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Article

# A nexus of crude oil prices and real effective exchange rate movement in Thailand

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**Abstract:** The impact of crude oil price fluctuations on the real effective exchange rate (REER) has been widely debated, but specific evidence, particularly for developing countries in Southeast Asia, is scarce and inconclusive. This issue, especially concerning both short- and long-term relationships, remains inadequately addressed, affecting these countries for risk management related to oil price fluctuations. This study aims to fill this gap by examining these relationships in Thailand context to provide more evidence on how the REER in Southeast Asia responds to changes in crude oil prices. Monthly data of crude oil prices in Dubai market and the Thai baht REER from 2000 to 2019 were employed. Johansen co-integration test and Vector Error Correction Model (VECM) were used for analyzing long-term and short-term relationships, respectively. The results indicate a significant negative long-term relationship between crude oil prices and the REER, with a 0.31% reduction in the REER for every 1% increase in the real price of oil. However, in the short term, VECM analysis reveals significant movements in the REER in response to external shocks. On average from 2000–2019, the significant fluctuations in the REER are quickly alleviated and adjusted to its long-run equilibrium, typically by 2% in the following month following external shocks such as crude oil price fluctuations. Given these findings, which highlight the long-term relationship between the REER and crude oil prices and its short-term adjustment, it is suggested that when there is a shock from the crude oil prices, the government can strengthen short-term oil price controls or monetary subsidies to mitigate the extensive repercussions of energy market fluctuations, as such interventions would have a lesser impact on the long-term equilibrium of the REER.

**Keywords:** real effective exchange rate; oil price; cointegration; volatility; VECM; Thailand

## 1. Introduction

Crude oil is one of the most fundamental resources in production, influencing a range of macroeconomic factors such as output growth, inflation, unemployment, and exchange rates. Fluctuations and shocks in crude oil prices wield considerable influence over exchange rate stability, especially in countries that heavily rely on oil imports (Abubakar, 2019; Baek, 2021; Coleman et al., 2016; Oriavwote and Eriemo, 2012; Tiwari et al., 2013). When oil prices surge, they trigger higher production costs, leading to increased commodity prices, subsequent domestic inflation, and currency devaluation (Ferraro et al., 2015; Huang and Feng, 2007). This scenario can motivate investors to seek greater returns on their financial assets, potentially redirecting capital to countries with more enticing investment prospects.

In the past period, the price of global crude oil has been volatile in several times, for example, in 2002, the price was $17–$26 per barrel, then almost doubling to $53 per barrel in October of the year 2004 and rose almost six times to $146 per barrel in July 2008. This was the peak point before sharply plunging in December of the same year to $42 and reaching approximately $61 per barrel in 2009. The volatility was largely due to unrest in crude oil-producing countries, such as the political crisis in the Middle East, or the revolutionary problems in Arab countries including boycott Iran's crude oil imports from the United States and European countries because of nuclear weapons problems (Hamilton, 2009; Kilian, 2009; Kilian and Park, 2009).

Based on existing studies, they have yielded varying outcomes regarding the correlation between the real effective exchange rate and crude oil prices. In certain cases, such as in Azerbaijan (Hasanov, 2010), Saudi Arabia (Mahmood, 2021), and Pakistan (Iqbal and Raziq, 2018), a positive relationship between these two variables has been established as an exporting country. Meanwhile, negative relationships are established in importing countries such as in India (Alam et al., 2020), Nigeria (Musa et al., 2020), and Mexico (Singhal et al., 2019). This might be influenced by terms of trade that when oil prices rise, the countries as oil-exporting countries experience an increase in export revenues, leading to a stronger trade balance and an appreciation of their currency. This appreciation is reflected in the real effective exchange rate (REER), which measures the value of a country's currency relative to a basket of foreign currencies weighted by trade flows. However, some studies have indicated that the direction of the relationship between these variables can be determined by other economic covariates (Jiang et al., 2022; Kaushik et al., 2014). These variations can be attributed, in part, to factors such as the size of economy (Chang and Su, 2014; Lizardo and Mollick, 2010), the method of currency bundle calculation (Chinn, 2006; Darvas, 2012), speculation (Breen and Hu, 2021; Manasseh et al., 2019; Zhang et al., 2022)., or market sentiments (Chen et al., 2016; Habib et al., 2016).

Thailand, which is a developing country and has an open economy, also depends heavily on crude oil imports from abroad. Several times, Thailand cannot avoid the impact of oil price volatility to forex system due to the import of crude oil from abroad must always be converted through the exchange rate into Thai Baht (Basnet and Upadhyaya, 2015; Jiranyakul, 2015; Law, 2018). If crude oil prices have risen, it requires more Baht to exchange foreign currency for imports. The Baht therefore tends to weaken (depreciate) or vice versa if the price of crude oil is lower will have to spend less baht on imports. The baht therefore tends to increase in value (appreciate). The effect of each fluctuation often affects a wide range of Thai production units involved in price competition with foreign countries, and Thai consumers who must face real income changes.

Despite the current literature that explores the relationship between crude oil price, economic growth, and the REER. There are limited and up-to-date studies examine the impact of changes in crude oil price on the exchange rate in 11 countries of the Association of Southeast Asian Nations (ASEAN) (including Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam), especially in Thailand. Therefore, this study aims to revisit and analyze the impact of changes in crude oil prices on the exchange rate of Thailand by using time series tools to find conclusions about both short-term and long-term adaptation of exchange rates with oil prices that are related in any pattern. The result will be beneficial to the government in oil-risk management and the manufacturing sector in preparing for the changes that will occur in the future.

## 2. Materials and methods

### 2.1. Theoretical considerations

The model from this study was applied from the study of Mundell-Fleming-Dornbusch (Dornbusch, 1976; Fleming, 1962; Mundell, 1963). Although this concept was developed in 20th century, it remains contemporary as it draws from international monetary perspectives concerning the management of money stock and manipulation of interest rates by central banks. The concept remains applicable for several countries that prioritize interest rate policies to stabilize their international monetary systems. Over time, the model has been validated, referenced, and cross-verified in numerous global studies in various contexts (Bjørnland, 2008; Burakov, 2017; Huang and Feng, 2007). Building on this groundwork and guided by the insights from its development by Huang and Feng (2007), we formulated the relationship between crude oil prices and the REER, as shown in Equation (1).

$$o_t = o_{t-1} + \varepsilon_t^o \tag{1}$$

where, $o$ is the real oil price representing the exogenous shock in this study and in the form autoregressive lag 1 or AR(1). The current crude oil price is represented as a function of the crude oil price in a previous period as explained in Equation (2).

$$y_t^s = s_t + \gamma o_t \tag{2}$$

where, $s_t = s_{t-1} + \varepsilon_t^s$.

The aggregate supply, $y_t^s$, depends on the production capacity, $s_t$, of production units. The current production capacity depends on the production capacity of previous periods when the real oil prices-as an exogenous factor-affect it. The parameter $\gamma \leq 0$ implies that rising oil prices will decrease gross domestic product.

$$y_t^d = d_t + \phi q_t \tag{3}$$

where, $d_t = d_{t-1} + \varepsilon_t^d$.

Here, $y^d, d, q$ is the aggregate demand for output, the aggregate demand, and the real exchange rate, respectively. According to Dornbusch model, the product demand depends on the real exchange rate. When the currency devalued, export capacity increased while imports decreased, increasing demand for productivity.

$$y_t^d = y_t^s \tag{4}$$

Equation (4) represents the equilibrium of the unit of production, meaning the total demand for units of production is equal to the supply of units of production.

$$r_t = r^f + \beta[E_t(p_{t+1} - p_t)] + \varepsilon_t^r \tag{5}$$

where, $r_t = r_{t-1} + \varepsilon_t^r$.

Here, $r, r^f, p$ is an interest rate, foreign interest rate, and price level of productivity, respectively. This equation represents domestic interest rate movements arising from foreign interest rates and changes in the expected inflation rate. The determination of interest rates responses to price levels complying with Thailand's monetary policy with inflation targeting.

$$r_1 = r^f + E(s_{t+1} - s_t) \tag{6}$$

Equation (6) shows the condition of Uncovered Interest Parity under the reasonable expectations where $E(s_{s+1} - s_t)$ is expected appreciation (depreciation).

Within Equations (1)–(6), the parameters $\varepsilon_t^0, \varepsilon_t^{\bar{s}}, \varepsilon_t^d, \varepsilon_t^r$ are assigned as the discrepancy or interference (distribute term) caused by oil prices, total supply, aggregate demand, and interest rate, respectively.

Reformatting Equation (1), we have Equation (7).

$$\Delta o_t = \varepsilon_t^o \tag{7}$$

Equations (7) represents the changes in oil prices between period which is a result of the variable noise of oil prices. Likewise, reformatting Equations (2) and (3), we achieve Equations (8) and (9).

$$\Delta y_t^s = \varepsilon_t^{\bar{s}} + \gamma \varepsilon_t^o \tag{8}$$

$$\Delta y_t^d = \Delta d_t + \phi \Delta q_t = \varepsilon_t^d + \phi \Delta q_t \tag{9}$$

Replacing Equations (8) and (9) with Equation (4), we get Equation (10).

$$\begin{gathered} \Delta y_t^d = \Delta y_t^s \\ \varepsilon_t^{\bar{s}} + \gamma \varepsilon_t^o = \varepsilon_t^d + \phi \Delta q_t \\ \Delta q_t = \frac{1}{\phi}\left[\varepsilon_t^{\bar{s}} + \gamma \varepsilon_t^o - \varepsilon_t^d\right] \end{gathered} \tag{10}$$

It can be explained from Equation (10) that changes in the real exchange rate are arising from variables that interfere with production capacity, confounding variables caused by oil prices, and variables caused by the country's gross domestic demand.

Likewise, when considering the changes of the price level with the real exchange rate that can be done by setting Equation (5) equal to Equation (6). The results are derived as shown in Equations (11).

$$\begin{gathered} r^f + \beta[E_t(p_{t+1} - p_t)] + \varepsilon_t^r = r^f + E(s_{t+1} - s_t) \\ \beta[E_t(p_{t+1} - p_t)] + \varepsilon_t^r - E_t(p_{t+1} - p_t) = E(s_{t+1} - s_t) - E_t(p_{t+1} - p_t) \\ (\beta - 1)[E_t(p_{t+1} - p_t)] + \varepsilon_t^r = \Delta q_t \\ (\beta - 1)\Delta p_t + \varepsilon_t^r = \Delta q_t \end{gathered} \tag{11}$$

Equation (11) indicates the real exchange rate change that occurred during the period is caused by the changes in the price level of the product and variables disturbed by interest rates.

## 2.2. Model and assumptions

Considering Equations (10) and (11), the relationship can be simplified and expressed as shown in Equation (12).

$$q_t = f(r_t, o_t, p_t, y_t) \tag{12}$$

where, the real exchange rate ($q_t$) is assumed to be affected by the interest rate ($r_t$), the real oil price ($o_t$), production capacity ($p_t$) , the economic growth ($y_t$).

Considering the volatility of oil prices that often broadly affects many countries, the real exchange rate ($q$) thus will use the real effective exchange rate (REER) as a representative because such variables can explain and indicate the direction of the real exchange rate comparing to other trading partners (Hasanov, 2010; Ferraro et al., 2015; Shaari et al., 2012). It is also an indicator of price competitiveness with trading partners (Chinn, 2006; Combes et al., 2012; Lipschitz and McDonald, 1992). That is, if the real Baht index is high, meaning the Baht depreciated compared to trading partners. In other words, from foreigners' perspectives, Thailand's products are cheap. This point will benefit the Thai export industry that can be able to expand even more.

As for the price level of productivity, the consumer price index (CPI) is applied.

Such variables can illustrate whether the price level in the market is rising or falling. Also, in the manufacturing sector, the best representative variable is GDP but because the real Baht index, CPI, or the real oil price are volatile data, thus, high-frequency data must be used for estimation. Alongside GDP, most data collection is quarterly, this study consequently uses the manufacturing production index (MPI) which is collected on a monthly basis as a representative of productivity in the economy system. The afore mentioned variables can show the direction of production in which each period of production tends to increase or decrease. If the MPI index value is high, it indicates that the production in the industrial sector has increased, meaning that the GDP of the country tends to increase accordingly. From the above variables, a new relationship can be presented as follows:

$$\mathrm{REER}_t = f(\mathrm{ROIL}_t, \mathrm{CPI}_t, \mathrm{MPI}_t) \quad (13)$$

Equation (13) can be inscribed in the form of a long-term relationship as shown in Equation (14).

$$\mathrm{REER}_t = \beta_0 + \beta_1\mathrm{CPI}_t + \beta_2\mathrm{MPI}_t + \beta_3\mathrm{ROIL}_t + \varepsilon_t \quad (14)$$

where, REER = logarithm of real Baht index; CPI = logarithm of consumer price index; MPI = logarithm of manufacturing production index; ROIL = logarithm of real crude oil price.

Equation (14) will be used to examine the data analysis of a long-term relationship abided by the following hypothesis.

Hypothesis:

Taking into consideration the real price of crude oil rises, this variable is an external factor that is correlated with REER. It is hypothesized that when the real price of crude oil rises, higher production costs are higher, including having to use more foreign currencies (such as USD) to pay for imported fuel. Therefore, the demand for Baht decreases. Then the real effective exchange rate will decrease. In terms of CPI and MPI, when it increases, REER is supposed to increase due to an increase in Baht demand.

Due to the period of the study (2000–2019) was during two major crises that affected crude oil prices in the global market, namely, sub-prime crisis in 2008 and oil price clash in 2014. In September 2008, when the company Lehman Brothers which was a large financial company in the United States and the world, declared bankruptcy due to severe financial problems. This event is one of the most important symbols showing the collapse of the United States economy (sub-prime crisis). As a result, the price of crude oil in the world market decreased from around 124 barrel/USD in September 2008 to 42 barrel/USD in January of 2009. Since at that time the United States was the top country that consumed the oil in the world, when the country's economy halted, the demand for oil was logically decreased as well. The event resulted in an oversupply of oil in the market (Hamilton, 2009). Moreover, after the incident, the US government applied monetary policy such as quantitative easing (QE) to solve economic problems, making investment flows to regions that yield higher returns, which would subsequently affect the exchange rate system (Kilian, 2009; Kilian and Park, 2009). On top of that, there were also several events of crude oil price fluctuation at that period, especially an important event in 2014, also known as the oil price crash of 2014. This crisis was a significant event that had far-reaching effects on the global economy, including its impact on the real effective exchange rate of developing countries (Hou et al., 2015). This crisis had led to a sharp decline in oil prices, and by early 2016, crude oil prices had fallen by more than 70% from their peak in June 2014 (Grigoli et al., 2019).

Therefore, in this study, dummy variables were added to the model, denoted as $D_1$ and $D_2$ to reflect these crude oil crises. $D_1$, when assigned a value of 1, represents the sub-prime crisis occurring from October 2008 to December 2013. In contrast, $D_2$ is set to 1 for the period from January 2014 to December 2019, signifying the onset of the crude oil crisis in 2014. It is worth to mention an impact of the dummy variable. If its coefficient is statistically significant, it can be implied that after the financial crisis in the United States, the Federal Reserve Board (FED) solved various financial problems using either QE or measures to address problems, affecting the movement of the Thai Baht index.

When the test proved that the above variables have a long-term correlation, short-term adaptation to long-term equilibrium can be tested using Vector Error Collection Model (VECM) as shown in Equation (15).

$$\begin{aligned}\Delta \mathrm{REER}_t = \alpha_0 + \theta_1 \mathrm{CPI}_{t-1} + \theta_2 \mathrm{MPI}_{t-1} + \theta_2 \mathrm{ROIL}_{t-1} + \lambda D_t \\ + \sum_{i=1}^{n} \beta_i \Delta \mathrm{CPI}_{t-1} + \sum_{i=1}^{n} \varphi_i \Delta \mathrm{MPI}_{t-1} + \sum_{i=1}^{n} \delta_i \Delta \mathrm{ROIL}_{t-1}\end{aligned} \tag{15}$$

where, $n$ is the level of optimal lag. $D_t$ refers to either $D_1$ or $D_2$ dummy variable as explained above.

The rationale for employing the VECM in this research stems from its capability to investigate both long-term and short-term relationships among variables, particularly in cases where cointegration exists. Alongside the potential for misspecification bias, the limitation of not being able to examine long-term relationships is one drawback associated with the use of the vector autoregression (VAR) model. Moreover, another important step is to select optimal lag length. This step is vital for the time-series model as it reveals how many periods back could well understand the current condition. Commonly, traditional criteria used to select are Akaike (AIC), Schwarz (SC) and Hannan-Quinn (HQ). The study emphasizes the selection based on Ivanov and Kilian (2005), suggest that the sample around 200 observations, the SC or HQ would give the optimal estimation.

## 2.3. Data collection

This study used monthly data covering the years from 2000–2019 (240 observations). Data at national level of Thailand, namely, REER was collected from Bangkok of Thailand, while CPI and MPI were compiled from the report of national account of selected years, produced by Office of the National Economic and Social Development Council of Thailand. Meanwhile, crude oil price was collected from Index Mundi database. The data used for analysis has been transformed into logarithmic form, where REER = logarithm of real Baht index; CPI = logarithm of consumer price index; MPI = logarithm of producer index; ROIL = logarithm of real crude oil price.

**Figure 1** illustrates the interplay of the variables under consideration, with a notable emphasis on their dynamics during the sub-prime crisis ($D_1$), which transpired in the latter part of 2008 and early 2009. Throughout this period, the movements of associated indicators in tandem with crude oil prices vividly portrayed a significant period of economic upheaval and adjustment in Thailand.

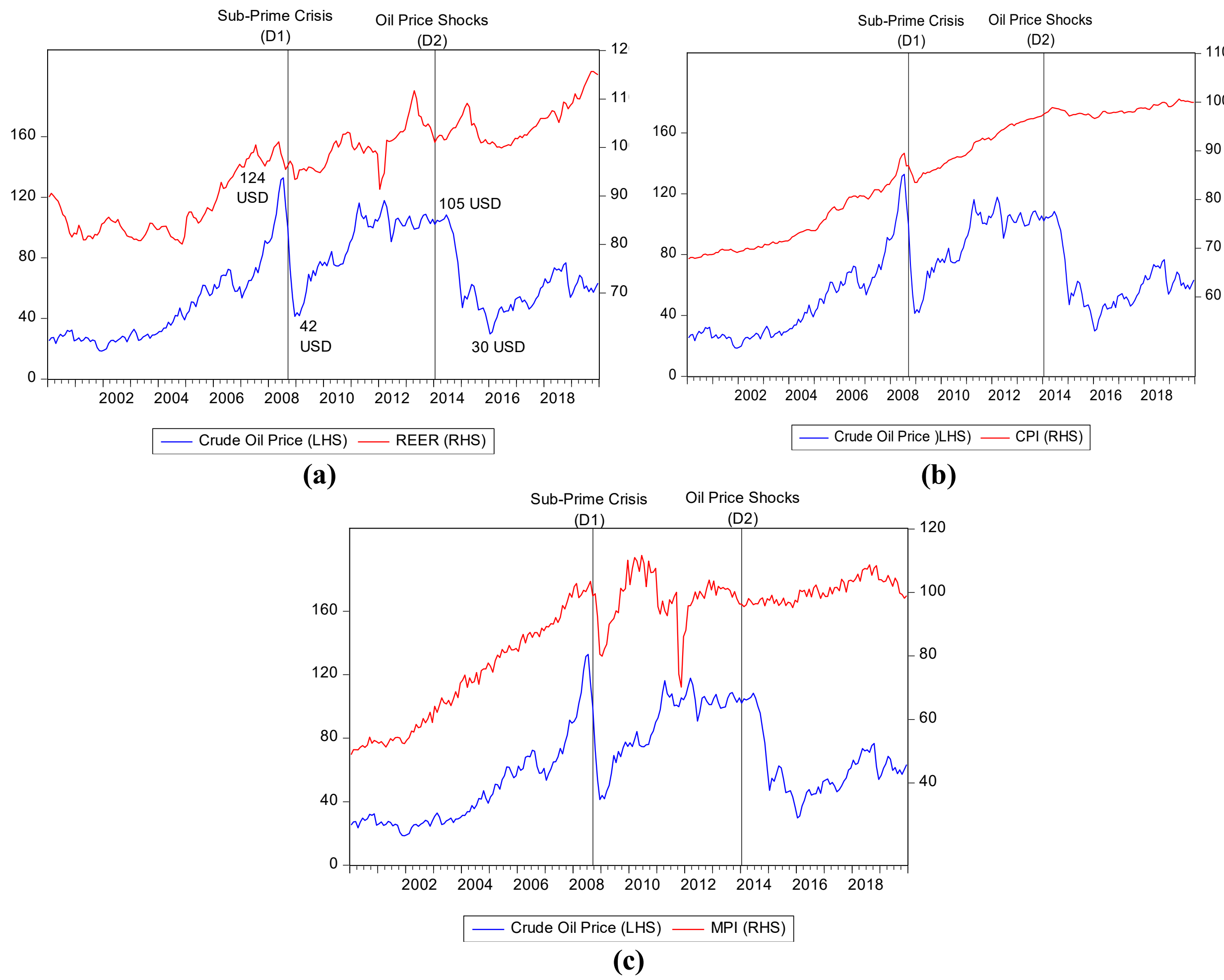


**Figure 1.** Relationship among variables in the study: **(a)** Crude oil price vs. REER; **(b)** Crude oil price vs. CPI; **(c)** Crude oil price vs. MPI.

Source: Compiled by authors from Bank of Thailand (REER), Office of the National Economic and Social Development Council of Thailand (CPI, MPI), and Index Mundi (Crude Oil Price).

In September 2008, as crude oil prices plummeted from approximately $124 per barrel to around $42 per barrel, marking a staggering 70% reduction by February 2009, the REER experienced a slight depreciation, moving from 97 to 95. Simultaneously, the Consumer Price Index (CPI) fell from 87 to 84, signaling a decline in the overall price level. This drop in the CPI could be ascribed to decreased demand and economic uncertainty, resulting in diminished inflationary pressures.

Notably, the Manufacturing Production Index (MPI) also witnessed a significant decline, falling from 100 to 82. This substantial drop in the MPI indicates a sharp reduction in domestic production, potentially carrying implications for employment, consumer consumption, and investor confidence.

## 2.4. Testing method

The time-series data of any variable have random variables character (Working, 1934). When these variables are placed in the chronological order of occurrence, these variables then called stochastic process or random process where the nature of the stochastic variables have 2 models which are stationary stochastic process (or stationary), and non-stationary stochastic process (or non-stationary). In case these data are estimated by the Ordinary Least Square (OLS) method, a spurious problem can occur (Anderson et al., 2001; Granger, 2003). This problem arises from statistical values that show the relationship of variables in the model ($R^2$) is very high, despite the fact that the correlation does not exist theoretically but is a correlation due to the time trend of the variables, including the resulting $t$-stat, which has a standard distribution. As a result, taking such values into consideration may cause mistakes. Therefore, that information must be brought for data stability test or unit root—checking if it is non-stationary or not. In the study of this report, the test by the method of Augmented Dickey Fuller test (ADF) was performed by adding a regression process to itself (autoregressive process) attend to consider in the process Dickey Fuller test (DF). The equation can be expressed in Equation (16).

$$\Delta X_t = \alpha + \beta t + \theta X_{t-1} + \sum_{i=1}^{\rho} \phi \Delta X_{t-i} \quad (16)$$

Hypothesis for the test is:

$H_0: \theta = 0$ (non-stationary)

$H_1: \theta < 0$ (stationary)

When it is determined that every variable is non-stationary, it will be further tested whether the variables are in long-term equilibrium (co-integration) or not. A widely accepted method proposed by Johansen (1988) can be used to assess the relationship between two or more variables, and can quantify the long-term equilibrium relationship between different variables which may have multiple forms.

This is a multivariate co-integration test based on the VAR Model as shown in Equation (17).

$$X_t = A_1 X_{t-1} + A_2 X_{t-2} + \ldots + A_\rho X_{t-\rho} + \varepsilon_t \quad (17)$$

where $X_t$ = vector size $n \times 1$, $\varepsilon_t$ = vector size $n \times 1$ vector magnitude of random error, the error with an average value of 0.

Equation (17) can be modified into the form of Vector Error Correction Model: VECM as Equation (18).

$$\Delta X_t = \pi X_{t-1} + \sum_{i=1}^{\rho-1} \pi_i \Delta X_{t-i} + \varepsilon_t \quad (18)$$

where $\pi = -\left(I - \sum_{i=1}^{\rho} A_i\right) = \pi_i = -\sum_{j=i+1}^{\rho} A_i$ and $\rho$ is an appropriate optimal lag value.

Determining the optimal lag level for this study report is based on the work of Ivanov and Kilian (2005), who investigated determining the optimal lag value of the model. Referring to their study, if the data have a monthly frequency and the sample size is around 200, then the appropriate method is Hanna-Quinn: HQ, represented by Equation (19).

$$\mathrm{HQ}(i) = \ln(|\Sigma|) + \frac{2\ln(\ln T)}{T} \times N \quad (19)$$

where, $i$ is the lag value, $\Sigma$ is the variance matrix value $\varepsilon_t$, and $T$ is the amount of data.

Following the calculation of cointegration Johansen (1988), matrix $\pi$ with $n \times n$

size, can be written in the form of a long-term relationship of ($\beta$) and the adjustment of speed value ($\alpha$) as shown in Equation (20).

$$\pi = \alpha\beta' \tag{20}$$

where matrix $\beta$ and $\alpha$ with $n \times n$ size and $r$ are the number of relationships in long-run equilibrium, the number of long-term equilibrium relations can be calculated by using trace test value, or maximum eigenvalue test in Equations (21) and (22).

$$\lambda_{\text{trace}}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \hat{\lambda}_i) \tag{21}$$

$$\lambda \ln(\hat{\lambda}_{r+1_{\max}}) \tag{22}$$

where $\hat{\lambda}_1, \hat{\lambda}_2, \ldots, \hat{\lambda}_3$ are the eigenvalue value which has been calculated by Equation (23).

$$\left|s_{10}s_{00}^{-1}s_{01} - \lambda s_{11}\right| = 0 \tag{23}$$

where $s_{ij} = \frac{1}{T} R_{it} \frac{R'}{ij}$ which $i, j = 0, 1$.

$R_{0t}$ is the error value matrix obtained from a regression equation with dependent variables $\Delta X$ and independent variables including constant values $\Delta X_{t-1}$, $\Delta X_{t-2}$, ..., $\Delta X_{t-p+1}$.

$R_{1t}$ is the error value matrix obtained from a regression equation with dependent variables $X_t$ and independent variables including constant values $\Delta X_{t-1}$, $\Delta X_{t-2}$, ..., $\Delta X_{t-p+1}$.

This study estimated those mentioned equations using STATA 17. The program is a versatile and robust statistical software package that provides a wide range of tools for data analysis. Its capabilities extend from data import and management to descriptive statistics, advanced statistical modeling, data visualization, and reproducibility, which can be found in several studies in relationship of oil price and real effective exchange rate (Larsen, 2022; Law, 2018). In this study, the data used for analysis has been transformed into logarithmic form.

## 3. Results

The analysis of the relationship between the Thai Baht index and the real oil price has been divided the study into 3 parts include: 1) unit root test; 2) long-term equilibrium test (co-integration); and 3) short-term adaptation testing by Vector Error Correction Model: VECM approach.

### 3.1. Unit root test

This study applied the unit root test through Augmented Dickey-Fuller test (ADF) approach which the results are shown in the **Tables 1** and **2**.

Based on the results of the unit root test in **Table 1**, it is found that we failed to reject the null hypothesis of all variables.

**Table 1.** The results of the unit root test of the data at the significant level 1%, 5%, and 10%.

| Variable | *p*-value | Hypothesis |
|---|---|---|
| REER | 0.8788 | Fail to reject $H_0$ |
| CPI | 0.7202 | Fail to reject $H_0$ |
| MPI | 0.2537 | Fail to reject $H_0$ |
| ROIL | 0.1454 | Fail to reject $H_0$ |

**Table 2.** The results of the unit root test of the data at first difference at the significant level 1%, 5%, and 10%.

| Variable | *p*-value | Hypothesis |
|---|---|---|
| ΔREER | 0.00 | Reject $H_0^*$ |
| ΔCPI | 0.00 | Reject $H_0^*$ |
| ΔMPI | 0.00 | Reject $H_0^*$ |
| ΔROIL | 0.00 | Reject $H_0^*$ |

Note: * means reject null hypothesis ($H_0$) at the significant level 5%.

The results of the unit root test in **Table 2** indicate that the null hypothesis should be rejected for all variables.

## 3.2. Long-term equilibrium test (cointegration test)

Lag biasness for long-term equilibrium test was analyzed in **Table 3** through AIC, SC and HQ method. We have found that the optimal lag length for our data set is 2 periods with giving a consideration to HQ methods as suggested by Ivanov and Kilian (2005).

**Table 3.** The selection of optimal lag by various methods.

| Lag | AIC | SC | HQ |
|---|---|---|---|
| 0 | 28.74770 | 28.80713 | 28.77167 |
| 1 | 15.22018 | 15.51731 | 15.34001 |
| 2 | 14.88818 | 15.42301* | 15.10387* |
| 3 | 14.83798 | 15.61052 | 15.14953 |
| 4 | 14.76769 | 15.77794 | 15.17511 |
| 5 | 14.76123* | 16.00919 | 15.26452 |
| 6 | 14.77889 | 16.26456 | 15.37805 |
| 7 | 14.78301 | 16.50638 | 15.47803 |
| 8 | 14.82343 | 16.78450 | 15.61431 |

Note: * indicates the optimal lag through various methods.

When the optimal lag value is obtained, those values are then tested by Equations (21) and (22) to quantify the long-term relationship (co-integration vector) of the information by the test results using Johansen Test' s method. The maximal eigen statistic value and trace statistic presented as in **Table 4**.

**Table 4.** The co-integration vector testing result by means of Johansen test.

| **Trace test** | | | | **Maximal eigen value statistic** | | | |
|---|---|---|---|---|---|---|---|
| $H_0$ | $H_1$ | **Test** | **Critical** | $H_0$ | $H_1$ | **Test** | **Critical** |
| $r = 0^*$ | $r > 1$ | 62.48531 | 47.85613 | $r = 0^*$ | $r = 1$ | 34.88576 | 27.58434 |
| $r \leq 1$ | $r > 2$ | 27.59955 | 29.79707 | $r = 1$ | $r = 2$ | 15.65030 | 21.13162 |
| $r \leq 2$ | $r > 3$ | 11.94924 | 15.49471 | $r = 2$ | $r = 3$ | 9.316829 | 14.26460 |
| $r \leq 3$ | $r > 4$ | 2.632414 | 3.841466 | $r = 3$ | $r = 4$ | 2.632414 | 3.841466 |

Note: * means reject null hypothesis ($H_0$) at the significant level 5%.

Referring to **Table 4**, it showed that the variables applied in the study are related in the long run at 1 co-integration vector. It is representable by written equations showing relationships that are consistent with the theory, which is a long-term relationship among various variables. Then, it can be adjusted in long-term coefficients (normalized co-integration coefficients) by Equation (14) as follows:

$$REER_t = 5.988 + 0.4935\mathrm{CPI}_t + 0.1905\mathrm{MPI}_t - 0.3116\mathrm{ROIL}_t$$
$$(0.9676) \qquad (0.7669) \qquad (5.1008)^{**}$$

The coefficient indicates the direction and relationship of each variable to the real Thai Baht index by fixing the other factors as a constant. The symbol ** represents statistical significance at 5%.

From the value estimation, it was found that real oil price (ROIL) has a significant negative relationship with the REER. The result was consistent with our hypothesis regarding the consequent impact of a reduction of the Baht. If the real price of oil increases 1%, it will cause the REER to be decreased 0.31% or it can be said that if the real price of oil increases 1% the price competitiveness of production units in Thailand will be reduced 0.31%. This implies that an increase in the Baht index may result in the reduction of the competitiveness of Thai Baht, compared to trading partner countries. Therefore, if the value of the country's currency increases, it will cause the price of Thai products from the foreign countries' perspectives to become more expensive. Demand for products from Thailand therefore decreases, as well as the ability to compete in price with foreign countries. This appreciation can be also explained that this is because the Thai Baht index is calculated by weighting with many trading partners in many countries such as the United States of America, China, or Japan. These industrialized countries import oil in larger quantities than Thailand. Therefore, the real currency index of Thailand when comparing to important trading partner countries it then did not depreciate as expected.

### 3.3. Short-term adaptation test (VECM test)

When it was tested, there was a long-term relationship between the variables. Next, there is a test of short-term adjustment to explain that if an event occurs and causes the Baht index to deviate from its long-term equilibrium by Equation (15). Then there will be a speed of adjustment to equilibrium in the long term which presented the estimation results as follows:

$$\Delta\mathrm{REER}_t = 0.0040 - 0.0237(5.988 - 4.935\mathrm{CPI}_t - 0.1905\mathrm{MPI}_t + 0.311\mathrm{ROIL}_t)^*$$
$$-0.0048D_{1,t}^* + 0.0057D_{2,t}^*$$
$$+0.2784\Delta\mathrm{REER}_{t-1}^* - 0.0356\Delta\mathrm{REER}_{t-2}^* + 0.0381\Delta\mathrm{CPI}_{t-1}^* - 0.3005\Delta\mathrm{CPI}_{t-2}$$

$$-0.0377\Delta \mathrm{MPI}_{t-1} - 0.0596\Delta \mathrm{MPI}_{t-2} - 0.0041\Delta \mathrm{ROIL}_{t-1} - 0.0111\Delta \mathrm{ROIL}_{t-2}$$

Note: * denotes a statistical significance at 5% level.

From the VECM estimation results, it was found that the long-term equilibrium adjustment coefficient was statistically significant and had a negative sign, which was in accordance with theory. That was to say when an event occurs making the REER value deviate from long-term equilibrium during the previous period 1 period. This value would be adjusted to reduce the error by 0.02% per period on monthly average.

When considering dummy variables, it was found that the dummy variables were statistically significant implying that there is a significant relationship between the financial crisis ($D_1$) or the crude oil prices ($D_2$) and the real Thai Baht, which was consistent with reality. After the United States encountered economic problems resulting in money flows from various investors to foreign capital markets were offered better returns, including Thailand. Furthermore, ΔREER had a negative value which was in line with theories as the increased demand for the Baht must strengthen the Baht. However, ΔREER had small effects on the relationship from shocks in ROIL. This is because the amount of money has been distributed among various capital markets including Thailand's trading partner countries. Thus, relative capital flows into Thailand are less, making Thailand's REER did not strengthen as expected.

## 4. Discussion

The results of the study revealed that the price of crude oil has a statistically significant relationship with the real Baht index or REER in long-run movement, with the negative relationship. This is consistent with the existing studies were found across the globe such as in India (Alam et al., 2020), Nigeria (Musa et al., 2020), and Mexico (Singhal et al., 2019) and others (Beckmann and Czudaj, 2013; Kaushik et al., 2014; Oriavwote and Eriemo, 2012; Shaari et al., 2012; Tiwari et al., 2013). It follows the assumption that when the price of crude oil rises, the real exchange rate of domestic currency should be appreciated. This is because the amount of the Baht must be used to buy more crude oil. However, we found small changes in Thai baht appreciation. A real effective exchange rate might be influenced by calculation methods as found in previous literature (Chinn, 2006; Darvas, 2012). In our analysis, the most important reason is that the calculation method of the effective Baht index considers exchange rates between several of Thailand's major trading partner countries including the United States, Japan, or China. These countries also import large quantities of oil. As a result, the value of Thailand's Baht did not highly respond to the appreciation as expected when comparing to the trading partner countries used in the calculations.

Also, when it can be tested that the variables are related in the long run, the short-term adjustment of the variables then has been tested. It was found that if a shock is coming from the oil production sector, domestic production sector, or the demand in the market; for example, there is a crisis in oil production in oil-exporting countries, or a flood event occurred, or whatever causes affect the change in the baht index. That has caused the Baht index to deviate from its long-term equilibrium. Those deviations will be adjusted to reduce the error (speed of adjustment) to 0.02% per period (month), implying a relatively fast speed of adjustment. In the short-term deviation, it can be explained by that exchange rates can be heavily influenced by market sentiment, speculation, and investor behavior (Chen et al., 2016; Habib et al., 2016). When there is an unexpected oil price shock, market participants may quickly adjust their expectations about future economic conditions, leading to rapid movements in exchange rates. Additionally, short-term exchange rate deviations can also be influenced by market imperfections, such as transaction costs, liquidity constraints, and information asymmetries, which may stimulate immediate adjustments to the equilibrium exchange rate (Batini et al., 2007; Boroumand et al., 2019; Ivrendi and Guloglu, 2010).

However, the deviation can be mitigated if there is a long-term relationship. Governments and central banks may implement policy measures to address persistent exchange rate misalignments, such as intervention in the foreign exchange market, changes in monetary policy, or fiscal policy adjustments. Moreover, with findings in our analysis and consistent with existing studies (Aliyu, 2009; Matthew and Adegboye, 2014), there are many other mechanisms that contribute to its adjustment. One that can be observed is arbitrage opportunities (Breen and Hu, 2021; Manasseh et al., 2019; Zhang et al., 2022). The arbitrage arises when exchange rates deviate from their equilibrium levels. Market participants, including traders, investors, and arbitrageurs, seek to exploit these opportunities, which helps to bring exchange rates back towards equilibrium over time. In addition, economic fundamentals might play roles in their adjustment. In fact, exchange rates are determined by underlying economic fundamentals, such as relative inflation rates, productivity growth, and trade balances. In the long term, deviations from these fundamentals are typically corrected through adjustments in exchange rates (Chang and Su, 2014; Lizardo and Mollick, 2010). On top of that, the adjustment can be influenced by expectations and adaptive behavior of market participants. Market participants form expectations about future exchange rate movements based on past experience and economic fundamentals (Ali and Anwar, 2017; Andrieș et al., 2014). Over time, these expectations can influence trading decisions and contribute to the convergence of exchange rates towards their equilibrium levels.

All these variable adjustments can be also explained using the Mundell-Fleming-Dornbusch model as we constructed in section 2. According to this model, in an open economy with flexible exchange rates, an increase in crude oil prices leads to higher import costs, causing inflationary pressures which is presented by Equations (6) and (11). To combat inflation, the central bank might raise interest rates, attracting foreign capital and appreciating the nominal exchange rate. However, if the domestic economy is less competitive due to higher production costs from expensive oil, exports may decline. The loss in export competitiveness can outweigh capital inflows, resulting in a depreciation of the REER.

## 5. Conclusion, limitation, and recommendation

Oil plays a critical role as a primary input in the production processes of the global economies, exerting substantial influence on economic activity. Consequently, drastic fluctuations in oil prices have significant ramifications on economic activity levels and, by extension, the wealth of nations through alterations in exchange rates. Hence, this research seeks to investigate the impact of changes in crude oil prices on exchange rates, with the aim of providing valuable insights for governmental and business entities to effectively navigate the risks linked with fluctuations in exchange rates, considering both short-term and long-term adjustments. In this study, monthly crude oil price data spanning from 2000 to 2019 in Thailand was utilized to examine the long-term relationship through the Johansen cointegration test and investigates short-term adjustments using the Vector Error Correction Model (VECM).

The Johansen cointegration test results observe a long-term relationship between the price of crude oil and the real Baht index. Every 1% increase in crude oil prices, the real effective Baht index rises by 0.31%. This can be said that if the real price of oil increases 1% the price competitiveness of production units in Thailand will be reduced 0.31 percent. Furthermore, the VECM explores that an unexpected event or shock in the oil market causing a significant fluctuation in the exchange rate would be gradually alleviated and adjusted to its equilibrium at a fast speed of 0.02 in the subsequent month. This shows that crude oil imports and exchange rate management of trading partner countries have an effect on changes in the Thai Baht index. Therefore, if the government can manage the effects of unpredictable changes in crude oil prices (shocks) efficiently, Thailand's ability to compete in price with foreign countries will inevitably increase. They may intervene in the crude oil market in the short term to reduce the impact of fluctuations. This is because such intervention will only cause interest rates to change in the short term, but it does not change the long-term equilibrium. To enhance the country's competitiveness in international trade and ensure economic stability, the government can implement financial interventions in the crude oil market. Measures such as controlling oil prices or providing monetary subsidies can effectively mitigate the extensive repercussions of energy market fluctuations on the economy while having a lesser impact on long-term equilibrium. To enhance the country's competitiveness in international trade and ensure economic stability, the government can implement financial interventions in the crude oil market. Measures such as controlling oil prices or providing monetary subsidies can effectively mitigate the extensive repercussions of energy market fluctuations on the economy while having a lesser impact on long-term equilibrium. In addition to these methods, the government should strengthen a Future Exchange Market on crude oil to help production units manage risks arising from changes in oil prices that will occur in the future effectively.

Despite the contribution, this research exhibits some limitations regarding the use of Johansen cointegration test and the VECM approach. Especially, the Johansen test may not fully capture dynamic effects and time-varying relationships between oil prices and other economic variables, which can be important for understanding the transmission mechanisms of oil price shocks. Therefore, the interpretation requires careful consideration of the results in this context. Considering other approaches is encouraging for future research. Moreover, it is useful to conduct research on oil shock net spillovers effects by using the exchange rate of other oil-importing countries in ASEAN to address this issue at regional and global scales.

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review and editing, PB and TDNH; visualization, WP; supervision, PB; project administration, TDNH. All authors have read and agreed to the published version of the manuscript.

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