countries: oil importers and exporters. These findings have important implications for monetary, fiscal, inflationary, and trade policies for these countries.

Keywords: ARCH, GARCH, GARCH BEKK, Volatility, Oil Price, Exchange Rate
JEL Classifications: C22, E31, F31

1. INTRODUCTION

As one of the most crucial commodities, the existence of oil is essential for the global economy. Therefore, oil price volatility has a significant impact on the economy. Over the past decades, oil prices have experienced significant fluctuations that have had a significant effect on the global economy. In the 1970s, oil prices surged due to the oil crisis caused by an oil embargo imposed by exporting countries. This price increase had a significant impact on the global economy, especially on oil-importing countries. In the early 2000s, oil prices rose again due to the rapid growth in demand from countries like China and India. This increase was further fueled by geopolitical tensions and conflicts in oil-producing regions such as the Middle East. However, starting in 2014, oil prices experienced a sharp decline due to global oil oversupply, the growth of renewable energies, and reduced oil demand in certain countries. This price drop had significant consequences for oil-producing countries and businesses dependent on the oil industry. Recently, prices have started to rebound in 2021 due to economic recovery in some countries, OPEC's regulation of oil production, and escalating conflict in Ukraine, as well as shale oil production in the United States. Crude oil prices have diverse effects on macroeconomic aggregates (stock indices, inflation, GDP, trade balance, etc.), among which the effect on exchange rates sparks numerous controversies among policymakers and researchers. The relationship between oil prices and exchange rates has been extensively studied in economic literature. Economic theories offer different explanations for the relationship between these two variables. Some argue that the effect of oil price variations on exchange rates is weak and not significant (Atems et al., 2015). Others believe that these variations pose a major risk to the value of the national currency, meaning that an increase in oil prices can lead to the depreciation of the currencies of oil-importing countries against other currencies. This can be explained by the fact that the increase in oil import costs can negatively affect the economies of oil-importing countries, thereby reducing the demand for their currency (Lizardo and Mollick, 2010; Nusair and Kisswani, 2015; Anjum and Malik, 2019; Khan and Ahmed, 2024). On the other hand, some argue that oil price volatility leads to an appreciation of the national currency (Narayan et al., 2008; Pershin et al., 2016). This is partly because oil is widely traded in US dollars on international markets. Thus, when oil prices rise, the demand for US dollars may also increase, leading to an appreciation of the US dollar.

Other studies have found that the impact of oil price volatility on exchange rates varies depending on whether the country is an oil exporter or importer. In the 1980s, Krugman and Golub observed that an oil-exporting country may experience currency appreciation when oil prices are higher and currency depreciation when oil prices are lower. However, oil-importing countries may experience currency depreciation when oil prices increase. Recently, some studies have highlighted the existence of an asymmetric relationship between oil prices and exchange rates (Young et al., 2019, and Jungho 2021), meaning that the effects on exchange rates are not the same in case of oil price increases or decreases. This asymmetry can be explained by several factors, such as effects on the trade balance, capital flows, and market expectations.

In this context, the objective of this article is to study the transmission of oil price volatility to exchange rates in two parts: The first provides an overview of the empirical literature on the impact of oil price volatility on exchange rates. The second part focuses on an empirical analysis of the transmission of oil price fluctuations to exchange rates using monthly data for the period from 2000 to 2022, employing ARCH, GARCH, and GARCH-BEKK models (Vector Autoregression) to better understand the relationship between oil prices and exchange rates and to better model nonlinear behaviors.

2. LITERATURE REVIEW

Several studies have been conducted to examine the link between oil prices and the US dollar exchange rate, confirming the existence of a positive relationship, meaning that an increase in oil prices leads to dollar appreciation. For example, the work of Bénassy-Quéré and Mignon (2005) and Bénassy-Quéré et al., (2007) highlighted the existence of a long-term equilibrium relationship (cointegration) between crude oil prices and the real effective exchange rate: A 10% increase in oil prices leads to a 4.3% appreciation of the dollar. Causality tests conducted by the authors show that the causality runs from oil prices to the dollar exchange rate.

To assess the robustness of their results, Bénassy-Quéré et al., (2007) also consider the dollar in bilateral terms against the euro. The results again show an equilibrium relationship between the two variables for the period 1980-2004. A positive relationship is observed: an increase in oil prices is accompanied by a 9.5% appreciation of the dollar against the euro. Following these results, Coudert et al., (2007) sought to identify the channel through which the increase in oil prices is transmitted to the dollar. They adopt the theoretical framework of the Behavioral Equilibrium Exchange Rate (BEER) approach, which posits that the real exchange rate is determined by a set of long-term fundamentals. The authors focus on studying two fundamentals: The net external position of the United States and terms of trade. The results show that in the long run, the relationship between oil prices and the dollar does not seem to be mediated by terms of trade but by the net external position.

Chaudhuri and Daniel (1998) investigate 16 OECD countries and, using cointegration and causality tests, find that the non-stationary behavior of the US dollar exchange rate is due to the non-stationary behavior of real oil prices. Similar results were obtained by Amano and Van Norden (1998), who established a strong and interesting relationship between oil prices and real effective exchange rates of Germany, Japan, and the United States. Using data on the effective exchange rates of Germany, Japan, and the United States, they found that the real price of oil is the most important factor in the long-term determination of the real exchange rate.

Cashin et al., (2002) examined whether the real exchange rates of commodity-exporting countries move together with the real price of their commodity exports over time. They indicated that in many countries whose economies rely on commodities, the real prices of commodity exports and real exchange rates move in a similar long-term pattern.

Camarero et al. (2002) used cointegration techniques to study the relationship between real oil prices and the Spanish peseta.

Chen and Rogoff (2003) empirically examined the real exchange rate, focusing on three OECD countries (Australia, Canada, and New Zealand) where commodities represent a significant share of their exports. For Australia and New Zealand in particular, they found that the US dollar price of their commodity exports has a strong and stable influence on real exchange rates.

Spatofora and Stavrev (2003) estimated the equilibrium real exchange rate of Russia and confirmed a positive relationship between the real exchange rate and oil prices.

Akram (2004) confirmed the existence of a nonlinear negative relationship between oil prices and the Norwegian exchange rate, meaning that an increase in oil prices leads to the depreciation of the Norwegian krone. The magnitude of this effect is more significant when oil prices are outside the range of (14; 20 dollars) and when prices are declining. Indeed, the impact of oil price variations on the exchange rate is stronger when the level of oil prices is below 14 dollars than at a higher level.

Cashin et al. (2004) examined 58 commodity-exporting countries and found that commodity prices have an effect on real exchange rates for one-third of them.

Koranchelian (2005) found that the Balassa-Samuelson effect and real oil prices explain the long-term evolution of the real equilibrium exchange rate in Algeria. Similarly, Zalduendo (2006) found, through the application of a vector error correction model, that oil prices have a significant effect on the real equilibrium exchange rate in Venezuela. Issa et al. (2006) studied how energy prices affect the value of the Canadian dollar. Before 1993, they found that high energy prices led to currency depreciation. However, after 1993, high energy prices had the opposite effect, meaning that high prices led to the appreciation of the Canadian dollar. This result was obtained because Canada transitioned from being an energy importer to an energy exporter in 1993.

Sosunov and Zamulin (2006) demonstrated that the appreciation of the Russian ruble is fully consistent with the growth of oil export revenues during the period 1998-2005. Chen and Chen (2007), in a panel study of G7 countries, showed that real oil prices may have been the main source of real exchange rate fluctuations and that there is a positive relationship between oil prices and the real exchange rate.

Kalcheva and Oomes (2007) attempted to evaluate whether Russia suffers from the Dutch disease and found, through cointegration analysis, that the elasticity of the real exchange rate to oil prices is very close to 0.53.

Korhonen and Juurikkala (2007) determined the equilibrium real exchange rate for a sample of oil-dependent countries based on OPEC data covering the period 1975-2005. They found a clear, direct, statistically significant, and positive effect of oil prices on real exchange rates in the group of oil-producing countries. High oil prices lead to the appreciation of real exchange rates, with the elasticity of the real exchange rate to oil prices generally ranging between 0.4 and 0.5.

Habib and Manolova-Kalamova (2007) examined whether the real oil price has an impact on the real exchange rate of three major oil-exporting countries: Norway, Russia, and Saudi Arabia. They created measures of real effective exchange rates for Norway and Saudi Arabia (1980-2006) and Russia (1995-2006) and tested whether real oil prices and productivity differentials among 15 OECD countries influence real exchange rates. They found a long-term relationship between real oil prices and the real exchange rate in the case of Russia but no impact in the case of Norway and Saudi Arabia.

Malik and Ewing (2009) analyzed the transmission of volatility and shocks between five oil and major sector stock returns using bivariate GARCH. The results show evidence of shock and volatility transmission between oil prices and certain market sectors.

Aziz M. and Izraf A (2009) estimated the long-term effects of real oil prices and interest rate differentials on real exchange rates for a panel of 8 countries from 1980 to 2008. He found a positive and statistically significant impact of real oil prices on the real exchange rate for oil-importing countries, implying that an increase in oil prices leads to a real depreciation of the exchange rate. However, there is no evidence of a long-term relationship between real oil prices and the real exchange rate in a panel of net oil-exporting countries.

Choi and Hammoudeh (2010) used data from the period 1990-2006 to study the volatility behavior of oil and industrial commodity markets and stock markets. Their results show high and low volatility between the prices of five commodities and the S&P 500 index. The GARCH-CCC model shows that since the Iraq war in 2003, correlations have increased for all products, while correlations with the US S&P 500 index have decreased.

El Hedi Arouri et al. (2011) examined the transmission of returns and volatility between global oil prices and stock markets of Gulf Cooperation Council (GCC) member countries during the period 2005-2010 using a generalized VAR-GARCH approach. Their results showed a significant effect of oil price volatility on the stock markets of three GCC countries (Bahrain, Oman, and Qatar). This effect is positive for Qatar and Oman, while it is negative for Bahrain.

Selmi et al. (2012) studied the impact of oil price variability on the real exchange rate for two small African oil-exporting and oil-importing countries: Tunisia and Morocco, from 1972 to 2010. Using a GARCH model, this study revealed that the oil price has a negative and significant effect on the real exchange rate in both categories of countries.

Mensi et al. (2013) applied a VAR-GARCH model to daily data from certain commodity markets and stock markets from January 3, 2000, to December 31, 2011. They demonstrated a significant correlation and volatility spillover between commodity markets and stock markets.

Ghorbel and Boujelbene (2013) applied a multivariate GARCH model (BEKK and DCC) to oil prices and stock markets for the period from May 2005 to December 2011 for the United States, GCC countries, and BRIC countries (Brazil, Russia, India, and China). Their results indicate persistent volatility in the crude oil market and the related stock markets.

By applying the GARCH-VAR model to Saudi Arabia's data from January 1, 2007, to December 31, 2011, Suliman (2013) demonstrated that oil price fluctuations lead to an increase in stock returns volatility.

Savari et al., (2014) using cointegration techniques showed the existence of a long-term relationship between oil revenues and the Iranian real exchange rate from 1981 to 2012.

Rafee and Hidhayathulla (2014), from 1972 to 2013, attempted to study the impact of oil prices on the exchange rate of the Indian rupee against the US dollar using multiple regression models. The results showed that the continuous increase in oil prices leads to the depreciation of the rupee.

Tsuji (2017) used a DCC-MEGARCH model to analyze the transmission of returns, volatility spillovers, and optimal hedging between oil futures contracts and oil stocks in oil-exporting countries (United States, Russia, Australia, and Canada, etc.). He proved the existence of unidirectional transmission of returns from oil futures contracts to oil stocks.

Osuji (2015) studied the impact of oil prices on the USD-Naira exchange rate from January 2008 to December 2014. The result of the vector autoregressive (VAR) model showed a unidirectional causality from oil prices to the exchange rate.

Narayan et al., (2019) used autoregressive distributed lag (ARDL) models to estimate the long-term effect of oil price variations on the Indonesian rupiah exchange rate in terms of dollars from 1986 to 2017. The results of this study prove that the cointegration relationship between oil prices and the real exchange rate is sensitive to the different exchange rate regimes adopted by Indonesia. In the case of a flexible exchange rate regime starting from August 1997, an increase in oil prices leads to an appreciation of the Indonesian rupiah exchange rate in terms of dollars in the long run. However, there is no evidence of a long-term relationship in the case of a managed floating exchange rate regime (November 1978-July 1997).

Baghestani et al., (2019) examined whether oil price fluctuations (Brent Crude) accurately predict the direction of real effective exchange rate variation for BRICS countries (Brazil, Russia, India, and China) during the period 1994-2017.

They found that, for net oil-exporting countries (Brazil and Russia), except for the period 1994-2007, oil price movements accurately predict the direction of exchange rate variation (for India, this predictive ability is observed during the period 2008-2012). As for the net oil-importing country (China), oil prices have no significant predictive power for the direction of the real effective exchange rate.

Jung et al., (2020) used a nonlinear autoregressive distributed lag (NARDL) model and Granger causality tests to empirically study the existence of long-and short-term asymmetric relationships between the US Dollar-Canadian dollar exchange rate and oil prices from January 1982 to March 2019. Referring to monthly data, the results of this study confirm the existence of a bidirectional long-term cointegration relationship between the price of oil (WTI) and the real effective exchange rate. According to the pairwise Granger causality test, the causal relationship between the variables indicates the existence of a causality relationship at the 5% threshold from oil prices (WTI) to the real effective exchange rate only in the short term.

Suliman and Abid (2020) studied the relationship between oil prices and the real exchange rate of the Saudi riyal through an empirical analysis using an autoregressive distributed lag (ARDL) model on monthly data for the period from January 1986 to March 2019. In the short term, the results show a unidirectional relationship from oil prices to exchange rates, while in the long term, this relationship is bidirectional. The estimation of the ARDL model indicates that a 1% increase in oil prices tends to depreciate the Saudi riyal against the US dollar by 2.4%.

Ahmad et al., (2020) analyzed the relationship between oil price fluctuations and exchange rate volatility in two major oil-importing countries (China and India). To examine this relationship, they applied the GARCH model to high-frequency daily time series data (at a 5-min interval) covering the period from January 1, 2013, to October 31, 2019. They found that in the case of India, an increase in oil prices (Brent) leads to an increase in the value of the Indian rupee against the US dollar. However, for China, oil price variations have no significant effect on the exchange rate.

Alam et al., (2020) employed cointegration techniques and a vector error correction model to study the impact of oil prices on the Indian rupee exchange rate in terms of dollars using monthly data from January 2001 to May 2020. They found a positive relationship between oil prices and the exchange rate in the short term. However, this relationship is negative in the long term between these two variables. Furthermore, the result of the Wald test indicates the short-term causality of crude oil prices to the exchange rate.

Ahmed and Huo (2021) applied a tri-variate GARCH-BEKK model to oil prices and stock markets for the period from May 2005 to December 2011 for the United States, GCC countries, and BRIC countries (Brazil, Russia, India, and China). Their results indicate the presence of persistent volatility in the crude oil market and the related stock markets.

Jungho (2021) tested whether asymmetric fluctuations in oil prices influence the real exchange rate of six OPEC member countries (Algeria, Kuwait, Nigeria, Saudi Arabia, United Arab Emirates, and Venezuela) through empirical analysis using NARDL models from 2000 to 2017. His estimation of the NARDL model indicated that crude oil prices have an asymmetric effect on real exchange rates in the short and long term for OPEC members with a floating exchange rate regime, such as Algeria and Nigeria. However, there is no evidence of an asymmetric effect for OPEC members with a fixed exchange rate regime, such as Kuwait and Saudi Arabia.

Hameed et al., (2021) studied the dynamic effects of different oil shocks on the real effective exchange rates of the top 5 oil-importing countries (Pakistan, India, China, Japan, and Germany) and the top 5 net oil-exporting countries (United Arab Emirates, Canada, Iraq, Russia, and Saudi Arabia) using a structural vector autoregression model during the period from January 2011 to December 2016.

The results reveal a bidirectional causal relationship between oil prices and the exchange rate for all countries in the sample. However, oil price fluctuations have a greater influence on the exchange rates of oil-exporting countries than oil-importing countries. An increase in oil prices leads to a depreciation pressure on the exchange rate of oil-exporting countries, while there is an appreciation pressure on the exchange rate of oil-importing countries.

Saidu et al., (2021) used linear regression models (ARDL) and nonlinear regression models (NARDL) to estimate the long-term and short-term asymmetric effects of oil price fluctuations on the exchange rate of 6 net oil-importing countries in Africa (South Africa, Morocco, Ivory Coast, Kenya, Ghana, and Senegal) using quarterly data from 1983 Q2 to 2018 Q4. The results of their study indicate a positive effect of oil price variations on the exchange rate in all cases, except for Morocco, where the effect is negative, suggesting that an increase in oil prices is associated with the depreciation of the South African rand, Ivorian franc, Kenyan shilling, Ghanaian cedi, and Senegalese franc, while the Moroccan dirham appreciates.

The results also suggest that oil prices have an asymmetric effect on the exchange rate in the short and long term, although it varies across countries, namely Ivory Coast, Ghana, and Senegal. In South Africa, Morocco, and Kenya, a symmetric long- and short-term relationship is identified. A positive increase in oil prices has a significant impact on the exchange rate of Senegal, while a negative decrease in oil prices is observed in Ivory Coast and a negative increase in oil prices in Ghana and Senegal.

Recently, Bouzizi and al et al., (2022) studied the effects of conditional volatility (instantaneous variability) of oil prices on the exchange rate and financial market returns for a panel of 3 countries: Germany, Japan, and the United States, from May 1987 to December 2019. The authors used daily data to examine the reaction of stock markets and the exchange rate to oil price fluctuations. They employed GARCH models, which are an extension of the ARMA model introduced by Box and Jenkins (1971). This study, through the use of tests on daily data, identified the speed and intensity of dynamic interactions between oil prices, exchange rates, and stock indices. Firstly, the analysis of conditional variance confirms the existence of a long-term equilibrium relationship (cointegration relationship) between crude oil prices and the exchange rate for different economies. Furthermore, by using cointegration theory and Granger causality, the authors confirmed the existence of a unidirectional causal relationship from oil price volatility to exchange rates for the three developed countries.

Zhang et al., (2022) studied the response of six foreign exchange markets (Switzerland, Australia, Canada, UK, Japan, and the US) to shocks affecting oil prices from December 19, 2005, to October 19, 2021, using a time-varying stochastic volatility vector autoregression model (TVP-SVAR-SV). They highlighted that the response of exchange markets to oil price variations can vary significantly depending on whether the increase in oil prices comes from a demand shock, a supply shock, or speculation. The results of this study show, firstly, that the impact of oil shocks on exchange rates is most significant when the lag is 1 day. Secondly, the analysis of time-varying impulse response functions shows that an increase in oil prices due to a demand shock has the highest effect on the exchange rate, while an increase due to a supply shock has the lowest effect. Furthermore, oil shocks resulting from speculative risk make the exchange rate more volatile.

3. PRESENTATION OF THE SAMPLE AND ECONOMETRIC METHODOLOGY

3.1. Sample Presentation

The sample for our study consists of 10 net oil-exporting countries: Tunisia, Saudi Arabia, Germany, Cameroon, Italy, Mexico, Nigeria, Norway, Poland, and Russia, and 4 net oil-importing countries: Morocco, the United States of America, Japan, and China. Crude oil price data is collected from the US Energy Information Administration (E.I.A). As for the real effective exchange rate data, it is obtained from the International Financial Statistics (I.F.S), collected by the International Monetary Fund (I.M.F). The data used is monthly and observed between January 02, 2000 and November 31, 2022, totaling 275 observations for each variable.

The specifications for the variables are as follows:

- OPWTI: Crude oil price (WTI)
- REERALLEM: Real effective exchange rate of Germany
- REERARABI: Real effective exchange rate of Saudi Arabia
- REERCAME: Real effective exchange rate of Cameroon
- REERCHINA: Real effective exchange rate of China
- REERITALIE: Real effective exchange rate of Italy
- REERJAPAN: Real effective exchange rate of Japan
- REERMAROC: Real effective exchange rate of Morocco
- REERMEXIQUE: Real effective exchange rate of Mexico
- REERNIGER: Real effective exchange rate of Niger
- REERNORW: Real effective exchange rate of Norway
- REERPOLA: Real effective exchange rate of Poland
- REERRUSSIE: Real effective exchange rate of Russia
- REERTUNISIE: Real effective exchange rate of Tunisia
- REERUSA: Real effective exchange rate of the United States of America.

3.2. Volatility Transmission: Econometric Approach

Based on the empirical literature review presented in the previous chapter, our approach consists of three steps. The first step examines the correlation between the selected series using both the parametric Pearson test and the non-parametric Spearman test. This correlation measures and compares the movements of the series as well as their ranking of each other. In the second step, the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model is applied to measure the magnitude of volatility in the selected series. The GARCH (1,1) model represents the most accessible and robust design within the volatility family of models (Engle and Patton 2007). This model, developed by Bollerslev (1986), is used to estimate the volatility returns of our sample, which includes both the oil market and the exchange markets of net oil-exporting and importing countries. The GARCH (1,1) model fundamentally represents the conditional variance, which is highlighted as a linear function of its lags. Furthermore, the conditional variance of all variables must depend on different lags. On the other hand, the first lag of squared residuals generates a mean equation and provides information on the volatility of the previous period.

In practice, the GARCH (1,1) model is characterized by a mean equation and a variance equation, which are respectively represented as follows:

$$r_t = \mu + \varepsilon_t \tag{1.1}$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \tag{1.2}$$

Where ω is strictly positive, and α and β are positive or zero.

The GARCH (1,1) model, like the ARCH model, has the advantage of simple and intuitive interpretation. The parameter ω can be interpreted as the volatility floor, meaning that any information that could not be directly transmitted due to market closures, holidays, and other factors is captured by this term. The parameters α reflect the impact of past shocks, while the β parameters describe the persistence of past shocks. In other words, the β parameters can be interpreted as the speed at which the volatility returns to its minimum level.

As a specific characteristic, the mean equation reveals the series' returns over time, which is the sum of the average returns denoted by μ. Meanwhile, the residual returns are denoted by ε_t. Additionally, the assumptions of the variance equation indicate that the value of the constant ω is greater than 0, followed by the values of α and β.

The third step involves estimating the GARCH model with the Baba-Engle-Kraft-Kroner (BEKK) parameterization, defined by Engle and Kroner (1995), and is expressed as follows:

$$H_t = C'C + \sum_{k=1}^{K}\sum_{i=1}^{q} A'_{ik}\varepsilon_{t-1}\varepsilon'_{t-i}A_{ik} + \sum_{k=1}^{K}\sum_{j=1}^{P} B'H_{t-j}B_{jk} \quad (3)$$

In the estimation of GARCH (1,1) BEKK model, the model becomes:

$$H_t = C'C + A'_{ik}\varepsilon_{t-1}\varepsilon'_{t-i}A_{ik} + B'H_{t-j}B_{jk} \quad (4)$$

Where "Ht" is a matrix representing the conditional variance-covariance matrix at time t, "C" is a diagonal matrix of initial variances representing the initial variances of each variable, while matrices "A" and "B" describe the volatility dynamics between the oil market and the exchange market of each country. Matrix "A" captures the impact of past errors on the conditional variance, while matrix "B" measures the impact of past covariances on the conditional covariance. Both matrices must be positive definite to ensure the positivity of the variance-covariance matrix "Ht".

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

The descriptive statistics presented in Table 1 show that the average price of crude oil (WTI) during the period from January 2000 to November 2022 is \$62.43480 per barrel. The minimum value (\$16.55) and maximum value (\$133.88) were observed in April 2020 and June 2008, respectively.

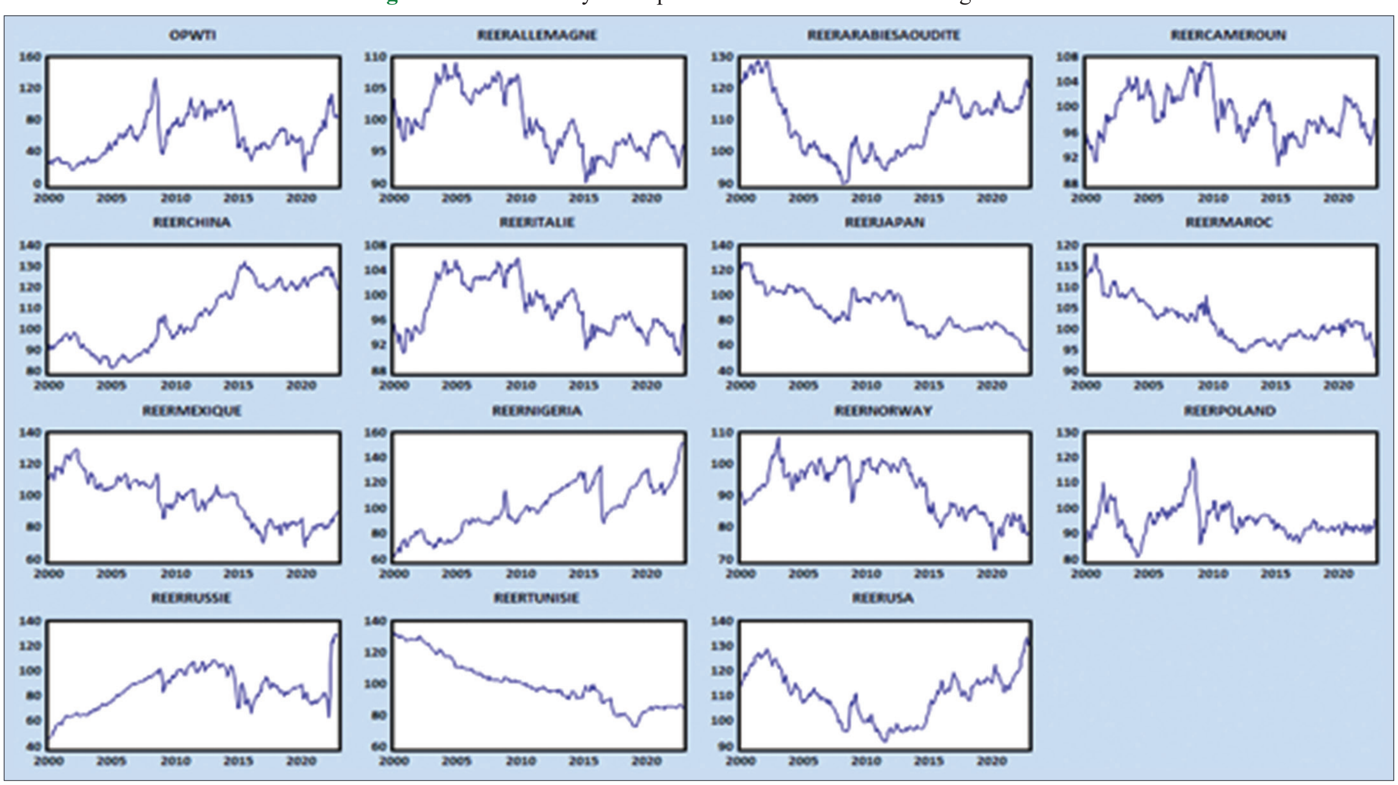
For net oil-exporting countries, the highest average real effective exchange rate (REER) over the period (January 2000-November 2022) is for Saudi Arabia, with a value of 108.9593, while the minimum value is for Norway, with a value of 92.56328. As for net oil-importing countries, the highest average real effective exchange rate is for America (110.8245). The maximum value of this rate is also held by America (133.8161), while the minimum value is for Japan (57.11065).

4.2. Volatility Study

Figure 1 represents the volatility of crude oil price (WTI) and the real effective exchange rate during the period from January 2020 to November 2022.

The figure above shows high volatility and large amplitude, generally exhibiting characteristics of volatility clustering. Additionally, the figure shows the presence of large-scale volatilities in 2008 and in the past 4 years, especially in 2022, which was exceptionally violent, with high volatilities and risks. However, the fluctuations in other years are relatively moderate, except for oil, where the fluctuations are sharp throughout the period. By comparing the different graphs, we can deduce that there are series that share a similar trend, such

Figure 1: The volatility of oil prices and real effective exchange rates



Source: Author's calculation

as the exchange rate of Saudi Arabia with that of Italy and Norway, the exchange rate of Mexico with that of Russia, and the exchange rate of Morocco with that of Poland.

Figure 2 displays the Q-Q plots of the selected variables' series. The presence of scattered points deviating from the normal distribution at the left and right tails strongly confirms the results obtained and displayed above. Through the descriptive statistical analysis above, we have found that the price of oil and the exchange rates of net oil-exporting and importing countries exhibit volatility characteristics (clusters), indicating the presence of periods where significant changes are followed by other significant changes and periods where small changes are followed by other minor changes.

4.3. Autocorrelation Matrix

Correlation is tested using the parametric Pearson test and the non-parametric Spearman test. The matrix presented in Tables 2 and 3 shows the results of these two tests, allowing us to assess the level of correlation between the variables.

The study of the parametric Pearson test, presented in the previous table, reveals the existence of a significant average correlation between the price of oil and the exchange market of net oil-exporting countries, except for Germany's exchange market. The correlation between these variables is positive for Cameroon, Italy, Nigeria, Norway, and Poland, while it is negative for Germany, Saudi Arabia, Mexico, Tunisia, and the United States of America.

For net oil-importing countries, all results are significant: the correlation between the price of oil and the real effective exchange rate of Morocco and Russia is strong, while it is weak for China and Japan.

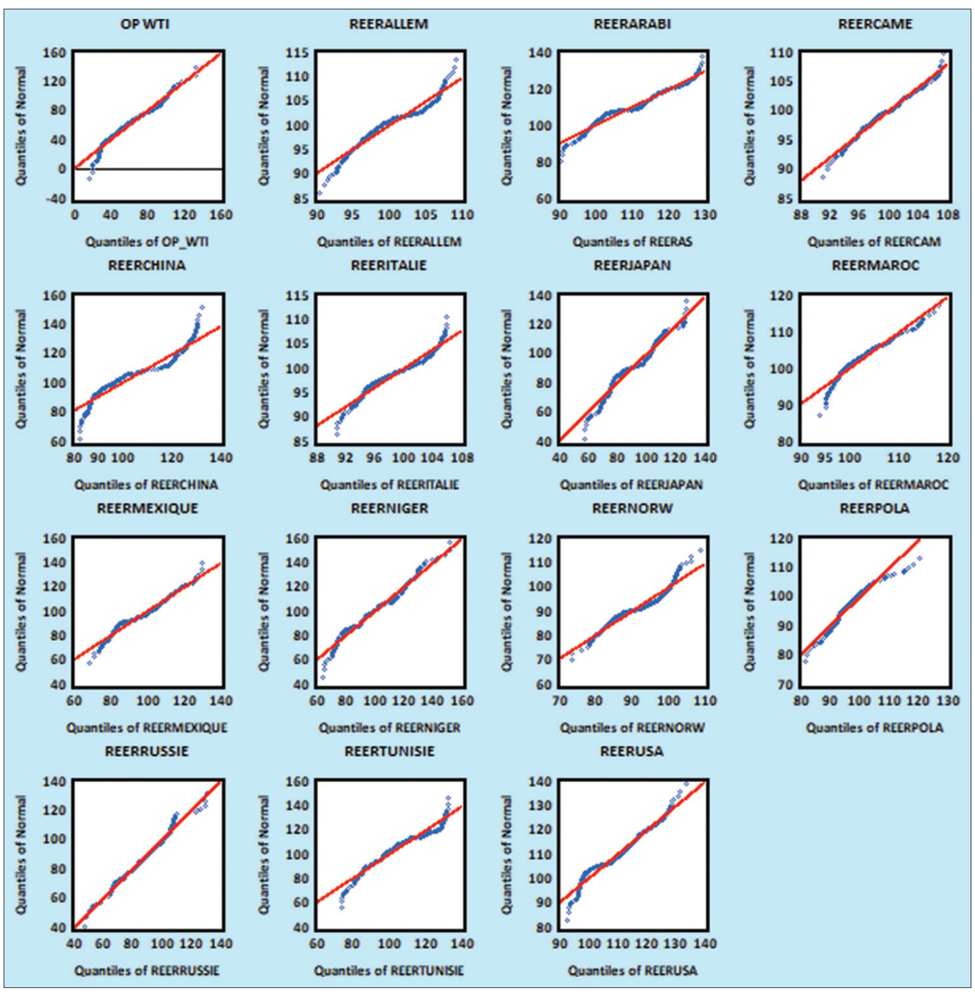
The study of the non-parametric Spearman test, presented in the table below, shows the existence of a significant average positive correlation between the price of oil and the exchange market of net oil-exporting countries, except for Germany's exchange market. The correlation between these variables is strong for Saudi Arabia and the United States of America.

For net oil-importing countries, all results are significant: the correlation between the price of oil and the real effective exchange rate of Morocco and Japan is negative, while it is positive for China and Russia.

4.4. Heteroscedasticity ARCH Test

The ARCH test for heteroscedasticity, also known as the likelihood ratio test, provides information on the need for ARCH-type modeling. The results of this test are shown in the Table 4 below: The probability values indicate that all series have a significant ARCH effect, meaning that the model is heteroscedastic.

Figure 2: Quantiles-quantiles plots of market price volatility



Source: Author's calculation

Table 1: Descriptive statistics

	OPTWI	REERALLEM	REERARABI	REERCAME	REERCHINA	REERITALIE	REERJAPAN	
Mean	62.43480	99.78463	108.9593	99.24138	106.7058	98.43882	89.30042	
Median	59.27000	98.61138	111.1343	98.60087	105.1446	97.86146	85.85323	
Maximum	133.8800	109.3097	129.2955	107.4718	132.6818	106.0181	127.4995	
Minimum	16.55000	90.33321	90.41028	90.99331	82.04792	90.74131	57.11065	
Standard deviation	26.07949	4.703794	9.844842	3.617131	15.43686	4.126660	16.21044	
Skewness	0.334968	0.301044	0.188850	0.225806	0.039105	0.175088	0.283681	
Kurtosis	2.218870	1.884656	2.008979	2.424376	1.498368	1.787824	2.233426	
Jarque-Bera	12.13410	18.40782	12.88811	6.133600	25.90748	18.24161	10.42176	
Probability	0.002318	0.000101	0.001590	0.046570	0.00002	0.000109	0.005457	
Observation	275	275	275	275	275	275	275	
	REERMAROC	**REERMEXIQ**	**REERNIGER**	**REERNORW**	**REERPOLA**	**REERRUSSIE**	**REERTUNISIE**	**REERUSA**
Mean	102.2937	98.47606	101.1404	92.56328	95.68029	86.33006	101.1691	110.8245
Median	101.4108	100.4687	100.6128	94.43882	93.37646	86.88914	98.33037	112.0174
Maximum	118.1679	130.1825	152.2540	108.9199	120.4043	130.5686	132.5784	133.8161
Minimum	93.67941	68.24748	63.89433	73.38532	81.18322	47.34701	73.39679	92.44621
Standard deviation	5.141047	14.19806	19.18238	7.744839	6.103798	15.58404	15.47293	9.692764
Skewness	0.789565	0.050668	0.100034	-0.332049	0.998710	0.001181	0.449889	-0.006773
Kurtosis	2.990759	2.120835	2.205813	1.916513	5.16414	2.904168	2.297282	2.112241
Jarque-Bera	28.57410	8.974174	7.685797	18.50488	99.44354	0.105294	14.93495	9.032607
Probability	0.000001	0.011253	0.021431	0.000096	0.000000	0.948715	0.000571	0.010929
Observation	275	275	275	275	275	275	275	275

Source: Author's calculation

Table 2: Correlation test (Pearson parametric test)

	OPTWI	REERALLEM	REERARABI	REERCAME	REERCHINA	REERITALIE	REERJAPAN	REERMAROC
OPTWI	1							
REERALLEM	−0.068375	1						
REERARABI	−0.691496***	−0.443124***	1					
REERCAME	0.162042***	0.838417***	−0.570855***	1				
REERCHINA	0.170635***	−0.842133***	0.304555***	−0.523133***	1			
REERITALIE	0.222926***	0.873943***	−0.755454***	0.871625***	−0.673676***	1		
REERJAPAN	−0.383193***	0.509003***	0.036634	0.195995***	−0.770564***	0.302002***	1	
REERMAROC	−0.629568***	0.564276***	0.383335***	0.213785***	−0.659553***	0.146166**	0.711054***	1
REERMEXIQUE	−0.157807***	0.552571***	−0.044595	0.242966***	−0.802439***	0.344764***	0.687550***	0.634627***
REERNIGER	0.477965***	−0.669584***	−0.051155	−0.330440***	0.831408***	−0.417921***	−0.823755***	−0.797632***
REERNORW	0.262129***	0.628602***	−0.584792***	0.530555***	−0.766536***	0.707977***	0.559050***	0.211459***
REERPOLA	0.415977***	0.264784***	−0.378771***	0.302533***	−0.305729***	0.260405***	0.068045	0.037236
REERRUSSIE	0.822529***	−0.167146***	−0.627072***	0.122664**	0.231860***	0.187873***	−0.449365***	−0.738906***
REERTUNISIE	−0.474470***	0.547152***	0.193746***	0.177128***	−0.780621***	0.251261***	0.828595***	0.820483***
REERUSA	−0.707249***	−0.150625**	0.876661***	−0.325696***	0.075199	−0.523468***	0.031209	0.507505***
	REERMEXIQUE	**REERNIGER**	**REERNORW**	**REERPOLA**	**REERRUSSIE**	**REERTUNISIE**	**REERUSA**	
OPTWI								
REERALLEM								
REERARABI								
REERCAME								
REERCHINA								
REERITALIE								
REERJAPAN								
REERMAROC								
REERMEXIQUE	1							
REERNIGER	−0.680354***	1						
REERNORW	0.693655***	−0.555524***	1					
REERPOLA	0.452772***	−0.89550	0.443485***	1				
REERRUSSIE	−0.292995***	0.568939***	0.147798**	0.278204***	1			
REERTUNISIE	0.870459***	−0.825150***	0.523166***	0.154666**	−0.571215***	1		
REERUSA	0.024310	−0.153580**	−0.493271***	−0.320683***	−0.601925***	0.255797***	1	

*, ** and *** respectively refer to the significance levels of 10%, 5%, and 1%

4.5. Estimation Results of the GARCH (1,1) Model

The estimation results of the GARCH (1,1) model are presented in the Table 5 below:

- For net oil-exporting countries, the ARCH parameters are highly significant with zero probabilities, while the GARCH parameter

Table 3: Corrélation test (Spearman's non-parametric test)

	OPTWI	REERALLEM	REERARABI	REERCAME	REERCHINA	REERITALIE	REERJAPAN	REERMAROC
OPTWI	1							
REERALLEM	−0.083085	1						
REERARABI	−0.694140***	−0.413479***	1					
REERCAME	0.134478**	0.839298***	−0.552560***	1				
REERCHINA	0.173751***	−0.840631***	0.331068***	−0.551052***	1			
REERITALIE	0.243924***	0.822315***	−0.739037***	0.869812***	−0.667534***	1		
REERJAPAN	−0.389554***	0.605271***	−0.049461	0.295070***	−0.782846***	0.366955***	1	
REERMAROC	−0.629974***	0.682083***	0.261953***	0.376808***	−0.662365***	0.232503**	0.631819***	1
REERMEXIQUE	−0.201244***	0.629078***	−0.100613*	0.291773***	−0.806734***	0.346898***	0.695997***	0.595172***
REERNIGER	0.487555***	−0.703696***	−0.015598	−0.361052***	0.828813***	−0.397882***	−0.814203***	−0.787584***
REERNORW	0.273072***	0.611900***	−0.614000***	0.541927***	−0.717203***	0.691022***	0.570587***	0.190463***
REERPOLA	0.376657***	0.326727***	−0.462026***	0.312902***	−0.331803***	0.298432***	0.158074***	0.046032
REERRUSSIE	0.856948***	−0.156704***	−0.665478***	0.107554*	0.162349***	0.242770***	−0.313337***	−0.676290***
REERTUNISIE	−0.4199260***	0.668712***	0.002730	0.304925***	−0.805033***	0.351743***	0.820399***	0.726585***
REERUSA	−0.705952***	−0.176678**	0.889307***	−0.330278***	0.104967*	−0.570722***	0.021668	0.492790***

	REERMEXIQUE	REERNIGER	REERNORW	REERPOLA	REERRUSSIE	REERTUNISIE	REERUSA
OPTWI							
REERALLEM							
REERARABI							
REERCAME							
REERCHINA							
REERITALIE							
REERJAPAN							
REERMAROC							
REERMEXIQUE	1						
REERNIGER	−0.708595***	1					
REERNORW	0.638364***	−0.526439***	1				
REERPOLA	0.476246***	−0.124326**	0.511200***	1			
REERRUSSIE	−0.251769***	0.474591***	0.257266**	0.361670***	1		
REERTUNISIE	0.876349***	−0.834807***	0.555293***	0.257722***	−0.431815***	1	
REERUSA	0.005616	−0.165510***	−0.509586***	−0.395014***	−0.704788***	0.111501*	1

*, ** and *** respectively refer to the significance levels of 10%, 5%, and 1%

Table 4: Results of heteroscedasticity ARCH test

	Statistique F	Statistique Obs*R-Squared	Prob.
OPWTI	1162.880	222.0598	0.0000
REERALLEM	1540.272	232.8759	0.0000
REERARABI	3593.890	254.7216	0.0000
REERCAME	1056.146	217.8857	0.0000
REERCHINA	5331.767	260.7004	0.0000
REERITALIE	1215.289	232.8900	0.0000
REERJAPAN	5349.383	260.7421	0.0000
REERMAROC	3305.822	253.1695	0.0000
REERMEXIQUE	2358.850	245.6715	0.0000
REERNIGER	3131.316	252.1014	0.0000
REERNORW	1160.929	221.9890	0.0000
REERPOLA	1528.855	232.6152	0.0000
REERRUSSIE	3005.145	251.2583	0.0000
REERTUNISIE	27503.32	271.3168	0.0000
REERUSA	3724.384	255.3511	0.0000

Source: Author's calculation

for the return of the real effective exchange rate of Saudi Arabia, Norway, Mexico, and Cameroon is not significant.

- For net oil-importing countries, the ARCH parameters are highly significant with zero probabilities, while the GARCH parameter for the return of the real effective exchange rate of China, Japan, and Morocco is not significant.

4.6. Estimation Results of the GARCH BEKK Model

In the BEKK model, the conditional covariance matrix is constructed to be positive definite. It indicates how shocks are transmitted between different markets over time. This type of model is preferred for its robustness.

To study the transmission of volatilities from the oil market to the exchange markets of net oil-exporting and importing countries, the selected systems are presented as follows:

For net oil-exporting countries:

$$REERALLEM=\alpha_0+\alpha_1\ OPWTI$$

$$REERARABI=\beta_0+\beta_1\ OPWTI$$

$$REERCAME=\gamma_0+\gamma_1\ OPWTI$$

$$REERITALIE=\delta_0+\delta_1\ OPWTI$$

$$REERMEXIQUE=\varepsilon_0+\varepsilon_1\ OPWTI$$

$$REERNIGER=\zeta_0+\zeta_1\ OPWTI \quad (5)$$

$$REERNORW=\eta_0+\eta_1\ OPWTI$$

Table 5: Results of GARCH (1,1) model

	$\hat{\mu}$	$\hat{\omega}$	$\hat{\alpha}$	$\hat{\beta}$
OPTWI	58.54512	83.16905***	1.023930***	−0.260565***
REERARABI	113.0420	0.757294***	0.852755***	0.157378
REERRUSSIE	87.63546	1.404691	0.821064***	0.260149***
REERNIGER	100.4865	2.981206*	1.092334***	−0.006593
REERNORW	97.19410	2.389550***	1.062981***	−0.124483
REERMEXIQUE	101.7992	3.145024***	1.027001**	−0.014991
REERTUNISIE	98.11688	0,794511**	1.311732***	−0.286995**
REERCAME	98.11688	0.970401***	0.996151***	−0.047714
REERITALIE	97.67214	0.762041***	1.187857***	−0.211795*
REERPOLA	93.13754	1.441813***	1.154045***	−0.041338**
REERALLEM	97.72160	0.559482**	1.185905***	−0.138857*
REERCHINA	106.3270	3.876100	1.234787*	−0.260640
REERJAPAN	76.49801	2.647713***	1.163710***	−0.196321
REERMAROC	100.1134	0.456107*	0.934900***	0.048098
REERUSA	112.8610	2.149982**	1.40089***	−0.119132*

*, ** and *** respectively refer to the significance levels of 10%, 5%, and 1%

$REERPOLA=\theta_0+\theta_1\ OPWTI$

$REERRUSSIE=\iota_0+\iota_1\ OPWTI$

$REERTUNISIE=\kappa_0+\kappa_1\ OPWTI$

For net oil-importing countries:

$REERCHINA=\lambda_0+\lambda_1\ OPWTI$

$$REERJAPAN=\mu_0+\mu_1\ OPWTI \quad (6)$$

$REERMAROC=\nu_0+\nu_1\ OPWTI$

$REERUSA=\xi_0+\xi_1\ OPWTI$

The GARCH BEKK modeling relative to the two systems of equations revealed the following results.

Table 6 concerns the transmission of volatilities from the oil market to the exchange markets of net oil-exporting countries, while Table 7 concerns the transmission of volatilities from the oil market to the exchange markets of net oil-importing countries.

The results in Table 6 indicate that the coefficients aii and bjj are significant for all 10 net oil-exporting countries. This indicates the presence of volatility persistence in the exchange markets of these countries. It means that past volatility has a significant impact on the future volatility of these exchange markets. This volatility persistence can be attributed to these countries' strong dependence on oil exports, making them vulnerable to fluctuations in oil prices in the global market.

The results in Table 7 show that the aii coefficients are significant for all net oil-importing countries, while the bjj coefficients are not. This suggests that the exchange markets of these countries are characterized by discontinuous volatility persistence. This may be due to these countries' dependence on oil imports and price fluctuations, as well as other economic and political factors such as fiscal and monetary policies, geopolitical events, and external economic shocks.

For net oil-exporting countries, the results in Table 6 indicate that the real effective exchange rates of these countries are significantly affected by oil price fluctuations during the study period, except for Cameroon, Italy, and Germany's exchange rates. This is the case for Saudi Arabia, whose exchange market is dependent on news from the oil market. This is expected as oil has a significant weight in Saudi Arabia's economy, ranking 3rd among the world's largest oil producers. Additionally, Saudis possess the world's 2nd largest oil reserves. For Russia, the real effective exchange rate of the Ruble is impacted by oil price volatility during the study period, as it ranks 2nd among the world's largest oil producers with a production of 536 million tonnes in 2021.

For Nigeria, the largest oil producer in Africa and a major member of OPEC, the results indicate that the transmission of volatility from the oil market to the exchange market is significant during the study period.

Furthermore, the results in Table 6 indicate that the estimated coefficients of the oil price (WTI) variable are positive for some net oil-exporting countries (Russia, Nigeria, Norway, Mexico, Italy, and Poland), while they are negative for others (Saudi Arabia, Tunisia, Cameroon, and Germany). In other words, an increase in oil price leads to an appreciation of the currency for the first category of net oil-exporting countries and depreciation for the second category.

For net oil-importing countries, the oil market does not transmit volatility to China's exchange market. However, for Japan, Morocco, and the United States, the results indicate that oil price volatility is transmitted significantly to their exchange markets. Additionally, the oil price exerts an overall negative pressure on the real effective exchange rate of these countries, meaning that an increase in oil price leads to a depreciation of the currency.

In conclusion, we can say that fluctuations in oil prices have a significant impact on the exchange rates of net oil-exporting and importing countries. However, the effect differs between the two categories of countries.

Net oil-exporting countries are often highly dependent on their oil exports to support their economies. Thus, when oil prices increase,

Table 6: Results of the estimation of the GARCH BEKK diagonal model for the foreign exchange markets of net oil exporting countries

	Net oil exporting countries									
	REERARABI	REERRUSSIE	REERNIGER	REERNORW	REERMEXIQUE	REERTUNISIE	REERCAME	REERITALIE	REERPOLA	REERALLEM
a_{ii}	1.031654***	1.025947***	1.033730***	1.010244***	1.019698***	1.024538***	1.000846***	1.015950***	1.011597***	1.014518***
b_{jj}	0.290053***	0.276757***	0.265891***	0.233112***	0.285551***	0.280667***	0.330583***	0.306526***	0.364909***	0.282756***
OPTWI	−0.075483***	0.161411***	0.073577*	0.101703***	0.125194***	−0.066031***	−0.002802	0.001935	0.081288***	−0.005633

Table 7: Results of the estimation of the GARCH BEKK diagonal model for the foreign exchange markets of net oil-importing countries

	Net oil-importing countries			
	REERCHINA	REERJAPAN	REERMAROC	REERUSA
a_{ii}	−1.005178***	−1.004843***	−0.999984***	−1.016222***
b_{jj}	−0.076620	−0.051939	−0.071614	0.021700
OPTWI	−0.006722	−0.081377***	−0.031804***	−0.103882***

*, ** and *** respectively refer to the significance levels of 10%, 5%, and 1%

oil exporters can benefit from an influx of foreign currency revenues, which can strengthen their currency. Conversely, when oil prices decline, it can weaken their currency.

On the other hand, net oil-importing countries are often highly dependent on oil imports for their economies. When oil prices increase, oil importers may face higher costs for purchasing oil, which can weaken their currency. Conversely, when oil prices decline, it can strengthen their currency.

5. CONCLUSIONS

The main objective of this article is to study the transmission of volatilities from the oil market to the exchange markets of net oil-exporting and importing countries. The results of this study reveal the following conclusions:

The descriptive statistical analysis we conducted revealed that the price of oil and the exchange rates of net oil-exporting and importing countries exhibit volatility characteristics (clusters).

The study of transmission through the GARCH-BEKK model reveals that for net oil-exporting countries, there is volatility persistence in the exchange markets of these countries, while for net oil-importing countries, there is volatility persistence in a discontinuous manner. Additionally, we found that oil price volatility is transmitted from the oil market to the exchange markets of both categories of countries (except for Cameroon, Italy, Germany, and China).

For net oil-exporting countries, the results indicate that an increase in oil price leads to a depreciation of the real effective exchange rate for 4 net oil-exporting countries and an appreciation for 6 countries. As for net oil-importing countries, an increase in oil price leads to a depreciation of the real effective exchange rate.

In conclusion, we can say that fluctuations in oil prices are transmitted to the exchange rates of net oil-exporting and importing countries. However, exchange rate fluctuations are not solely caused by variations in crude oil prices. Other economic factors such as interest rate differentials, monetary and fiscal policies, international economic conditions, and investor confidence can also influence exchange rates. Economic policymakers must be aware of these complex relationships and be able to develop effective policies to minimize negative effects on the economy.

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