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# Analyzing the volatility spillover and cointegration relationship between daily spot West Texas intermediate crude oil price and US dollar

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**ABSTRACT**

In the study, it is aimed to analyze the diffusion and cointegration relationship between WTI and US Dollar in the period of 2016-2021. In the study, after a comprehensive literature review of the theoretical review, the econometric analysis section was started. In the first part of the analysis, the short and long-term relationships between the variables were examined with the autoregressive distributed lag methodology and the existence of a cointegration relationship was reached. According to the findings, the effect of WTI on foreign exchange volatility in the long run is statistically significant and negative. In the short-term evaluation, ECT is negative and significant within expectations. In this context, the changes between the variables approach the long-term equilibrium level. According to the results obtained in the causality and variance causality analyzes applied in the last part of the analysis, it is understood that there is a volatility spillover effect from WTI to foreign currency.

### *I. Introduction*

The connection between the oil price and the foreign currency has been widely discussed in the literature, but different results have been obtained according to the period in which it was examined and the country and region under investigation. Petroleum and petroleum products have gained increasing importance in terms of the real economy since their use as industrial inputs. Especially after the 1973 oil crisis, this situation emerged more clearly in terms of countries. The price changes frequently encountered in oil prices in current days have revealed the necessity of focusing on its potential determinants and its macroeconomic effects. Foreign currency, on the other hand, provide an idea about the competitiveness of economies at the global level. Due to these characteristics, increase and decrease in considered variables can have very significant macroeconomic and monetary consequences.

Following the 2008 Crisis, the volatility of the oil cost increased, and its predictability decreased due to both OPEC's decline in determining the oil price and global geopolitical risks. The high oil price means an increase in input costs for countries that are net importers. This situation causes both foreign currencies to increase by causing more foreign currency to come out of the country and weakening the competitiveness in exports by increasing production costs. For this reason, the correlation among the oil prices and foreign currency is of vital importance for energy-dependent countries. So much so that the rise in the foreign currency during the periods while the oil cost is in a downward trend eliminates the advantage that the country hopes to gain from the price decrease.

The US dollar, which is the most important currency of the world reserve currency position, plays a key role in the trade of many products, especially petroleum manufactured goods. Rise and fall in foreign currency have various impacts on oil importing and exporting countries. The overvaluation of the foreign currency may cause foreign trade deficit by affecting the trade in cost for oil trade in countries.

In addition, the depreciation of the foreign currency reduces the export revenues of oil-exporting countries and may adversely affect their growth performance (Kızılkaya, 2021:552).

Therefore, unexpected, and damaging rate shocks in international markets might affect important macroeconomic indicators. In this sense, this crucial link among the variables is closely observed by both policy makers and financiers (Reboredo, 2012, 419-420).

In this study, volatility spillover and cointegration relationship between WTI price and USD Dollar. In this context, firstly, relations of the data sets will be examined with the bounds test methodology. Thus, it will be determined if cointegration relationship exist among the series and it will be understood that the effect of oil prices on foreign currency volatility is negative or positive. In the end, the causality relationship will be analyzed considering the causality analysis in variance. The rest of the paper is arranged as follows: main framework of theoretical background of the volatility spillover and cointegration includes the theoretical approach, literature review; and empirical analysis.

## 2. Theoretical Background

There are many theoretic and experimental studies investigating the link among the considered variables, but it is difficult to take a clear approach due to the lack of consensus on the results. From a theoretic perspective, the relationship among the mentioned variables can operate

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through more than one channel (Huang et al; 2021: 720). While some of these approaches state that the change in oil prices is effective on foreign currency, others state that changes in foreign currency influence WTI. The theoretical results of Caprio & Clark (1981) the effect of the increase in oil prices on foreign currency depends on the portfolio preferences of the oil importing country as well as the oil exporting country. Apart from this, the current account balance also affects the foreign currency results of oil price changes. However, understanding this effect is only possible provided that the asset preferences expressed in the first effect are known. Finally, the foreign currency expectations reflecting the adaptation of the countries to the increasing oil price are also effective in determining the current spot rate (Caprio & Clark 1981: 17-18). It is seen that the terms of trade approach developed by Amano & van Norden (1998b) and the wealth effect approach established by Golub (1983) & Krugman (1983) stand out among the approaches expressing the impact of variations in oil prices on foreign currency. Amano and Van Norden (1998a) showed that oil prices are the main cause of permanent shocks in foreign currency in their study using tradable and non-tradable goods in a simple two-sector model. According to the terms of trade channel approach, if a country's economy is more dependent on imported oil than the other country and if the non-tradable sectors of the economy of that country are more sensitive to changes in oil prices than the tradable sectors, the increase in oil prices will cause a shift in foreign currency instead of the domestic currency. This could lead to a real appreciation of the currency.

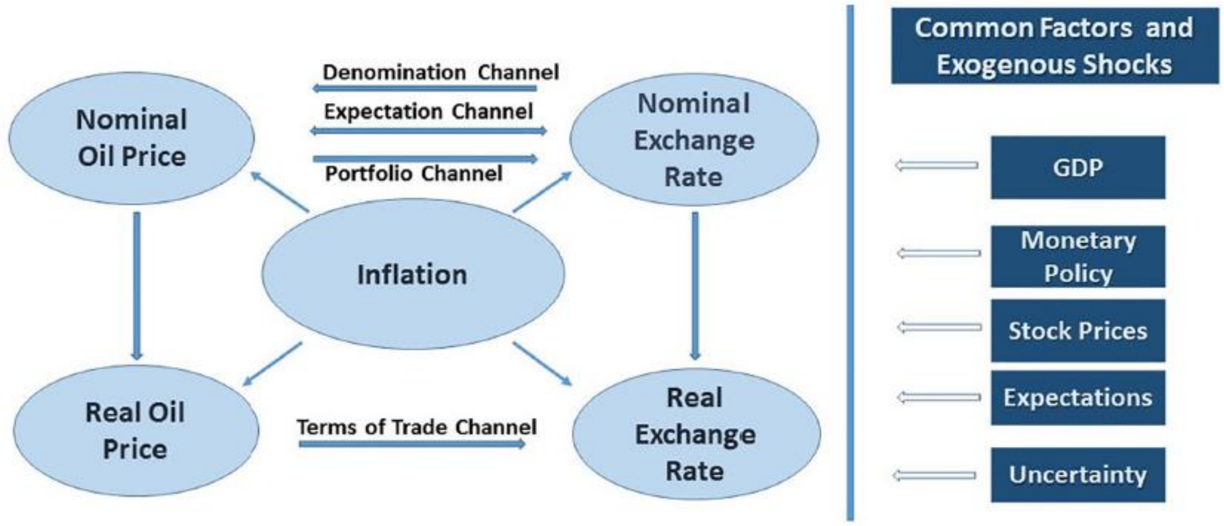
Nevertheless, if tradable sectors in the economy of the relevant country are additional sensitive to changes in oil prices than non-tradable sectors, then a rise in oil prices may cause the currency of this country to depreciate in real terms compared to the currency of the other country (Beckmann, Czudaj, & Arora, 2020:3). For the wealth effect channel, Golub (1983) & Krugman (1983) offer a hypothetical basis for stating that movement in oil price effects in prosperity transmission from oil importers to oil exporting nations and will completely affect balance of payments of the oil exporting nation (Yaman,2021: 160). That may cause the money of the oil exporting nation to appreciate. The current account balance of the oil importing nation will be negatively affected and the country's currency may lose value.

When we look at the theoretical approaches state that changes in foreign currency can be effective on oil costs, it is seen that three approaches stand out here. These; denomination channel, adjustment channel and financial markets channel (Büberkökü, 2021:292). Reboredo (2012), Zhang et al. (2016) and Beckmann et al. (2017) argue that in the short run, nominal foreign currency affects nominal oil prices through the denomination channel, while nominal foreign currency affects oil prices through the portfolio channel.

The mainstay of the adjustment channel is the reorganization of the pricing policies of oil exporting companies and/or the decisions of institutions such as OPEC on the amount of oil to be produced, according to the current conjuncture, to protect the market share and/or the purchasing power of oil revenues after the variations in the value of the US dollar on a global basis (Huang & Sissoko, 2014: 408; Büberkökü, 2021:293). The infrastructure of the financial markets channel, on the other hand, is the tendency of investors to rearrange their portfolios and/or to benefit from hedging transactions against the risks that may arise depending on the future values of the US dollar. In case of a powerful relationship between the US dollar and oil prices, the risks posed by price movements in the US dollar can be hedged with oil futures contracts. This situation may cause a causal relationship from foreign currency to oil prices.

If the resulting rise in WTI starts to an appreciation of the currency, a decrease in the WTI should trigger the currency to depreciate at the same rate. This is an indication that crude oil affects a country's foreign currency symmetrically. The hypothesis of symmetry for oil price changes may not always be true in the real world, as the impact of oil price rises and declines on the foreign currency is likely to vary in sign and/or magnitude (Kızılkaya,2021:553). If the effects of oil prices on foreign currency are asymmetrical, the results of empirical studies conducted under the assumption of symmetry may be misleading. Therefore, it is of great significance to be concerned about the asymmetric assumption to make more precise assessments when examining the effects of oil prices on foreign currency (Baek & Kim, 2020: 120).

Figure 1: Independence Between WTI, Foreign Currency and Other Factors




Source: Beckmann et al. (2020).

The different transmission channels are summarized in Figure 1. Chanel of trade mainly emphasis on foreign currency and real oil prices while the channel of portfolio and wealth suggest an impact from the nominal foreign currency to the nominal oil price. The channel of expectations permits for nominal causality in both directions. In general, it is significant to point out that both foreign currency and oil price changes in volume are defined by various causes and are extremely hard to calculate. While the volatile link between macroeconomic fundamentals and foreign currency are mirrored in the foreign currency separate problem understanding the cycles in oil price variations is often difficult by classifying the basic source of supply shocks and demand (Baumeister and Kilian, 2015).

## 3. **Literature**

The connection between foreign currency and WTI has also been widely discussed in applied studies. In the current literature, the subject has been examined using different methods for both oil importing and exporting countries.

Eichenbaum & Singleton (1986) , Chaudhuri & Daniel (1998), Amano & Norden (1998), Zhang, Fan, Tsai & Wei (2008), Wang & Wu (2012) & Zhang (2013), Beckmann & Czudaj (2013), Lv at al.(2018), Ağazade (2020), Shi at al. (2020) and Torun & Demirelli (2022) mostly using cointegration and causality techniques that make for developed countries that import oil and generally reached results showing that there is a long-term relationship. Besides, Huang & Guo (2007), Chen, Lee & Goh (2013), Turhan, Hacihasanoglu & Soytas (2013), Ogundipe at al. (2014), Bal & Rath (2015) and De Vita & Trachanas (2016), Yılmaz & Altay (2016), Ojebiyi & Wilson (2011) and Büberkökü (2021) reach different results in studies on developing countries.

Some studies in the literature are also related to OPEC members or other oil exporting countries. Koranchelian (2005), Zalduendo (2006), Korhonen & Juurikkala (2007), Nikbakht (2010), Jahan-Parvar & Mohammadi (2011) and Ağazade (2018) can be given as examples of these studies. In these studies, it has been concluded that oil prices have a positive effect on the real exchange rate.

The previous studies reveal a bi-directional causal connection between WTI and foreign currency. First, the impact of WTI on foreign currency in the medium/long period is obtained from periods of trade and the wealth effect channels. Amano & van Norden (1998) establish the long-term framework with terms of trade channels to obtain oil prices permanently on real exchange rates. Buetzer et al. (2016) show both the oil prices and the countries that produce the oil and the foreign currency with the trade channels in the industrialized countries. Beckmann & Czudaj (2013) aim on the causality connection between currencies and oil price ending that the most meaningful causality goes from foreign currency to oil price. Tantatape et al. (2014) examine the link between foreign currency and U.S. imported WTI. They demonstrated that, in the short term, foreign currency Granger-cause the price of oil. Moreover, the study showed that the oil price response to the foreign currency shock is negative. Nevertheless, oil price shocks obviously have not any effect on the foreign currency. Jammazi et al. (2015) analyze the US dollar foreign currency against WTI and 18 different currencies. Emphasizing that there is an asymmetric shift from foreign currency to oil prices in both the long and short run, the authors argue that negative foreign currency shocks have a greater effect on oil prices than positive ones. Kisswani et al. (2019) examine the asymmetrical connection between foreign currency and oil prices in selected Asian countries for the period 1970-2016 with the non-linear ARDL (NARDL) approach. The article also explores the direction of the causality link between foreign currency and oil price by using the Toda-Yamamoto causality test. Results point to a long-term asymmetry relationship only for Malaysia and Indonesia when structural breaks are considered. In addition, since there is a bidirectional causality among the variables in some countries, the causality test findings are complex, since in some countries there is a unidirectional causality. Şenol (2020) uses Hong's (2001) causality test in variance after estimating the volatility spreads between Borsa Istanbul exchange rate ($/₺) and oil (WTI) for the Turkish economy with the GARCH model of daily data for the period 2010-2019. The volatility spillovers and the relations between the variables were investigated using the DCC GARCH method. The findings of the research showed that there are reciprocal volatility spreads between BIST and the exchange rate, and one-way volatility spreads from oil to BIST and the foreign currency. These findings show that oil is an important factor in the volatility of Borsa Istanbul and foreign currency. Baek & Kim (2020) study11 sub-Saharan African countries with a monthly data set covering the years 2000-2017 and estimated the relationship with the help of the NARDL model. The findings reveal that there is an asymmetrical relationship among the variables, and that foreign currency are mostly affected by WTI increases. Baek (2021) examines the link between WTI and foreign currency with a monthly data set covering the years 1997-2017 in Indonesia. In the study, the relationship was estimated by the QARDL method. The findings show that the relationship between the two is heterogeneous among the quantiles. Therefore, it is suggested that there is an asymmetrical link between WTI and foreign currency in the short and long run. On the other hand, in the study, it was determined that increases in WTI only have an increasing effect on the local currency in the long run.

Kızılkaya (2021), in his study examines the oil price-currency shock relationship for the period 1960-2019 with the asymmetric Fourier Toda-Yamamoto causality test, found a one-way causality from positive oil price shocks to positive real exchange rate shocks. In this context, it emphasizes that asymmetric effects should also be considered while analyzing these two variables. Yaman (2021) evaluates the link between mentioned variables with the help of the daily data set covering the period 2002-2021 with the help of symmetric and asymmetric causality tests. While symmetric causality tests show that there is a feedback relationship between the two, asymmetric analyzes show that there is only one-way causality from oil prices to foreign currency in both positive and negative components. Huang et al. (2021), taking real oil prices and real exchange rate data, they classify 81 countries according to their net oil imports for the period 1997-2015. According to this classification, oil importers show a significant negative bidirectional correlation for countries in the free-floating exchange rate system, while oil exporters do not show a correlation among the variables. In the managed floating system, foreign currency is used to predict oil prices for oil importers or exporters. It is emphasized that knowing these relationships can shed light on the development of government policy to prevent sudden and significant shocks caused by volatility in exchange rate and WTI. Aracan (2022) uses the QARDL model in his study in which he examined the potential long and short run impacts of WTI on the real effective exchange rate of the Turkish lira with data covering the period 2003-2021. The results reveal that oil prices do not affect the real effective exchange rate in the long run but are effective in the short run and this impact is asymmetrical.

## **4. Empirical Analysis**

The empirical analysis consists of two parts, and in the first part, the relationship between imported WTI and foreign currency volatility will be analyzed by causality and cointegration methods.

In terms of market trading, it is assumed that WTI is one of the main councils of the worldwide crude oil comparison cost. In addition, it is accepted that spot trade is developing in world trade and economic literature and is the main direction indicator in worldwide oil markets (Yousefi & Wirjanto, 2004). As a result, daily spot WTI in US dollars/barrel is used in this study. The trade-weighted dollar index was created to measure the value of the Federal Reserve's US dollar based on its competitiveness against its trading partners. The US dollar index – also known as the Broad index – is a measure of the trade-weighted US dollar's value relative to other currencies. It is a trade-weighted index that enhances the older US Dollar Index by updating its weights annually and using more currencies.

In this context, real trade-weighted US dollar index has been considered as the dollar currency in the study. For this purpose, the variables to be used in the analysis, their symbols and the sources obtained can be viewed in Table 1.

Table 1: Series, Symbols and Sources

| Variable | Symbol | Source |
|---|---|---|
| Trade-weighted US dollar index (Real) | indx | FED |
| West Texas Intermediate crude oil price | WTI | Bloomberg |

*: *Board of Governors of the Federal Reserve System (US), Real Broad Dollar Index (Goods Only)*

Since speculative and geopolitical non-capitalist factors have had a significant consequence on the worldwide oil market in the recent period, the period of the analysis was determined as 1 March 2016 to 31 December 2021. Thus, it is aimed to reduce the effect of excessive interference of non-market factors as much as possible and to make the contact between the change in oil prices and the foreign currency more realistic and quantitative. As a result of the research conducted with the Tramo/Seat method, which is widely used for both series, it was concluded that the mentioned effect did not exist in the series.

In this study, the link between WTI and US Dollar are examined by causality and cointegration methods, within the framework of the following model:

$$indx = \beta_0 + \beta_1 wti + e_1$$

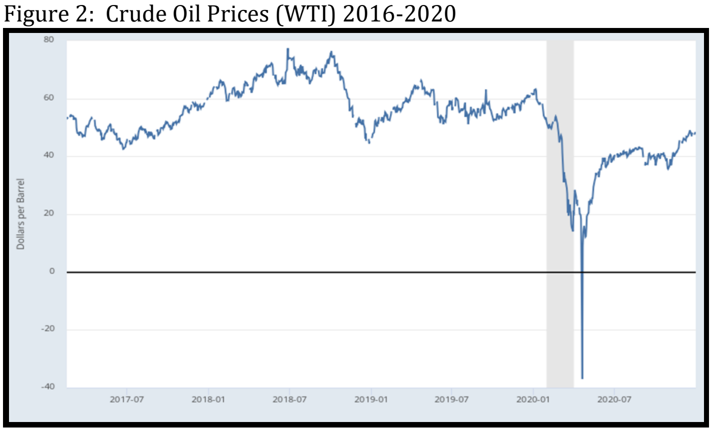
The tendency of the variables subject to the analysis for the period 1 March 2016 to 31 December 2021 can be seen in Figure 1 and Figure 2.

Looking at Figure 2, the remarkable point is that the price of a barrel of US crude oil fell negative for the first time in history. Concerns that the US's oil storage capacity would soon be full caused a sharp decrease in oil prices. In the country, the futures contracts for WTI type crude oil expired on Tuesday, while the barrel price of the oil in question fell by more than 300 percent to minus 37.63, as the contract holders avoided taking the delivery of physical crude oil. WTI experienced its biggest daily drop since it started trading in March 1983.

The dominance of the US dollar in the international trade and financial system has increased the importance of dollar movements, especially for emerging and developing market economies. Considering that the main factor behind the movements in the US dollar is the change in US growth expectations, unemployment figures, changes in fiscal policy or monetary policy, it is considered that the US dollar and dollar index may have different effects on developing countries. The US dollar index is important as it is an indicator of the relative strength of the US dollar worldwide. This is especially true for commodities (gold, silver, oil, etc.) priced in US dollars, when the US dollar is the main currency in currency pairs, and for stocks and indices. Commodity prices generally tend to fall as the value of the US dollar increases. The base currency in currency pairs is the US dollar.

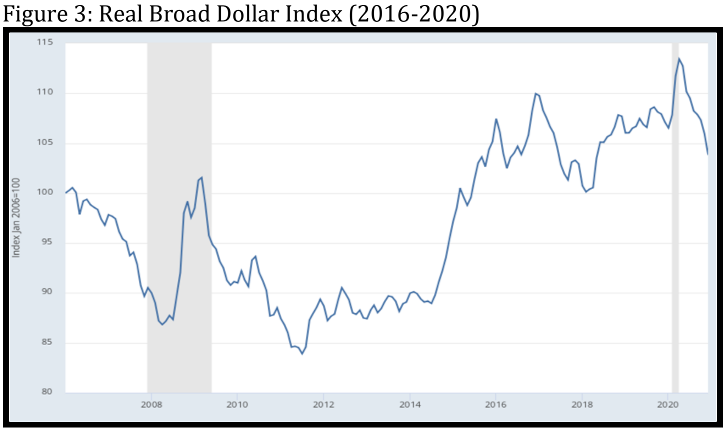
When there is a foreign currency, it usually moves in the same direction as the dollar index and the opposite currency moves in the opposite direction. The trend of the dollar index for the years subject to the analysis can be followed in Figure 3.

Figure 2: Crude Oil Prices (WTI) 2016-2020




Source: U.S. Energy Information Administration

Figure 3: Real Broad Dollar Index (2016-2020)




Source: Federal Reserve

When analyzed on an investor basis, it is expected that the dollar index will increase in case investors prefer the dollar over other country currencies, the interest rates of the American 10-year bonds increase and the US government bonds are preferred, and the risk-taking tendency of the investors decreases. Negative indicators in the American economy, on the other hand, may cause the dollar index to decline. In this sense, the dollar index will be an important indicator and reference for investors and market regulators in national and international investment decisions.

Before beginning the analysis, it is required to analyze the descriptive statistics. Primarily (skewness) and kurtosis (kurtosis) in descriptive statistics values can be viewed. These provide preliminary information in examining whether the distribution of data is normal. Skewness, i.e., slant value, expresses the symmetry of the distribution with respect to the mean (Doane, Seward: 2011). Kurtosis value, on the other hand, expresses flatness or bulge according to the normal distribution. To make a more precise judgment about normality, the normal distribution test results of Jarque-Bera values should be checked. This test is an asymptotic or large sample test. Descriptive statistics are presented in Table 1.

In Table 1, positive skewness values for variables indicate that the distribution is slanted slightly to the right. A value less than 3 for crude oil data indicates that the distribution has a flattened shape, and a value greater than 3 for the foreign currency volatility series indicates that the distribution has a pointed structure. A kurtosis value less than 3 for the WTI data indicates a flattened distribution, and a kurtosis value greater than 3 for the index series indicates that the distribution has a pointed structure. It has a Chi-square distribution with 2 degrees of independent. According to the resulting probability values, the hypothesis of "$H_0$: error terms are normally distributed" was rejected for both series. Covariance and correlation are used to reveal the relationship between two variables. Unlike covariance, correlation also shows the degree of this relationship. Accordingly, the negative correlation value between foreign currency volatility and WTI is 39%.

Table 1: Descriptive Statistics

| | WTI | indx |
|---|---|---|
| mean | 3.460 | 0.011 |
| median | 3.221 | 0.008 |
| maximum | 3.991 | 0.181 |
| minimum | 2.562 | -0,022 |
| std.dev. | 0,321 | 0.016 |
| skewness | 0,401 | 3.011 |
| kurtosis | 1.671 | 24.899 |
| j.Berra | 28.567 | 6412.990 |
| probability | 0.000 | 0.000 |
| sum | 1211.221 | 3.900 |
| sum sq.dev. | 133.709 | 0.176 |
| | Correlation | |
| | WTI | indx |
| WTI | 1 | -0,3921 |
| indx | -0,3921 | 1 |
| | Covariance | |
| | WTI | indx |
| WTI | 0.41320 | -0,00412 |
| indx | -0,00412 | 0.000229 |

Because non-stationary series will cause spurious regression problem, unit root tests were used to decide if the variables were stationary before the econometric analysis was determined. To increase the reliability of the analysis, Clemente, Montañés & Reyes (1998) and Lee & Strazicich (2003) tests, which allow breaks, were preferred besides the traditional Augmented Dickey Fuller (ADF) unit root test. ADF test is a method used for cases involving time trend and constant number. In this context, the ADF test is expressed as in Equation (2) and (3) (Dickey and Fuller, 1981:1960).

$$\Delta X_t = \mu + BX_{t-1} + \sum_{i=1}^{k} \varphi \Delta X_{t-i} + u_t \tag{2}$$

$$\Delta X_t = \mu + \alpha + BX_{t-1} + \sum_{i=1}^{k} \varphi \Delta X_{t-i} + trend + u_t \tag{3}$$

In the calculation in question, the null hypothesis "the series is not stationary" and the alternative hypothesis "the series is stationary" are analyzed. ADF unit root test results can be viewed in Table 2.

*Tablo 2: ADF Results*

| Variables | At level | First Difference | Critical Value (1%) |
|---|---|---|---|
| indx | -2,10(8) | -5,29(5)* | -4.18 |
| WTI | -7,20(1) | - | -4,90 |

Note:* They are significant at the 1 level, and the values in parentheses indicate the optimal lag lengths determined by the Akaike Information Criteria (AIC).

As can be seen from Table 2, WTI is stationary at the level, while Trade-weighted US dollar index (indx) becomes stationary when their first difference is taken. Clemente, Montañés, Reyes (CMR;1998) unit root test the variables separately under one and two breaks, and breaks are included in the analysis internally, as in the Lee-Strazicich test. In addition, CMR (1998) considers the possibility of shock, which is the cause of structural break in the unit root test variables, to occur gradually or momentarily. In the CMR (1998) test, the null assumption in Equation (4) is tested against the alternative hypothesis in Equation (5).

$$H_0: y_t = y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + u_t \tag{4}$$
$$H_A: y_t = \mu + d_1 DU_{1t} + d_2 DTB_{2t} + e_t \tag{5}$$

Table 3: CMR Unit Root Test Results

| Variables | ***AO Model*** | | ***IO Model*** | |
|---|---|---|---|---|
| | t statistic | Break date | t statistic | Break date |
| indx | -3.09 (k=3) | 2009, 2020 | -2.66 (k=6) | 2009, 2020 |
| WTI | -5.11(k=0) | 2009, 2020 | -4,70 (k=14) | 2009, 2020 |

Note: Critical value for both AO and IO models for Clemente, Montañés, Reyes unit root testing: -6.141 (5%). The lag lengths are shown in parentheses.

The estimations of CMR, the dependent variable ''indx'' contains a variable level unit root. The WTI variable is stationary in the series. The breaking dates are significant dates for the world economy and express the impact of the global crisis in 2009. In 2020, there were two important developments for the world economy. One is the Covid-19 epidemic, and the other is the sharp drop in oil prices. After the meeting of the OPEC and some non-OPEC crude oil producing countries, the decision to cut production did not come out and the statements from the authorities' reduced expectations for any agreement, the price of Brent oil per barrel decreased by 30 percent today to $32. Regarding the production cut, especially Saudi Arabia. While the disagreement between Saudi Arabia and Russia caused the risk of an increase in excess supply in the global market to be priced in, this development combined with the certainty that the Kovid-19 outbreak would slow down economic activity, oil prices saw their lowest level since January 2016.

According to the unit root analysis results, it was understood that the integration degrees of the variables were different. In this context, it is impossible to apply the cointegration approaches recommended by Engle and Granger (1987), Johansen (1988) and Johansen and Juselius (1990), which permit co-integration analysis for equally integrated variables.

The Autoregressive Distributed Lag (ARDL) established by Peseran (2001) does not impose any restrictions on the degree of integration, and it can also be applied to studies with a small number of observations. One of the basic conditions in the ARDL test is that the dependent variable has a unit root at the level. Due to the fulfillment of all these conditions, it was decided that the most appropriate analysis for the analysis was the ARDL limit test. First, the ARDL model is created according to the appropriate number of delays. Next step, this model is converted as an error correction model (VECM). In the last step, the F statistic is calculated by using the sum of the squares of the error obtained by estimating the constrained and unconstrained models based on the error correction model. If the F statistic is below the lower limit, I (0), the H0 hypothesis of "no cointegration" is accepted, and if it is above the upper limit, I (1), it is rejected. The region between two values is the region of instability. When falling into the indecision region, the long-term coefficients of the model can be estimated and interpreted if they are significant. The constrained and unconstrained model to be used in this context can be followed in Equations (6) and (7).

Constrained Model

$$\Delta y = c + \sum_{j=1}^{p} \alpha_i \, \Delta y_{t-j} + \sum_{j=1}^{q} \beta_j \Delta x_{t-j} + \varepsilon_t \quad (6)$$

Unconstrained Model

$$\Delta_y = c + \delta_1 y_{t-1} + \delta_2 y_{t-1} + \sum_{j=1}^{p} \alpha_i \, \Delta y_{t-j} + \sum_{j=1}^{q} \beta_j \Delta y_{t-j} + \varepsilon_t \, (7)$$

The unconstrained model here is the expression of the ARDL model as VECM. By converting the ARDL model to VECM, both the cointegration relationship is investigated and it can be seen how to correct it when there is a deviation in the short-run balance. In Equation (7), $\delta_1 y_{t-1} + \delta_2 y_{t-1}$ show the long run VECM. According to F statistic, if $\delta_1 = \delta_2 = 0 \delta_1 = \delta_2 = 0$," $H_0$: no cointegration" hypothesis is accepted (Shresta & Chowdhury, 2005).

In the information criteria considered for the unconstrained error correction models to be established, the delay length with the smallest critical value is selected as the appropriate delay length. Besides, if the selected smallest value has an autocorrelation problem, the next smallest value is accepted as the lag length. This situation is repeated as the autocorrelation problem persists. The lag lengths reached by using the AIC and the Schwarz information criterion can be seen in Table 4.

Table 4: Determining the Appropriate Lag Length

| ***M*** | AIC | SIC | $X^2$ BREUSCH-GODFREY |
|---|---|---|---|
| *1** | 2.0011 | 5.312 | 4.104***(0.210) |
| 2 | 4.2716 | 6.322 | 8.101 (0.200) |
| 3 | 4.3318 | 6.110 | 5.615**(0.208) |
| 4 | 4.0401 | 6.810 | 5.100**(0.318) |
| 5 | 4.2111 | 5.391 | 3.010*(0.444) |
| 6 | 3.3009 | 7.180 | 3.101*(0.198) |
| 7 | 3.1289 | 7.220 | 2.310**(0.332) |
| 8 | 3.3121 | 6.241 | 1.217**(0.227) |
| 9 | 3.2110 | 7.108 | 2.514**(0.156) |

***Note:*** *, ** and *** indicate the appropriate delay length selected at the level of 1%, 5% and 10%, respectively. Values in brackets represent the probability value.

According to the results in Table 4, the lag length with the smallest critical value was determined as 1. It is necessary to investigate whether the variables are in a co-integration relationship in the boundary test analyzes for which the lag length is determined. In this context, the F test is used. If the obtained F-statistic is higher than the higher bound value, the null hypothesis is rejected. In other words, a cointegration relationship among the variables is reached. Otherwise, the null hypothesis is accepted. In case the obtained F value is between the lower and upper limit values, no interpretation can be made. ARDL test results are presented in Table 5.

The 8,600 F statistical value reached in Table 5 is higher than the critical value upper limit of 7,920 at the 5% level. According to this result, the null hypothesis stating that there is no long-term level relationship is rejected. In other saying, there is a long-term relationship among the Diagnostic tests are in line with expectations. After deciding whether there is a cointegration relationship according to the critical values, short and long-term relationships can be analyzed. To investigate the short-term relationship, the error correction model calculated from the ARDL (1, 1) model was established according to Equation (6) and (7). The estimation results of Equation (8) are presented in Table 6.

Table 5: ARDL Test Results

| F Statistic Critical Values | | | | | | |
|---|---|---|---|---|---|---|
| | 10% | | 5% | | 1% | |
| k | | I(I) | I(0) | I(I) | I(0) | I(I) |
| 1 | 5,993 | 6,804 | 6,666 | 7,920 | 8,94 | 9,411 |

| Obtained F Statistic Critical Values | | | | |
|---|---|---|---|---|
| $F_{rate}$ | 8,600 | | | |

| Diagnostic Tests | | | | |
|---|---|---|---|---|
| $R^2 = 0{,}59$ | *F İstatistiği: 5,827(0,00)* | *Breusch – Godfrey LM*: 0,28(0,11) | *Ramsey Reset:1,81(0,06)* | |
| *Adjusted* $R^2 = 0{,}48$ | *ARCH-LM:2,16(0,10)* | *Jarque-Berra :0,061(0,74)* | | |

Table 6: ARDL (1, 1) Model Estimation Results (Dependent Variable:indx)

| Constant | | | | Constant and trend | | | |
|---|---|---|---|---|---|---|---|
| Variables | Coefficient | t statistic | Probability | Variables | Coefficient | t statistic | Probability |
| indx(-1) | 0,411 | 9,516 | 0,00 | indx | 0,419 | 7,819 | 0,00 |
| WTI | -0,008 | -3,221 | 0,02 | WTI | -0,010 | -4,171 | 0,01 |
| WTI(-1) | 0,009 | 2,991 | 0,00 | WTI (-1) | 0,001 | 2,221 | 0,00 |
| C | 0,011 | 5,111 | 0,00 | C | 0,010 | 5,817 | 0,00 |
| | | | | TREND | 0,000 | -0,888 | 0,00 |
| **Constant** | | | | **Constant and trend** | | | |
| Variables | Coefficient | t statistic | Probability | Variables | Coefficient | t statistic | Probability |
| WTI | -0,016 | -2,98 | 0,000 | WTI | -0,018 | -1,56 | 0,000 |
| C | 0,011 | 6,78 | 0,000 | C | 0,014 | 5,90 | 0,000 |
| **Diagnostic Tests** | | | | **Diagnostic Tests** | | | |
| $R^2$ :0,177 | | | | $R^2$ : 0,177 | | | |
| $\overline{R}^2$:0,2219 | | | | $\overline{R}^2$: 0,2201 | | | |
| $X^2_{BG}$:1,001 (0,41) | | | | $X^2_{BG}$ :1,012(0,44) | | | |
| $X^2_{NORM}$ :1071(0,00) | | | | $X^2_{NORM}$: 1191(0,00) | | | |
| $X^2_{WHITE}$:44,11(0,00) | | | | $X^2_{WHITE}$: 49,11(0,00) | | | |
| $X^2_{RAMSEY}$ :8,11(0,00) | | | | $X^2_{RAMSEY}$:9,99(0,00) | | | |

It is seen in Table 6 that the WTI coefficient is negatively linked to the foreign currency series in both models. The coefficient of the oil price variable is significant in both models. According to the long-term coefficients obtained, a 1% increase in oil prices reduces the dollar rate index by 0.016% for constant model and by 0,018 for Constant and trend. $X^2_{NORM}$, $X^2_{BG}$, $X^2_{WHITE}$ and $X^2_{RAMSEY}$ tests were used for the diagnostic tests of the model. These are the statistics of normality, autocorrelation, varying variance, and model building error testing, respectively. Accordingly, the jarque-bera test was used in the model for normality. According to the test statistics, the error terms are normally distributed and no autocorrelation in the model. White test results, on the other hand, show that there is no varying variance. In addition, the null hypothesis, which states that the function form of the model is correct (no model building error), is rejected in the fixed model according to the ramsey-reset result, while it is accepted at all significance levels for the fixed and trended model.

Results are in a parallel with the study of Eichenbaum & Singleton (1986), Chaudhuri & Daniel (1998), Amano & Norden (1998), Zhang, Fan, Tsai & Wei (2008), Wang & Wu (2012), Zhang (2013), Beckmann & Czudaj (2013), Lv at al. (2018), Ağazade (2020), Shi at al. (2020), and Torun & Demirelli (2022).

To investigate the short-term relationship, the error correction model (ECM) calculated from the ARDL (1, 1) model was established as follows.

$$\Delta indx_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} \Delta indx_{t-i} + \sum_{i=0}^{m} \alpha_{2i} wti_{t-i} + \alpha_3 + \Delta indx_{t-1} + \alpha_4 + \Delta wti_{t-1} + ECT_{t-1} + u_t \quad (8)$$

In the model, the constant term "c" represents the trend value "t". The $ECT_{t-1}$ is one period lagged value of the series of error terms acquired from the long-run. The coefficient of this variable indicates how much of the deviation from the short-run equilibrium will be corrected in the long run. The short-term estimation results of Equation 8 can be viewed in Table 7.

As seen in Table 7, the short-term effect of the change in WTI on foreign currency is negative and statistically significant in both fixed and fixed and trend models. The coefficient of error correction variable was determined as -0.54 in the fixed model and -0.55 in the fixed and trend model. Probability values are statistically significant. Accordingly, about half of the effect of a shock in WTI on foreign currency disappears within a year for both fixed and fixed and trend models. Accordingly, about half (54%-55%) of the impact of a shock in WTI on foreign currency disappears within a year for both fixed and fixed and trend models. According to the results of the diagnostic test, no problems were encountered in the short-term model either.

Table 7: ECM Based on ARDL (1, 1) Approach

| Constant | | | | Constant and trend | | | |
|---|---|---|---|---|---|---|---|
| Variables | Coefficient | t statistic | Probability | Variables | Coefficient | t statistic | Probability |
| WTI | -0,011 | -2,71 | 0,000 | WTI | -0,012 | -1,56 | 0,000 |
| C | 0,010 | 6,68 | 0,000 | C | 0,012 | 6,01 | 0,000 |
| $ECT_{t-1}$ | -0,54 | 0,033 | 0,000 | $ECT_{t-1}$ | -0,55 | -10,10 | 0,000 |
| Diagnostic Tests | | | | Diagnostic Tests | | | |
| $R^2$ :0,180 | | | | $R^2$ : 0,181 | | | |
| $\overline{R^2}$:0,2291 | | | | $\overline{R^2}$: 0,2311 | | | |
| $X^2_{BG}$:1,001 (0,45) | | | | $X^2_{BG}$ :1,012(0,50) | | | |
| $X^2_{NORM}$ :1066(0,00) | | | | $X^2_{NORM}$: 1169(0,00) | | | |
| $X^2_{WHITE}$:44,18(0,00) | | | | $X^2_{WHITE}$: 49,22(0,00) | | | |
| $X^2_{RAMSEY}$ :8,11(0,00) | | | | $X^2_{RAMSEY}$:9,99(0,00) | | | |

**4.1. Variant Causality (Volatility Spillover)**

After determining the cointegration relationship, it was investigated whether there was a causal relationship between the two series. There are various methods used to determine the causality relationship. However, the causality test in the variance selected for the study is significantly different from other causality tests. In causality tests such as time varying causality, causality is tested in error term averages, while causality is tested in variance in this method. In standard econometric models, the error term variance is expected to be constant. However, many time series fluctuate with major crisis periods and the assumption of fixed variance is not valid. Other causality tests are based on the variance of two variables. They fall short of measuring the volatility spillover effect from changes.

There are two test methods used in this regard. First, the Cheung & Ng (1996) method is based on the cross-correlation function (CCF) of standard residues obtained from the GARCH estimation. However, the portmanteau test used to test the null hypothesis is based on the CCF function and is affected by the sample size problem for small and medium-sized samples when the volatility process is flattened from the sides. The second difficulty in this method is that in the CCF-based volatility spread test, the results take different values according to the degrees of the leads and lags in the VAR model (Hafner & Herwatz, 2008: 222). The second method, the Hafner & Herwartz (2006) test, is based on the LM (Lagrange Multiplier) principle, its application is simpler, and the above-mentioned problems are not experienced. In the Hafner & Herwartz (2006) method, the univariate GARCH model is estimated first.

In previous tests improved by Cheung & Ng (1996) and Hong (2001), methodologies focused on cross-correlation functions. In these tests it is estimated from standardized residuals of univariate GARCHs. Also, a major shortcoming of these methods is that they take on problems, especially when the volatility of the sample series is Leptokurtic. Another critical shortcoming of previous methods is that they are vulnerable to the order selection of leads and lags (Nazlioğlu et al., 2013), which raises questions about the stability and robustness of the method. On the other hand, the Hafner & Herwartz (2006) method eliminates the shortcomings based on the Lagrange Multiplier principle. In addition, since our sample size is quite large, Hafner & Herwartz (2006) works much better under these conditions.

The null hypothesis, which says that there is no causality in the variance between two variables, is defined in Equation (9) as follows.

$$\varepsilon_{it} = \sqrt[\Phi_{it}]{\sigma^2_{it}(1 + z_j'\pi)} \quad (9)$$

Where;

$$z_{jt} = (\varepsilon^2_{jt-1}, \sigma^2_{jt-1})' \quad (10)$$

In Equation (10), $\sigma_{it}$ $\sigma^2_{it}$ are the standardized residuals and conditional volatility of the i series. $\varepsilon^2_{jt-1}$ and $\sigma^2_{jt-1}$ respectively denotes disturbance term and conditional standard deviation, both squared of series j. Normalized balances are regressed on derivatives and the null hypothesis for the process is dependent upon the $\pi$ in the equation. If $\pi = 0$, this implies there is no volatility spillover between variables *i* and *j*. The other hypothesis for, though, is $\pi \neq 0$ which denies there is no volatility spillover from *j* to *i*. The Hafner Herwartz (2006) test confirms the null test through LM test statistics as follows.

$$\lambda_{LM} = \frac{1}{4T}\left(\sum_{t=1}^{T}(\sigma^2_{it} - 1)z'_{jt}\right)V(\Phi_{\mathrm{I}})^{-1}\left(\sum_{t=1}^{T}(\zeta^2_{it} - 1)z_{jt}\right. \quad (11)$$

The value of V ($\Phi_{\mathrm{I}}$) in this equation is as in Equation (12).

In the Haftner and Herwartz method, first $\varepsilon_{it}$ and $\varepsilon_{jt}$ for the GARCH (1:1) model is estimated. Then the standardized residuals $\zeta^2_{it}$ and the GARCH model derivative the value $X_{it}$ is obtained.

In the third step, the $\sigma^2_{it}$term, which is the GARCH model variance, which expresses the volatility process, is calculated using the $z_{jt}$ term. In the next step, the specification indicators in the $\zeta^2_{it} - 1$ expression is regressed on $x_{it}$ and $z'_{jt}$. $\lambda_{LM}$ is obtained by multiplying the $R^2$ from this model with the number of observations T (Hafner & Herwartz, 2006:137-141). In this context, the ARCH (1;1) and GARCH (1;1) model results can be viewed in Table 8.

Table 8: ARCH (1,1) and GARCH (1,1) Models

| Variable | Coefficient | St.Dev. | Z stst. | Probability |
|---|---|---|---|---|
| C | 0.005118 | 0.000221 | 7.77141 | 0.000 |
| Y (-1) | 0.552791 | 0.022141 | 12.2784 | 0.000 |
| Equality of Variance | | | | |
| C | 0.0000214101 | 2.10901 | 4.21011 | 0.000 |
| RESID $(-1)^2$ | 0.58011 | 0.06119 | 7.36012 | 0.000 |
| GARCH (-1) | 0.22197 | 0.03112 | 7.73211 | 0.000 |
| Variable | Coefficient | St.Dev. | Z stst. | Probability |
| C | 0.001293 | 0.002410 | 0.74511 | 0.02 |
| X (-1) | 0.18111 | 0.087432 | 2.22121 | 0.00 |
| Equality of Variance | | | | |
| C | 0.00394 | 0.0000 | 2.41217 | 0.00 |
| RESID $(-1)^2$ | 0.22908 | 0.03111 | 4.29786 | 0.00 |
| GARCH (-1) | 0.554509 | 0.07600 | 5.55455 | 0.00 |

In the equation, where Y is the volatility of foreign currency and X is WTI, ARCH (1;1) and GARCH (1;1) models are as follows, first for Y and then for X, respectively.

$$Y=0.005118+0.552791\ y\ (-1)$$
$$X=0.001293+0.18111\ x\ (-1)$$
$$Y=0.0000214101 + 0.58011 resid\ (-1)^2 + 0.22197\ GARCH\ (-1)$$
$$X=0.001293 + 0.22908\ resid\ (-1)^2 + 0.554509\ GARCH\ (-1)$$

Accordingly, the coefficients in all models are statistically significant. The coefficients in the variance equations are positive and the conditional variance of the foreign currency volatility converges towards oil prices.

ARCH parameter indicates resid $(-1)^2$ and GARCH parameter indicates GARCH (-1) and different values are reached in both models. If α+β expression is less than "1", it indicates the degree of persistence of the shock. The magnitude of the coefficient "α" while giving its response to market movements, the size of the "β" coefficient expresses the reaction of volatility-to-volatility resistance (Yılmaz & Altay, 2016: 668). In the study, in the GARCH where x is the dependent variable, when the coefficient of GARCH (-1) is compared with 0.55 and the ARCH coefficient RESID $(-1)^2$ is 0.22, the volatility of oil prices is mostly due to the GARCH effect, that is, in the long run. It can be said that the volatility effect has increased. In the last part of the study, the results of the $\lambda_{LM}$ statistics are evaluated and can be viewed in Table 9.

Table 9: Volatility Spillover Results

| Volatility in Variance | LM Stat. | Probability |
|---|---|---|
| WTI $\rightarrow$ foreign currency volatility | 10.01 | 0.00 |
| foreign currency volatility $\rightarrow$ WTI | 9.18 | 0.00 |

According to the results, both the volatility spillover effect from oil prices to foreign currency and the existence of a volatility relationship from foreign currency to WTI have been reached.

**5. Conclusion**

Two of the variables that directly affect the success of macroeconomic policies are foreign currency and oil prices. Oil, which is used as a raw material in many industries, is a variable that is always on the attention of policy makers. Sharp changes in oil prices during periods of events that directly affect economic variables are an indication of how dependent their economies are on crude oil. Apart from the oil crises, this situation has been felt even more by the recent pandemic and the Russia-Ukraine war. On the other hand, low savings, and investment rates especially in developing countries, high budget and foreign trade deficits, and high imports of raw materials and intermediate goods due to foreign savings increase the importance of foreign currency even more.

Causality in variance shows the reaction of the market to new information. Information reaching the markets causes volatility in the returns of assets. This information may originate from the national market as well as from international markets. Likewise, the flow of information may originate from stock markets as well as from commodity markets such as oil. Knowing the volatility spillovers that cause volatility in markets and asset returns is important for portfolio risk management, investment decisions, internationally operating companies, and international capital movements. Instability in foreign currency negatively affects many variables, especially foreign trade. According to the empirical analysis results of the study, a long-term cointegration relationship was determined between WTI and the US dollar, that is, these two variables act together in the long run. In addition, there is a volatility spillover effect from the fluctuation in WTI to the foreign currency. Recently, excessive fluctuations in oil prices have increased the upward pressure on foreign currency, which disrupts macroeconomic stability and makes it difficult to reach macro targets. Therefore, it may be useful to consider the shocks in oil prices in foreign currency policies. Excessive fluctuations in oil prices increase the upward pressure on exchange rates, which destabilizes the macroeconomic and makes it difficult to reach macro targets. Therefore, it may be useful to consider the shocks in oil prices in exchange rate policies.

**Data availability:** The datasets generated and analyzed during the current study are available in the World Bank Indicator, Materialflows.net, World Intellectual Property Organization repository.
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**Compliance with ethical standards**
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