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Crude Oil Price and Exchange Rate: An Analysis of the Asymmetric Effect and Volatility Using the Non Linear Autoregressive Distributed Lag and General Autoregressive Conditional Heterochedasticity in Mean Models

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ABSTRACT

This study aims to examine the asymmetric effect of crude oil price and volatility on exchange rate. The price of West Texas Intermediate (WTI) crude oil is a proxy for crude oil, while IDR/USD exchange rate is a proxy for exchange rate. The time series of both WTI crude oil price and IDR/USD exchange rate span the period of January 2006 to December 2017. To test the asymmetric effect, the non linear autoregressive distributed lag - general autoregressive conditional heterochedasticity in mean model is used. The results of the analysis show that in the short-term there is an asymmetric effect of crude oil price and volatility on the IDR/USD exchange rate while in the long-term such effect does not exist.

Keywords: Crude Oil Prices, Exchange Rates, Volatility, Non Linear Autoregressive Distributed Lag Model, General Autoregressive Conditional Heterochedasticity in Mean Model
JEL Classifications: C120, C320, E310, G150

1. INTRODUCTION

Crude oil is one commodity that plays an important role in the world's economy, and all countries require this particular commodity to build their economy. For this reason, crude oil is one of the commodities traded on the international market, and each country takes part in trading this commodity both as the exporters and the importers. In crude oil commodities trade, the transaction tool used is generally the United States currency. Therefore, changes in crude oil prices can cause changes in currency rate.

The effect of crude oil prices on currency exchange rate can be explained through channels, as follows: (1) an increase in crude oil prices can lead to the transfer of wealth from crude oil importing countries to crude oil exporting countries which causes the wealth of the exporting countries to rise. The rise in wealth can cause the desired consumption expenditure to go up (desired savings fall) which eventually increases domestic interest rates (Cologni and Manera, 2008; Abel et al. 2014); (2) an increase in crude oil price can cause companies in the importing countries to be in need of more money to buy crude oil which lead to an increase in demand for money. If the demand for money is greater than the money supply, then the domestic interest rate in the importing countries rises (Brown and Yucel, 2002; Dogrul and Soytas, 2010) and forces the domestic currency to depreciate; (3) an increase in crude oil prices can cause an increase in manufactured goods prices (Adam et al. 2016; Muthalib et al. 2018) as crude oil forms an input of production in all industrial sectors such as goods, electricity, transportation, and financial industries. The continuous increase in the price of manufactured goods can cause an increase in inflation so that the government of a country through its monetary policy will raise interest rate to suppress the inflation (Benada, 2014; Adam et al., 2015; Saidi et al., 2019). A higher interest rate can cause the exchange rate of the domestic currency to depreciate (Adam et al., 2017).

A number of studies that particularly examine the influence that crude oil prices have on exchange rates have been carried out. Some researchers classify this influence into two types of effects, namely symmetry and asymmetry effect (Ngoma et al. 2016; Arouri and Jawadi, 2010; Kumar, 2019). While the studies related to the former have been widely carried out, the studies related to the latter, the asymmetry effects of crude oil on exchange rates have been very few. Among the few are the study of Nouira et al. (2018) and Oyelami (2018). So far, the analytical tools used in previous studies to test the asymmetry effect of crude oil prices on the exchange rates were non linear autoregressive distributed lag (NARDL), asymmetric VAR (AVAR), and autoregressive momentum threshold (M-TAR) as well as multifractal cross-correlation analysis (MF-CCA).

In Indonesia, studies of the symmetry relationship between crude oil prices and exchange rates have been carried out, among others, by Adam et al. (2018). The study found a short-term symmetrical relationship from the price of crude oil to the exchange rate. Meanwhile, the asymmetry effect of crude oil prices on exchange rates was among others, investigated by Baek and Choi (2018) using the NARDL model as a tool of analysis. The study found that in the long run, there is an asymmetry effect of crude oil price on exchange rate.

This present study also uses the NARDL model. However, it includes the variable of volatility as a regressor and thus, it is different from the previous study conducted by Baek and Choi (2018). Furthermore, according to our best of knowledge, studies that particularly look at the asymmetric effects of crude oil prices and volatility on the exchange rate have never been done in Indonesia. Therefore, this study aims to examine the asymmetric effect of crude oil prices and volatility on the IDR/USD exchange rates. To test this effect, the NARDL model and the general autoregressive conditional heterochedasticity in mean (GARCH-M) model are used.

2. LITERATURE REVIEW

Several studies have looked into the asymetric effect of crude oil prices on exchange rates. Even so, they are still very little. The previous researchers, for the purpose of analysis, used models such as the NARDL, the AVAR, the M-TAR, and the MF-CCA.

Kisswani et al. (2019), Muse and Omoniyi (2018), and Oyelami (2018) are among those who applied the NARDL in their research. Kisswani et al. (2019) examined the asymmetric relationship between oil prices and exchange rates in ASEAN-5 countries (Malaysia, Thailand, Indonesia, Singapore, and Brunei Darussalam). The results of relationship test using quarterly data from 1970Q1 to 2016Q4 revealed a long-term asymmetric influence of oil prices on exchange rates in Indonesia and Malaysia, but it was not the case for the other ASEAN-5 countries. Meanwhile, Muse and Omoniyi (2018) investigated both symmetry and asymmetry effect of oil price on exchange rate in Nigeria. They used annual data within January 2000 to December 2015 period. The test results showed that there are no symmetry and asymmetry effects of oil price on the exchange rate. Similarly, Oyelami (2018) also investigated the existence of symmetry and asymmetry impact of oil price on several macroeconomic variables (output, inflation and exchange rates). The test results revealed that in the long and short term, an asymmetric effect of oil prices on output, inflation and exchange rates exists, whereas a symmetry effect does not exist.

Other researchers applied the AVAR model to estimate the asymmetry effect of oil prices on exchange rates, among others Yalcin et al. (2014), Atem et al. (2015), Babatunde (2015), and Tasar (2017). Yalcin et al. (2004) investigated the asymmetric effects of oil prices on GDP, CPI and real exchange rate in Turkey. The test results showed that in the long run, oil price affect GDP, CPI and exchange rates. As the oil prices rose, the CPI and the exchange rates also rose, while GDP dropped. Similarly, Atems et al. (2015) examined the asymmetric effect of oil prices on the exchange rates of Australian countries (AUD/USD), Canada (CAN/USD), New Zealand (NZD/USD), Norway (NOK/USD), Sweden (SEK/USD), and the United Kingdom (UK/USD). The test results on monthly data that stretched from January 1974 to June 2013 showed that the exchange rates respond asymmetrically to oil prices. Babatunde (2015) also investigated symmetry and asymmetry effect of oil price on exchange rate in Nigeria using monthly data from January 1997 to December 2012. The test results revealed that oil price has symmetry and asymmetry influence on exchange rate. Furthermore, an investigation on asymmetry effect of oil price on exchange rate in Romania was conducted by Tasar (2017). He used monthly data from January 2004 to June 2016. In contrast with the three studies earlier mentioned, there is no asymmetry effect of oil price on exchange rate in this study.

Additionally, some researchers applied the M-TAR model to see whether or not oil prices asymmetrically affect exchange rates. Ahmad and Hernandes (2013) for example, applied this model and revealed the existence of a long-term asymmetric impact of oil prices on exchange rate in Brazil, Nigeria and The United Kingdom. Their analysis was based on monthly data from January 1970 to January 2012 in those countries. Ali et al. (2016) also examined the effect of oil prices on exchange rates in India using the monthly data that stretched from January 1980 to July 2013. The test results showed that in the long run, there is an asymmetric effect of oil price on the exchange rate.

Furthermore, Jiang and Gu (2016) applied the F-DCCA model to test the asymmetric effect of oil prices on the currency rates of a number of countries including Canada (CAD/USD), Mexico (NOK/USD), Norway (GBP/USD) the United Kingdom (UK/USD), Japan (JPY/USD), Australia (AUD/USD), Europe (EUR/USD), and Korea (KRW/USD). The results of the test on monthly data from January 1994 to December 2014 revealed the asymmetric effect of oil prices on the exchange rates to exist.

3. DATA AND METHODOLOGY

3.1. Data

To analyze the asymmetric effect of crude oil price on exchange rate, we use two types of time series data comprising the time series data on crude oil price and on exchange rate. The IDR/USD (in Indonesian Rupiah) is used as a proxy for the exchange rate as Indonesia uses it as a means of transaction in international trade. Meanwhile, the price of West Texas Intermediate (WTI) crude oil (in USD per barrel) is used as a proxy for crude oil price.

Both the time series data are monthly time series from January 2006 to December 2017. The data for IDR/USD exchange rate are obtained from the Fussion Media Limited while the data for WTI crude oil price are sourced from Federal Reserve Bank of St Louis, United States.

3.2. Methodology

For the purpose of data analysis, this study applies the NARDL-GARCH-M model which is a combination of the NARDL model introduced by Shin et al. (2014), and the GARCH-M model developed by Engle et al. (1987). The NARDL model has similar steps of estimation to the ARDL model developed by Pesaran and Shin (1999), while the NARDL-GARCH model follows the NARDL-GARCH steps proposed by Heij et al. (2004), and Asteriou and Price (2001).

The NARDL-GARCH-M model stating a one-way relationship from the price of crude oil (denoted by OIL) to the IDR/USD exchange rate (denoted by EXC) involves the partial sum of positive changes in crude oil price variable (labelled with OIP) and the partial sum of negative changes in crude oil price (labelled with OIN) variable. The OIP and OIN variables at *t* time are defined as follows:

$$OIP_t = \sum_{i=1}^{t} \max[\Delta OIL_i, 0] = \sum_{i=1}^{t} \max[D(OIL_i), 0]$$

$$OIN_t = \sum_{i=1}^{t} \min[\Delta OIL_i, 0] = \sum_{i=1}^{t} \min[D(OIL_i), 0]$$

Where max [D (OIL_i), 0] = D (OIL_i) for D $(OIL_i) > 0$ and max [D (OIL_i), 0] = D(OIL_i) for D$(OIL_i) \leq 0$, and also min [D(OIL_i),0] = D (OIL_i) for D$(OIL_i) < 0$ and min [D(OIL_i),0] = D(OIL_i) for D$(OIL_i) \geq 0$. Notation of $\Delta OIL_i = D(OIL_i)$ denotes the changes in the prices of crude oil where $D(OIL_i) = OIL_i - OIL_{i-1} = OIL - OIL(-1)$.

The NARDL(p,q,r)-GARCH-M (1,m) model which states the one-way asymmetric relationship from the price of crude oil to the IDR/USD exchange rate is as follows:

$$EXC_t = C + \sum_{i=1}^{p} \alpha_i EXC_{t-i} + \sum_{j=1}^{q} \beta_j OIP_{t-j} + \sum_{k=1}^{r} \theta_k OIN_{t-k} + \vartheta \log(H_t) + \varepsilon_t \quad (1)$$

$$H_t = w + \sum_{i=1}^{l} \gamma_i \varepsilon_t^2 + \sum_{j=1}^{m} \delta_j H_t^2 \quad (2)$$

where C, w, are intercept, α_i (i = 1,…,p), β_j (j = 0,…q), θ_k (k= 0,…,r), ϑ, γ_i (i = 1,…,l), and δ_j (j = 1,…,m) are the variable coefficients. Furthermore, ε_t is error and H_t is error variance of ε_t, while p, q, r, l and m are lengths of time lag. Equation (1) is an NARDL equation that involves an error variance logarithmic variable that is log(H_t) as a variable of volatility between OIP, OIN and EXC. Meanwhile, equation (2) is the variance equation. In equation (1), the OIP, OIN and EXC variables are assumed to be stationary, and with errors that are unautocorrelated and homoscedastic.

Equations (1) and (2) can be changed to the error correction model (Heij et al. 2004) as follows:

$$D(EXC_t) = \beta_0 D(OIP_t) + \theta_0 D(OIN_t) + \pi EC_{t-1} + \sum_{i=1}^{p-1} \alpha_i^* EXC_{t-i} + \sum_{j=1}^{q-1} \beta_j^* OIP_{t-j} + \sum_{k=1}^{s-1} \theta_j^* OIN_{t-k} + \vartheta \log(H_t) + \varepsilon_t \quad (3)$$

$$H_t = w + \sum_{i=1}^{l} \gamma_i \varepsilon_{t-i}^2 + \sum_{j=1}^{m} \delta_j H_{t-j}^2 \quad (4)$$

where πEC_{t-1} is an error correction which states that the long-term asymmetric effect of oil prices on the IDR/USD exchange rate is corrected by π% to go into equilibrium. EC_{t-1} is a time series formed from the equation.

$$EC_{t-1} = EXC_{t-1} - C^* - \beta OIP_{t-1} - \theta OIN_{t-1} \quad (5)$$

where β and θ are long-term multiplier coefficients. If between the partial sum of positive change in crude oil price (OIP), the partial sum of negative change in crude oil price (OIN), and exchange rate IDR/USD (EXC) are not cointegrated, then the models (3) and (4) are the NARDL-GARCH-M models in the first difference but the term πEC_{t-1} is dropped. Thus the asymmetric effect of crude oil prices on the IDR/USD exchange rate will be a short-term effect.

To estimate the NARDL-GARCH-M model, the steps taken are as follows. The first step is to carry out stationary testing using the Augmented Dickey-Fuller (ADF) test developed by Dickey and Fuller (1979), and the Philips Perron (PP) test developed by Phillips and Perron (1988). The null hypothesis of these two tests is that the time series has a unit root (time series is not stationary). The second step is to perform a testing for cointegration, only if the test results in the first step, one or three variables involved in

Table 1: Unit root test

Variable	ADF test statistics		PP test statistics	
	Constant	Constant and linear trend	Constant	Constant and linear trend
OIP	−0.7668	−0.7668	−11.0464	−0.8794
D (OIP)	−10.3240*	−10.5975*	−10.3399*	−10.5351*
OIN	−0.7135	−2.8821	−0.7066	−2.4151
D (OIN)	−6.5936*	−6.5781*	−6.6542*	−6.6390*
EXC	−0.5114	−1.9237	−0.5969	−2.0559
D (EXC)	−11.0710*	−11.0609*	−11.0595*	−11.0464*

*,**Are significant at 1%, 10%. Source: Own processing

the NARDL model are stationary in the first difference (also called integrated of order 1, or I[1] process). The cointegration tests used are the Engle-Granger (EE) developed by Engle and Granger (1987) and the Phillips-Ouliaris (PO) developed by Phillips and Ouliaris (1990). Both the EE and PO cointegration tests are used if the three variables: OIP, OIN and EXC in equation (5) are I (1) process. The EE cointegration test uses the ADF stationary test methodology, while the PO test uses the PP stationary test methodology. The null hypothesis of both cointegration tests, EE and PO is H_o: all 3 time series OIP, OIN and EXC are notcointegrated (or if RES is stationary on level).

4. RESULTS AND DISCUSSION

4.1. Results

The first step is to carry out a test for stationarity on the three time series: the partial sum of positive change in crude oil price (OIP), the partial sum of negative change in crude oil price (OIN), and the exchange rate of IDR/USD (EXC). Table 1 presents the summary of the stationarity test results. Based on the result, the 3 time series are stationary in the first difference or I(1) process.

The second step is to carry out a test for cointegration. This step is conducted because all the time series: the partial sum of positive changes in the price of crude oil, the partial sum of negative changes in the price of crude oil, and the exchange rate of IDR/USD is I(1) process. The results of the EE and PO cointegration tests are summarized in Table 2. It can be seen from Table 2 that the statistical values of the EE and PO test are not significant. Thus, the null hypothesis which states that the 3 time series: the partial sum of positive changes in the price of crude oil, the partial sum of negative changes in the price of crude oil, and the non-aggregated IDR/USD exchange rate are accepted. In the other words, the partial sum of positive changes in the price of crude oil, the partial sum of negative changes in the price of crude oil, and the exchange rate of IDR/USD do not have a long-term relationship.

In relation to the results of the cointegration test above, the model estimated is the NARDL-GARCH-M model in the first difference. The length of time lag is determined based on the AIC information criteria (Akaike information criterium), namely p = 2, q = 0, r = l, m = 1. So, the estimated NARDL-GARCH-M model is the NARDL(2.0,1)-GARCH-M(1,1) model. The results of this model's estimation are summarized in Table 3.

The coefficient D (OIP) is positive and 5% significant. Thus it is concluded that in the short term, the partial sum of positive changes in the crude oil prices has an influence on the IDR/USD exchange rate. A positive sign of the coefficient D (OIP) indicates that such influence is positive which means that if the price of crude oil rises, the exchange rate IDR/USD depreciates (or the Indonesian currency depreciates). Meanwhile, the coefficient D (OIN) and D (OIN [−1]) are negative and 1% significant. It means that in the short term, a decline in crude oil price causes the Indonesian currency to depreciate. Furthermore, the coefficients of D (OIN) and D (OIP) differ from sign and are not the same so that, in the short term, there is an asymmetric effect of crude oil price on IDR/USD exchange rate.

Table 2: The EE and PO test for cointegration

Variable	EE Test/ADF test statistics		PO test/PP test Statistics	
	Constant	Constant and linear trend	Constant	Constant and linear trend
RES	−2.3103*	−2.7570*	−2.2570*	−2.6496*

*Mean insignificant (Or the null hypothesis is accepted). Source: Own processing

Table 3: The estimation results of NARDL (2,0,1)-GARCH-M (1,1) model

Independent variable and constant (intercept)	Coefficient	Z-statistic	Probability
Coefficients of NARDL (2,0,1) Model Dependent Variable: D (EXC)			
LOG (H)	−4.8059	−2.1193	0.0341
D (EXC[−1])	−0.0522	−0.4719	0.6370
D (EXC[−2])	−0.2139	−1.7410	0.0817
D (OIP)	10.7438	2.2793	0.0227
D (OIN)	−22.3821	−8.4685	0.0000
D (OIN1[−1])	−9.0786	−1.8318	0.0670
Coefficient of Variance Equation Dependent Variable: H (residual variance of NARDL (2,0,1) model)			
C	5453.708	1.7215	0.0852
$\varepsilon(-1)^2$	0.5410	3.6288	0.0003
H (−1)	0.4699	3.9815	0.0001

The Q-statistic value for the time lag =3 is 3.8014, and ARCH statistic value based on Chi-square statistic is 5.022334. NARDL: Non linear autoregressive distributed lag, GARCH-M: General autoregressive conditional heterochedasticity in mean

4.2. Discussion

The study found that in the short term, there was an asymmetric effect of crude oil prices on the IDR/USD exchange rate. This finding agrees with the theory put forward by Cologni and Manera (2008), and Abel et al. (2014). Empirically, the finding is in line with the findings of Kisswani et al. (2019), Oyelami (2018), Yalcin et al. (2004), and Babatunde (2015). In addition, it is also in accordance with the finding of Abdullahi et al. (2016), Ahmad and Hernandes (2013), and Jiang and Gu (2016).

Nevertheless, the finding in this study is particularly different from that of Baek and Choi (2018), in which crude oil price was found to impact exchange rate in the long-term but not in the short-term. This difference in finding can be caused by the study period and the exchange rate variables used in the model. The results of this study are also not in line with the studies conducted by Tasar (2017), and Muse and Omoniyi (2018). The research locations or the countries in which the studies were conducted may account for such differences as each country has different social, cultural and economic conditions.

5. CONCLUSION

This study aims to examine the asymmetric effect of crude oil prices and the volatility on the IDR/USD exchange rate. The data used consist of time series data on crude oil price and the IDR/USD exchange rate. Both the time series spanned the period of January 2006 to December 2017. The time series data on crude oil price were divided into the time series of the partial sum of positive changes, and the time series of the partial sum of negative changes.

To test the asymmetric effect, the data analysis tool applied is the NARDL-GARCH-M model. Since the 3 time series: the partial sum of positive changes in crude oil price, the partial sum of negative changes in crude oil price, and the IDR/USD exchange rate are process I(1) and not cointegrated, then based on the results of analysis using the NARDL-GARCH-M model, it was found that in the short-term, there is an asymmetric effect of crude oil price on the IDR/USD exchange rate.

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