Time-varying causality between oil price and exchange rate in five ASEAN economies

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Received: 28 April 2022 / Accepted: 4 November 2022 / Published online: 21 November 2022
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Abstract
The aim of this study is to investigate the effect of oil price changes on the exchange rates of the five ASEAN economies. In the study, a rolling and recursive evolving window algorithm is applied to detect changes in the link between oil price and exchange rate from January 1988 to June 2022 for five ASEAN countries. We extend the existing literature using the Time-varying Granger causality model, which captures sensitivities across various time horizons. The findings revealed heterogeneous effects of oil price on the exchange rate at different time horizons in terms of importance and magnitude over time. Our empirical results support the combined movements of oil prices and exchange rates against some important dates and events. The findings provide investors with insight into the utility of the shock transmission mechanism and how central banks design market intervention policies.

Keywords Exchange rate · Time-varying causality · Oil price · ASEAN economies

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1 Introduction

With the 1973–74 oil price (OPR) shocks and Hamilton (1983) pioneering work, the study of the relationships between OPR shocks and economic activity acquired prominence. The most significant break in OPR occurred in 1973 when OPEC restricted oil shipments owing to the Arab-Israel war. Another sensitivity in OPR was noted in 1979 when Iran restricted its oil output following the outbreak of the Iran-Iraq conflict in 1980. As a result of these events, OPR soared from $4 per barrel in 1973 to $9 per barrel in 1974, and from 13 dollars in 1979 to 36 dollars in 1981. Furthermore, from mid-2000 to July 2008, OPR reached $145.3 per barrel, before decreasing to $42.4 per barrel in March 2015. This demonstrates that during the time of global crisis, the growing instability in the oil market often cast-off shocks across the major sectors of the economy. As a result, considerable volatility in OPR has a direct impact on a variety of production, macroeconomic performance, and economic activities. Since the 1973 OPR shock, a myriad of research has been conducted to study the link between OPR and macroeconomic indicators (Hamilton 1983, 1996; Mork 1989; Cunado and De Gracia 2005). Most of the US economic recessions after the 2nd World War were mainly caused by fluctuations in OPR (Hamilton 1983). While OPR volatility impacts the worldwide production system, it also has a significant influence on global economic fluctuations, especially at the macro levels (Wang et al. 2022). The co-movements between the OPR and the exchange rate (EXR) attracted several researchers (Bodenstein et al. 2011). Furthermore, rise and fall in OPR have serious consequences for any country i.e., the oil crisis of 1973 directly impact the manufacturing sector of the western economies (Wang 2013; Jin 2008; Rafiq et al. 2009; Turhan et al. 2013).

The fluctuation in energy prices is defined as a constant problem, especially for oil-importing countries and this affects them in various ways such as periods of declining economic performance, depreciation of EXR and possible decrease in capital investment. Moreover, it causes an increase in oil expenditures, a wider trade deficit, decreasing the foreign exchange reserves, fluctuation in the balance of payments and skyrocketing the inflat (Fratzscher et al. 2014; Bahmani-Oskooee and Mohammadian 2017). Significant volatility in international OPR in 2008–2009 and after the free fall in OPR in 2014, the importance of the effects of OPR on EXR is emphasized as it can be previously seen in the Asian Market during the Asian crisis in 1997 (Ghosh 2011; Tiwari et al. 2013).

When OPR rise, a country’s currency may appreciate or depreciate, and when OPR fall, its currency may occur vice versa. Thus, the method elucidates how the OPR drives EXR fluctuations (Golub 1983a, b; Krugman 1983; Amano and Van Norden 1998; Fratzscher et al. 2014). In net oil-importing nations, an OPR increase causes a downturn in the trade balance, which may result in a devaluation of the local currency and a loss in gross foreign exchange reserves. The fluctuation in the OPR does not only bring consequences for the oil importing and oil exporting nations rather it brings dire consequences for the global economy. On the other side, it may result in a positive trade balance.
and currency appreciation for net oil-exporting countries but at the same time, it brings huge consequences for the oil importing countries (Basher et al. 2016; Habib et al. 2016).

The causal relationship between international OPR and EXR has significant implications for profitability in the petroleum, transportation, industrial, and food industries (Szturo et al. 2021). The instabilities in the OPR may change the EXR differently for an oil-importing country than for an oil-exporting country (Golub 1983a, b). Oil-importing countries are affected differently by changes in OPR than oil-exporting countries. In addition, the mutual interaction that defines the relationship between OPR and EXR is the basic movement for the EXR (Turhan et al. 2014). It has been determined that EXR in oil-importing countries are negatively affected by OPR (Bahmani-Oskooee et al. 2017; Papapetrou 2013). On the other hand, countries that export oil takes advantage of increasing OPR, as reported by (Dizaji 2014; Nusair 2016). Moreover, with the rapid increase in globalization and financialization, portfolio managers and global investors consider oil as part of their portfolio management (Ma et al. 2019a, b, c, d). Given the importance to oil in investors’ portfolio management, clearly illustrates the correlation between OPR and EXR (Reboredo and Rivera-Castro 2013). As a result, countries with a higher level of financial integration and globalization are more vulnerable to exchange-related economic issues. For instance, during the time of high oil prices, the oil importing nations suffer at both fiscal and monetary spheres (Ma et al. 2019a, b, c, d). In addition, existing literature claims that the relationship between OPR and EXR primarily depends on oil dependence, the rate regime, and the efficiency of the financial market (Volkov and Yuhn 2016). Similarly, OPR influence the EXR and the trade balance, consequently, the country has to adjust the EXR accordingly to keep its competitiveness (Zhou 1995). In this context, Hussain (2017) empirical results support the joint movements of OPR and EXR.

Various studies focused on applying distinct econometric models to analyze the causal relationship between OPR and EXR (Ahmad and Hernandez 2013; Basher et al. 2016; Wen et al. 2018). (Coudert et al. 2007) showed that the increases in OPR coincide with the appreciation of the dollar in the long run, and the causality is from oil to the dollar effective EXR. Tiwari et al. (2013), the causality between the Indian rupee EXR and OPR was frequency dependent, and found evidence for unidirectional causality at higher scales (lower frequency), especially from EXR to OPR. On the one hand, for OPEC the real EXR is positively affected by OPR (Korhonen and Juurikkala 2009), but on the other hand (Reboredo 2012) has found a weak association between the two variables. These studies have provided mixed results; therefore, justification exists for an advanced econometric model that accommodates the limitations of previous models. Furthermore, it is also argued that the time dimension is also vital to analyze the relationship between OPR and EXR (Tiwari et al. 2013). Similarly, the causal relationship between the two is better described in the time domain (Benhmad 2012). Furthermore, neglecting the EXR’s distributional heterogeneity may lead to biased conclusions (Su et al. 2016a, b). In the same vein, (Sim and Zhou 2015) have argued that the OPR reaction to bearish or bullish stock markets is likely to be different. Similarly, the market may react positively or negatively to the rise and fall in the EXR. Moreover, various researchers
examined the impact of the global pandemic on the OPR (Bourghelle et al. 2021; Narayan 2020; Salisu et al. 2021) and then the EXR response to fluctuations in the OPR (Devpura 2021; Nwosa 2021; Salisu et al. 2021). However, their findings are heterogeneous across countries.

Meanwhile, this study also focuses on the broader individual countries. However, empirical studies using time series data that include a possible Time-varying causality effect in single-country studies are limited. Few studies examined the influence of shocks in OPR on the foreign exchange market in ASEAN countries. The majority of the research on this relationship focused on developed nations. Furthermore, after the Asian financial crisis in 1997, the EXR regimes in these selected ASEAN countries shifted dramatically. Given these shifts, the risk concerns for international investors make these countries a good case study (Liang et al. 2013). Lastly, these ASEAN countries are selected because of their financial market integration, especially in case of oil market (Qureshi and Aftab 2020) and financial contagion (Liang et al. 2015). In addition, looking deeply into heterogeneous and across-time relationships is vital for countries to build good policies. To the best of the authors’ knowledge, this is the first study on selected ASEAN economies that analyzes the role of fluctuating OPR on the EXR by using a time-varying causality approach. To the best of the author’s knowledge, the available literature does not examine causality from OPR to EXR in the context of the ASEAN economies, taking into account time-varying causality algorithms.

Many studies report a unidirectional Granger causality running from OPR to EXR (Amano and Norden 1998; Chaudhuri and Daniel 1998; Chen ve Chen 2007; Bénassy-Quéré et al. 2007; Coudert et al. 2007; Lizardo and Mollick 2010; Basher et al. 2012). Also, in the post-Bretton Woods period, the links between crude OPR and the US effective EXR were cointegrated and causality behavior was found from OPR to EXR (Chaudhuri and Daniel 1998; Amano and Van Norden 1998). Sadorsky (2000), empirical evidence reveals that energy prices and EXR are cointegrated and that the EXR dominates OPR (Beckmann and Czudaj 2013b).

Moreover, some studies in recent years have taken into account the time-varying nature of the link between OPR and EXR (Beckmann and Czudaj 2013a, b; Tiwari and Albulescu 2016; Ji et al. 2020; Albulescu and Ajmi 2021; Huang and Li 2022). These studies underline that the relationships between OPR and EXR can change over time and reveal that nonlinearity is an important issue when analyzing OPR and EXR. When we focus on ASEAN economies, some studies have examined the relationships between OPR and EXR in the literature but ignored time-varying and heterogeneous relationships (Kisswani 2016a, b; Kisswani et al. 2019). In addition, Hüseyin et al. (2017) used a new methodology that measures cross-correlation at different time scales proposed by Zebende (2011) and empirically supports the joint movements of OPR and EXR.

From this point of view, in this study to both expand the existing literature and capture the heterogeneity in the time scale between OPR and EXR in ASEAN economies we will reveal a new perspective with the time-varying causality tests proposed by (Shi et al. 2020, 2018). This approach has an advantage over the other methods, firstly, according to Shi et al. (2018; 2020) the advantages of the recursive evolving window approach are more than the other two approaches in
finite samples including stationary and non-stationary processes. As a result, the variables’ cointegration properties do not necessitate data differentiation or trend removal. Second, it allows dating economic turbulences and detecting time-scale heterogeneities in the causal relationship directions between variables. Third, the test provides more robust evidence as it does not ignore conditions for both homoskedasticity and conditional heteroskedasticity.

The remaining part of the study goes as follows: In the subsequent Sect. 2, the relevant literature of some relevant studies is provided. Then, in Sect. 3 a detailed account of the data and method involved in the present study. Section 4 shows the results and main findings, and Sect. 5 presents a discussion of empirical findings and lastly, Sect. 6 presents the conclusion.

2 Literature review

The literature, considering the effects of OPR on EXR, argues that an increase in OPR for an oil exporting country will result in a current account surplus, while it will result in a current account deficit in oil importing countries (Golub 1983a, b; Amano and Norden 1998; Chen and Rogoff 2003; Huang and Guo 2007).

Some researchers in the literature have focused on examining the effects of OPR shocks on the stock market (Jones and Kaul 1996; Wei 2003; Arouiri 2011; Arouri et al. 2011; Federer 1996; Sadorsky 1999, 2003; Basher and Sadorsky 2006; Rahman 2022). Others have examined the relationships between OPR and economic activity by considering the key sectors of the economy (Hamilton 1983, 1996; Mork 1989; Cunado and De Gracia 2005; Eika and Magnussen 2000; Kilian 2009; Prasad et al. 2007; Blanchard and Gali 2007). On the other hand, many studies investigate the effects of OPR on inflation because the instability in the oil market often causes economic instability (Bachmeier and Cha 2011; Chen 2009; LeBlanc and Chinn 2004; Salisu et al., 2017; Zakaria et al. 2021). The literature on the causal relationship between OPR and EXR is extensive. The first part finds evidence of unidirectional causal relationships, usually from OPR to EXR (Bénassy-Quéré et al. 2007; Chen and Chen 2007; Wang and Wu 2012). Unlike these studies, Barsky and Kilian (2004) and Wu et al. (2012) presented evidence that the US dollar EXR can affect OPR because as reserve currency U.S. dollar has spillover effect on the global exchange rates. Furthermore, Zhang et al. (2008) discovered that there is a causal relationship between the US dollar EXR and the OPR and that US dollar’s devaluation is a significant factor that influences the worldwide OPR.

OPR may influence the EXR through several channels, changes in nominal OPR trigger a direct effect on the nominal EXR, and on the other hand, real EXR effects through price differentials (Beckmann and Czudaj 2013b). However, there are two famous channels, namely demand–supply (Darby 1982) and portfolio-wealth (Krugman 1980; Amano and Van Norden 1998). The spillover effect between oil shocks and EXR strengthened after the 2007–08 global financial crisis and the response of EXR to OPR shocks is not consistent over time (Ji et al. 2020). Beckmann et al. (2020) states that both the oil importing, and oil exporting countries are sensitive to oil demand shocks in the global market. Likewise, the sensitivity
to the oil demand shocks in the global oil market often causes exchange rate fluctuations.

Since Hamilton’s pioneering study on the impact of changes in the OPR on the US business cycle (Hamilton 1983), other studies have attempted to explore the influence of these changes on macroeconomic indices (Golub 1983a, b; Krugman 1983; Rogoff 1991). At the same time, several others have looked into the causality of two variables for countries with different levels of dependence on oil trade (Beckmann and Czudaj 2013b). Some studies used the VAR framework to study causality in the two series (Huang and Feng 2007; Turhan et al. 2013; Fueki et al. 2021). Many studies have used the cointegration approach (Lizardo and Mollick 2010; Rautava 2004); (Jung et al. 2020); (Lin and Su 2020). Chen and Chen (2007) investigated the cointegration between EXR and OPR in G7 countries and revealed that OPR have the power to explain changes in EXR. Due to the casualty between the OPR and EXR, the cointegration between them is vivid in the context of real oil prices.

Some Literature suggests some evidence that the relationship between OPR to EXR is non-linear or asymmetric (For example, Tiwari et al. 2013; Tiwari and Albulescu 2016; Jiang et al. 2020; Baek 2021) used to investigate the connection among the OPR and the foreign exchange market. Moreover, since 1980s oil emerged as an important commodity in the global economy that has close connection with global exchange rates. In a similar vein, (Reboredo and Rivera-Castro 2013) have attempted to analyze the causality linkage among the OPR and the exchange markets. Their results revealed that the OPR and currency rates show no strong association before the financial crisis. Their study identified that prior to the crisis there was significant dependency of EXR on OPR that completely shifted in the post-crisis phase. Although several studies have investigated the causal relationships between the two variables, the outcomes have been mixed. For instance, to explore the causality in Eurozone countries, Canada, Japan, and Australia, (Youssef and Mokni 2020) have used regression with Markov regime-switching quantiles. In terms of size, importance, and level of returns on the ER, the findings demonstrate that oscillations in OPR have a heterogeneous effect on the EXR of these countries. Our study uses a quantile regression built on the prior work of (Nusair and Olson 2019; Su et al. 2016a, b). While analyzing the impact of variations in the OPR on fluctuations in the EXR, we have accounted for the possibility of distributional heterogeneity. The wavelet method was used to investigate the time-varying relationship between the oil and exchange regimes in a time-varying analysis (Fan and Xu 2011; Beckmann et al. 2016; Turhan et al. 2014; Tiwari and Albulescu, 2013; 2016). The findings of these studies showed a long-term causal relationship. This finding is similar to the earlier work of (Zhang et al. 2008) that reported an equilibrium between the OPR and the Euro to the USD EXR in long term.

ASEAN member countries also attracted various studies to examine the relationship between the OPR and the EXR. A recent study on seven Asian countries investigated the impact of OPR on the EXR (Nusair and Olson 2019). Their study shows that rising OPR and decreasing OPR have heterogeneous effects on the EXR. The study concluded that the OPR affects the EXR in these Asian countries. Moreover, their study also identified the dependence of EXR on the market.
conditions (bullying currency markets) because the local currency fluctuations depend on the real oil prices. Similarly, (Kisswani et al. 2019) have investigated the Granger causality between the OPR and the EXR in ASEAN countries. A recent study on ASEAN countries (Basnet and Upadhyaya 2015) has analyzed the impact of the OPR on the EXR in five ASEAN countries. They applied the structural VAR model and impulse response function to test this impact. Their findings show no strong evidence of an impact of the changes in the OPR on the EXR. Some studies focus on the causal relationship between OPR shocks and macroeconomic variables. This study further identified the EXR dependence of oil importing countries (i.e., ASEAN) on price variation and total output (Vu and Nakata 2014; Raghavan 2015). However, these studies used a traditional Granger causality approach, and their example did not cover the COVID-19 pandemic. To the best of our knowledge, our study is the first to attempt to investigate the dynamic impacts of the OPR on the EXR in ASEAN countries.

On the contrary, despite the relationship of OPR to EXR, several studies have focused on the causal relation between economic growth and EXR, industrial structure and EXR, and foreign trade and EXR. For instance, (Pradhan et al. 2014) studied the casual relationship of several macroeconomic variables such as economic growth, development of stock markets and banking sector with exchange rates by using panel vector auto-regressive model and found a unidirectional and bidirectional causality between the latter variables and EXR. Similarly, (Lee-Lee and Hui-Boon 2007) studied the casual relations between macroeconomic factors and exchange rate volatility for the four neighboring countries of ASEAN bloc and found that the macroeconomic variables such as industrial output, market size and market competitiveness influences the exchange rate volatility. Likewise, (Asteriou et al. 2016) investigated the relationship between the exchange rate and the international trade by using Granger Causality model and found that in the long run, there is no causality between international trade and EXR, while in the short run, there is a significant causality between international trade and EXR due to volatility of import/export demand.

3 Methodology and data

3.1 Data

In this study, the sensitivity of the nominal EXR of five Asian countries, namely Thailand, Indonesia, Malaysia, Philippines, and Singapore, to Brent and WTI OPR are analyzed with the Time-Varying Causality tests proposed by Shi et al. (2018, 2020). Following (Reboredo and Rivera-Castro (2013); Sun et al. (2022), data on the nominal EXR for Philippine Pesos was collected from Bangko Sentral ng Pilipinas BSP (2022) and the Singapore Dollars, Thai Baht, Malaysian Ringgits, Indonesian Rupiahs were sourced from the Federal Reserve Economic Data (FRED 2022). Brent crude oil data were obtained from US Energy Information Administration (EIA 2022) following Sarwar et al. (2020); Saidu et al. (2021). Monthly data from January 1988 to June 2022 were used in the analyses. Descriptive statistical analysis
|                      | BRENT Crude Oil | WTI Crude Oil | USD/Indonesian Rupiahs | USD/Malaysian Ringgits | USD/Philippine Peso | USD/Singapore Dollars | USD/Thai Baht |
|----------------------|----------------|--------------|------------------------|------------------------|----------------------|------------------------|--------------|
| **Mean**             | 48.50633       | 47.12592     | 8320.106               | 3.409066               | 41.44388             | 1.535295               | 32.72864     |
| **Median**           | 39.77500       | 39.51500     | 9116.500               | 3.522000               | 44.62600             | 1.489900               | 32.33405     |
| **Max**              | 132.7200       | 133.8800     | 16,367.01              | 4.457300               | 56.35700             | 2.045900               | 52.98250     |
| **Min**              | 9.820000       | 11.35000     | 1660.000               | 2.439600               | 20.87000             | 1.208900               | 24.53430     |
| **S. Deviation**     | 32.73453       | 29.27874     | 4436.347               | 0.598238               | 11.04194             | 0.206939               | 5.969962     |
| **Skew**             | 0.763529       | 0.725318     | −0.292169              | −0.167296              | −0.576728            | 0.463805               | 0.390424     |
| **Kurt**             | 2.398622       | 2.412733     | 1.804322               | 1.679134               | 1.880836             | 2.263339               | 2.328833     |
| **JB**               | 46.46395       | 42.24921     | 30.55141               | 32.02701               | 44.55661             | 24.20402               | 18.28827     |
| **P-value**          | 0.000000       | 0.000000     | 0.000000               | 0.000000               | 0.000000             | 0.000006               | 0.000107     |
| **Observations**     | 414            | 414          | 414                    | 414                    | 414                  | 414                    | 414          |
| **Breakpoints**      | May-1999       | May-1999     | Dec-1997               | Sep-1997               | Jul-1997             | Feb-1993               | Aug-1997     |
|                      | Jul-2004       | Jul-2004     | Sep-2008               | Jan-2005               | Sep-2002             | Apr-1998               | Oct-2006     |
|                      | Sep-2009       | Sep-2009     | Aug-2014               | Mar-2010               | Nov-2007             | Jan-2005               | –            |
|                      | Nov-2014       | Nov-2014     | –                      | May-2015               | Aug-2016             | Mar-2010               | –            |
|                      | –              | –            | –                      | –                      | –                    | May-2015               | –            |
results of the variables are shown in Table 1. Furthermore, the time trends with multiple structural breaks of relevant series are shown in Fig. 1. Bai and Perron (1998) and Bai and Perron (2003) proposed a sequential test method based on minimizing the residual sum of squares. To determine the optimal number of breaks in the data, we employ the test in Bai and Perron (2003). Dynamic programming is used in the test to find the sum of squared residuals through global minimizers. We find that there are four breakpoints giving rise to an optimal five-segment partition.

Fig. 1 Breakpoints and the corresponding segments OPR and Nominal EXR for Five Asian Countries
As illustrated in Fig. 2, Indonesia was a net oil exporter between 1988 and 2013 but falling oil production and rising domestic demand caused it to become a net oil importer in 2014. However, we can see that Malaysia is a net oil exporter (EIA 2022). Therefore, it will be noteworthy to analyze the impact of OPR shocks on EXR in a sample of ASEAN countries which is a mix of net oil exporting and importing countries.

3.2 Time-varying causality

SHI et al. (2018, 2020) recently proposed time-varying causation approach, which assumes the use of recurrent growing algorithms, is used to investigate the causal link between the currency EXR and crude OPR. In comparison, the iterative evolving technique is used with the moving Wald test causal methodology. The literature proposes the LA-VAR model for conducting a Granger causality test for a potentially interrelated variable (Toda and Yamamoto 1995; Dolado and Lütkepohl 1996). In the literature on causality, one can find several VAR-based methods to gage time-varying causality including the “forward expanding window” approach (Swanson 1998; Thoma 1994); the “rolling window” (Balcilar et al. 2010); and recently introduced recursive evolving window (Shi et al. 2018, 2020). This study uses Shi et al. (2020) novel time-varying causality approach, which reconstructs the problem of time-varying causation while offering numerous benefits over previous time-varying causation methodologies used in the literature.

A Granger causality evaluation for a potentially interrelated variable $z_t$ could be done, according to Dolado and Lütkepohl (1996), if the VAR model is represented as:

$$z_t = \zeta_0 + \zeta_1 t + \sum_{i=1}^{k} \psi_{i,t} z_{t-i} + \sum_{j=k+1}^{k+d} \psi_{j,t-j} z_{t-j} + u_t \quad t = 1, 2, \ldots, T$$

(1)
\[ H_0 : \psi_{k+1} = \cdots = \psi_{k+d} = 0 \]

where \( z_t = (z_{1t}, z_{2t}, \ldots, z_{mt})' \) and \( d \) is the bivariate case with a highest order of variable integration \( z_t \).

The equation can be written as:

\[ z_t = \Psi \eta_t + \delta y_t + u_t, \]

where \( \Psi = (\xi_1, \ldots, \xi_k)' \) and \( \eta_t = (\psi_{k+1}', \ldots, \psi_{k+d}')' \) and \( y_t = (\zeta_1', \ldots, \zeta_{k-d}' )' \) of the final \( nd \times 1 \)

The constraints provide Granger non-causality based null hypothesis.

\[ H_0 : M\omega = 0 \]

Applying row computation, on the parameter \( \omega = \text{vec}(\Psi) \), where \( M \) is a \( m \times n^2 k \) matrix with rank(\( M \)) = \( b \) and 0 is \( b-\) dimensional zero vector. Because its components are assumed to be zero, then factor matrix \( \theta \) of the final \( d \) lagged vectors is omitted.

The expression in Eq. (2) can be expressed more concisely as

\[ Z = \eta \Psi' + Y \theta' + u, \]

where \( Z = (z_1, z_2, \ldots, z_T)' \), \( \eta = (\eta_1, \ldots, \eta_T)' \) and \( Y = (y_1, \ldots, y_T)' \) and \( u = (u_1, \ldots, u_T)' \)

\[ H_0 : M\omega = 0 \] is the null hypothesis that put restrictions to modify the traditional Wald statistic \( W \) to check the hypothesis \( H_0 \) in Eq. (3) as follows:

. imposes the following constraints on the conventional Wald statistic \( W \) when testing

\[ W = (\hat{M}\hat{\omega})' \left[ M \{ \hat{\Sigma}_u \otimes (\eta'Q\eta)^{-1} \} M' \right]^{-1} M\hat{\omega} \]

where \( \hat{\omega} = \text{vec}(\hat{\Psi}) \) is the row vector, \( \hat{\Psi} \) signifies a least-squares parameter of type \( \hat{\Psi} = \eta'Q\eta(\eta'Q\eta)^{-1} \), \( Q = I_T - Y(Y'Y)^{-1}Y' \), \( \hat{\Sigma}_u = \Psi^{-1}\hat{\omega}'\hat{\omega} \) where \( I \) is matrix of identity, \( M \) is a \( m \times n^2 p \) matrix \( m \) denotes the number of restrictions and \( \otimes \) is the Kronecker product.

The Wald value is monotonically \( \chi^2_m \) under the condition of conditional homoscedasticity. This Wald statistic has the normal \( \chi^2_m \) exponential null dispersion, when \( m \) has numerous shortcomings (Toda and Yamamoto 1995).

According to the assumptions and the null hypothesis, the Wald stat is \( \chi^2_m \). Shi et al. (2018, 2020) used Wald statistic the supremum (sup) sequences as an innovative real-time-varying causality approach.

Shi et al. (2018, 2020) real causation test incorporates supremum (sup) Wald statistic sequences and is based on a cyclical evolving method (Phillips et al., 2015). From subsamples of data, the iterative Granger causality analysis computes Wald statistics. Assume that \( f_1 \) and \( f_2 \) are the regression sample’s initial and final points, respectively, and that \( f_w = f_2 - f_1 \).
Therefore, we denote with $w_{f_2}(f_1)$ the Wald statistic over $[f_1, f_2]$ where the sample size is shown as $f_w = f_2 - f_1 \geq f_0$. The supremum Wald statistic can be shown as:

$$sw_f(f_0) = \sup_{(f_1, f_2) \in \Lambda_0, f_2 = f} \{w_{f_2}(f_1)\}$$  (6)

The Wald statistic obtained from this sub-sample (derived on the LAVAR) is indicated by $W_{f_2}$. Let $\eta_1 = [f_1 T], \eta_2 = [f_2 T], \eta_w = [f_w T]$, where $T$ is the maximum number of data points necessarily needed to evaluate the VAR system and $\eta_0 = [f_0 T]$ is the minimum number of data points needed to evaluate the VAR system.

The supremum (sup) Wald statistic sequences were planned to be used in Shi et al. (2018, 2020) innovative real-time changing causality technique. As a result, the Wald statistic across $[f_1, f_2]$, where the sample size fraction is given by $f_w = f_2 - f_1 \geq f_0$ is $W_{f_2}(f_1)$.

where sample size in reduced form $f_0 \in (0, 1)$, $\Lambda_0 = \{(f_1, f_2) : 0 < f_0 + f_1 \leq f_2 \leq 1, \text{and} 0 \leq f_1 \leq 1 - f_0\}$. As a result, the rolling-window technique turns into a particular example of the recursive evolving procedure following Shi et al. (2018). Shi et al. (2018) found that increasing $f_0$ from 0.18 to 0.24 boosted the strength of the rolling and recursive methods. According to Shi et al. (2018), the window $f_0 = 0.2$ is the best choice for ensuring sufficient data to run the regression.

The dating criteria for a basic switch scenario are defined as follows, based on the recursive developing algorithm:

- **Recursive evolving**

  $$\hat{f}_e = \inf_{f \in [+0, 1]} \{f : sw_f(f_0) > scv\}, \text{ and } \hat{f}_t = \inf_{f \in [\hat{f}_e, 1]} \{f : sw_f(f_0) < scv\}$$  (7)

- **Rolling**

  $$\hat{f}_e = \inf_{f \in [0, 1]} \{f : W_f(f - f_0) > cv\}, \text{ and } \hat{f}_t = \inf_{f \in [\hat{f}_e, 1]} \{f : W_f(f - f_0) < cv\}$$  (8)

where $cv$ and $scv$ denote the $W_f$ and $SW_f$ statistics’ critical values, respectively; $\hat{f}_e$ and $\hat{f}_t$ denote the first (chronologically estimated) observation, the estimated initial temporal events when the $t-$statistics pass or drop under the significant values for the causal relationship. Generalizing numerous switches, the initiation and expiration dates are determined similarly.

### 4 Results

From January 1988 to June 2022, monthly data were collected for the study. The study used rolling and recursive evolving processes to investigate the presence of a causal relation involving OPR and EXR. The lag length is determined by applying BIC to the entire sample period, with a lag length of 12. Wald
statistics are not affected by heteroskedasticity. The crucial values and system parameters in the context of a null are computed using the entire sample period in bootstrapped 5%. The estimates are based on 1,000 simulations and the statistics’ 5% bootstrapped parameter estimates. Despite the fact that the rolling and recursive evolving processes are virtually equivalent in most circumstances, the power gain of the recursive evolving strategy is highly evident the sample size is substantial (Time = 200–300).

Figures 3a, b, 4a, b, 5a, b 6a, b and 7a, b illustrate the time-varying co-moments between OPR and the nominal EXR in five ASEAN countries independently. We relied on the reference criteria in all of these charts via a black line that represents the test statistic series and their associated bootstrapped 5% significance level for rolling and recursive evolving techniques. According to Shi et al. (2018), the evolving recursive approach has better predictive power; therefore, the
Fig. 5  a Brent OPR to Philippine’s EXR—Rolling method.  
          b Brent OPR to Philippine’s EXR—Recursive evolving

Fig. 6  a Brent OPR to Singapore’s EXR—rolling method.  
          b Brent OPR to Singapore’s EXR—Recursive evolving

Fig. 7  a Brent OPR to Thailand’s EXR—rolling method.  
          b Brent OPR to Thailand’s EXR—Recursive evolving
results from this method are likely to be superior. A significant causation is discovered when the Wald parameter surpasses its associated critical value within a time. As the time domain analysis provides detailed information about the causal relationship between the two series, we can follow the causality relationship at various points of time.

Through time-varying Wald test statistics, we find that causal relationships from international OPR to nominal EXR are dynamic and that nominal EXR in five ASEAN countries are sensitive to international OPR for some periods. This includes, especially the situations arising from internal shocks and recession phases caused by external shocks (Asian financial crisis, 1997; global economic crisis period 2008–2010, sovereign debt crisis in Europe 2012, US-China trade tensions and Brexit 2019, Coronavirus 2020).

Based on rolling evolving results, Fig. 3a shows one-way causality from international OPR from Brent to Indonesian Rupiahs from September 2008 to March 2011 and July 2012. Similarly, based on Recursive evolving results Fig. 3b shows October 2005 as significant co-movement between the two series. In addition, it also verifies the findings from rolling method that causality exists from September 2008 to March 2011 and from July 2012 to November 2019.

Time-varying granger causality between OPR from Brent and EXR of Malaysian Ringgits is shown in Fig. 4a using rolling evolving method. The findings reveal that in September 2001 there was a co-movement between OPR and EXR in Malaysia however, results are not significant at 5%. Figure 4b shows the results based on recursive evolving results method showing that from June 2012 to December 2012 there was a one-way causality.

Using the two methods of rolling and recursive, the time-varying causality between international OPR (Brent) and the Philippine peso is depicted in Fig. 5a, b, respectively. Rolling evolving results in Fig. 5a shows that there is no causality from international OPR (Brent) to the Philippine peso and the Neutrality hypothesis is valid. Figure 5b illustrates that based on recursive evolving results show one way causality from July 2004 to Jan 2005.

In the same line, Fig. 6a shows results from rolling evolving and depicts that there exists a significant one-way causality from Brent OPR to Singapore’s Dollars during May 2011. Besides, Fig. 6b on the basis of recursive evolving results, highlights causality from May 2011 to February 2005 verifying the one-way causality hypothesis. Figure 7a shows output from rolling method. It depicts that there is one-way causality from Brent OPR to Thai Baht. On the other hand, the recursive evolving results are shown in Fig. 7b highlighting significant causality during June 1990 to May 1992, September 1994 to July 1995, April 2003 to October 2006, and December 2019 to June 2022 Both Rolling and Recursive Evolving findings demonstrate that nominal EXR are sensitive to international OPR. In the absence of one-way causality from international OPR to nominal EXR, the finding that the Neutrality hypothesis is not validation in case of Thailand.
5 Robustness test

To confirm the robustness of our empirical results and that they are not affected by the choice of representative variables of international OPR, this article uses the WTI OPR to check robustness of the findings. The estimation results of the time-varying Granger causality test to analyze causality from international OPR (WTI) to nominal EXR in five Asian countries are shown in Figs. 8a, b, 9a, b, 10a, b, 11a, b and 12a, b. To our expectations, the results remain pretty much consistent.

Fig. 8  a WTI oil to EXR in Indonesia using rolling method. b WTI oil to EXR in Indonesia using recursive evolving

Fig. 9  a WTI oil to EXR in Malaysia using rolling method. b WTI oil to EXR in Malaysia using recursive evolving
Empirical findings produced by dynamic time-varying causality have shown that OPR changes at various points of time affect EXR. Time-varying dynamics supported that these causal relations and co-moments remained heterogeneous at different time—this includes both the time of crisis and the time of normality. In particular, Bai and Perron’s (2003) structural break findings in Table 1 and Fig. 2 show the fluctuation in nominal EXR in all five ASEAN economies after the 1997 Asian financial crisis. This finding indicates the existence of a significant causality during the Asian crisis triggering the co-movements between EXR and international OPR. This clearly indicates there is no-linear relationship between EXR and OPR during the time of crisis. Similarly, the same structural breaks can be seen during the 2008 global financial meltdown and 2014 oil market price fluctuations.

6 Discussions

Empirical findings produced by dynamic time-varying causality have shown that OPR changes at various points of time affect EXR. Time-varying dynamics supported that these causal relations and co-moments remained heterogeneous at different time—this includes both the time of crisis and the time of normality. In particular, Bai and Perron’s (2003) structural break findings in Table 1 and Fig. 2 show the fluctuation in nominal EXR in all five ASEAN economies after the 1997 Asian financial crisis. This finding indicates the existence of a significant causality during the Asian crisis triggering the co-movements between EXR and international OPR. This clearly indicates there is no-linear relationship between EXR and OPR during the time of crisis. Similarly, the same structural breaks can be seen during the 2008 global financial meltdown and 2014 oil market price fluctuations.
fluctuations. Hence, this indicates the EXR is sensitive to OPR during the time of global crisis.

Figure 3a, b displays the rolling, and recursive method involving a time-varying causality that exists between the OPR and the EXR in Indonesia during the crisis period such as 2008 GFC and U.S. subprime mortgage crisis in 2011. The recursive evolving results found that the Indonesian nominal EXR appeared more sensitive to both the US subprime mortgage crisis, European debt crisis in 2014 and US-China trade war during 2019. These findings are similar to those of (Bedoui et al. 2019; Wen et al. 2018). Moreover, (Baek and Choi 2021) concluded that among ASEAN bloc, Indonesia remained less sensitive to shocks during the latter crisis due to oil exports. However, during the 1997 financial crisis it was exactly opposite because the OPR loses its predictive power on the EXR in Indonesia in this period. The Gulf War may explain these results during the 1990s but after 1997 financial shock Indonesia developed market for the alternative energy sources. On the contrary, Indonesia is the largest palm oil exporter to the European countries and palm oil exports contributes a significant share to the economy. However, the European union suspension of Palm oil exports in 2017 shocked the Indonesian palm oil industry and the reason of ban was Indonesian government led deforestation of rainforests for the plantation of palm oil. (Rifin 2020) evaluates the impact of palm oil export limitation to European Union on the Indonesian economy both at macro- and micro-level. Even our data as shown Fig. 8a show the casualty between the OPR and EXR due to the suspension of Indonesian palm oil exports.

In addition, the financialization theory of the commodity market supports these findings by arguing that during the time of crisis, risk spillovers also exacerbate. Furthermore, using both rolling and recursive window approaches, Indonesia has the strongest time-varying granger causality for the OPR and EXR during the 2007–2010 subprime global financial crisis. Sharma et al. (2019) found the similar results by employing monthly time series data and speculated that in case of Indonesia OPR significantly determines the macroeconomic indicators.
Malaysia has the stronger time-varying granger-causality from the OPR to EXR after December 2012 during the time of U.S. fiscal cliff and sovereign debt crisis in Europe with recursive window approaches. However, compared to other ASEAN countries, time-varying granger-causality of OPR to EXR for Malaysia differs for Brent oil in 2004 due to the U.S. invasion of Iraq and WTI during European sovereign debt crisis in 2012. Li et al. (2022) identifies same effects of OPR on EXR for the emerging markets and hence, validated the differing fluctuation for Brent oil and WTI during the same period. Our findings show the consistency to those conducted by (Al-hajj et al. 2018; Butt et al. 2020; Butt et al. 2020; Kisswani 2016a; Raghavan 2015; Vu and Nakata 2014).

In Singapore, the OPR has a significant causal effect on the EXR during the May 2011–Feb 2013 aligned with the political turmoil in Bahrain, Egypt, Yemen and Libya as shown in rolling and recursive window approach. The primary reason behind this fluctuation was the disruption of oil supplies from the Middle East due to the political unrest ignited by the Arab Spring. In Thailand, the OPR has a significant causal effect on the EXR during the July 1990 Gulf War I, May 1992, April 2003 Iraq War and January-2020 coronavirus with rolling and recursive window approaches.

In case of Thailand, the casualty between OPR and EXR mainly occurred during period of Iraq war that send out shock waves across the oil markets because Iraq was a major oil supplier. Moreover, as it is shown in Fig. 7a, b, and Fig. 12a, b, unlike other ASEAN nations the causality between OPR and EXR is high for Thailand because Thailand was more sensitive to the internal and external shocks. For instance, during the May 1992 crisis, there is significantly high causality between OPR and EXR compared to other members of ASEAN. Unlike the other ASEAN members, Thailand’s economy was unprepared to absorb the internal and external shocks (Nguyen Do and Rahut 2020).

In Philippines, the OPR has a significant causal effect on the EXR during July 2004 to January 2005 signifying the importance of Iraq war when OPR reached historic high price of 57 USD as per Brent. Just like Malaysia, during the period of Iraq war, the fluctuation for the Brent oil from 2004–2005 reached the record high, which is shown in Fig. 5b. The recursive evolving of OPR to EXR during the latter period is similar for the other ASEAN countries due to financial market integration in the ASEAN bloc. (Green 2008) studied the impact of Iraq war on Asian economies particularly ASEAN countries and concluded that the Iraq war created major consequences for the Asian economies at the macro-economic level. Moreover, in case of ASEAN economies especially Philippines and Thailand the author identified second- and third-order impact on their economies. In the domain of political economy, the term second-and third-order impacts refer to the change in events at the system level that in turn directly affect the response, behavior and attitudes of the agents such as people and businesses (Erdmann and Hilty 2010).

Our results on time-varying causality relationships among the five ASEAN countries support the findings of (Korhonen and Juurikkala 2009). Malaysia, and Singapore especially Indonesia are oil-exporting countries among the five countries. Any increase in the OPR benefits them as they earn more revenue that plays a central role in stabilizing the exchange rate. Other studies on oil-exporting countries have
found similar results and their results for Algeria show that there is an equilibrium in the long run time-varying compared other commodity exporting countries (Koranchelian 2005). Zalduendo (2006) found the similar results for the Venezuela, which has the largest oil reserves in the world and is a major oil exporting nation. In a recent study, (Baek and Choi 2021) documented that an appreciation of the OPR more strongly affects the Indonesian Rupiah than a decrease in the OPR. According to the recursive and rolling approaches, OPR changed the EXR in the Singapore currency market in 2014. One possible explanation is that after 2014, the crude OPR started decreasing significantly. On 20 June 2014, the crude OPR was 104.92, reduced to $53 on 31 December 2014 and further reduced to 29.42 on 15 Jan 2016. Singapore exports $52 billion worth of refined oil which was 16% of its total exports in 2018 (OEC 2021).

Indonesia joined OPEC in 1962 and left the organization in 2009. After 2004, Indonesia became a net importer of oil because its consumption exceeded its domestic production. Furthermore, the country lacks oil refinery technology to import petroleum products such as gasoline. Our results from the recursive rolling method show that from 1992 to 98, there was significant time-varying causality between the OPR and the EXR in Indonesia. ASEAN countries changed their ER regime in response to the Asian financial crisis in 1997–98 (Vu and Nakata 2014). During this period, Indonesia significantly cut down its oil production, and thus the EXR was affected. The other possible explanation for these findings is that the Gulf War significantly affected the international oil market during the 1990s. As a result, following this period, we do not notice a significant causal association between the OPR and the EXR (Vu and Nakata 2014).

7 Conclusion

The main purpose of the present study is to evaluate the time-varying causal relationship between the OPR and the EXR in five ASEAN countries: Malaysia, Indonesia, Thailand, Singapore, and the Philippines. We used time-varying Granger causality for these countries to link the OPR and the EXR (Shin 2018, 2019). The major findings indicate that the causal relationship the OPR and the EXR may be summarized as follows:

EXR and OPR are sensitive to each other, as are specified by various dates and events in our findings. The diversity of ASEAN countries in our sample across time horizons is intriguing. Our findings show that during the time of major events there appears a significant causality between OPR and EXR due to sensitivity of ASEAN economies to internal and external shocks. Moreover, the impact of OPR on the EXR is heterogeneous over time across the five ASEAN countries. Specifically, the findings show that the results of time-varying causality in these sampled countries vary. The findings confirm that the time-varying features are useful insights for investors and policymakers to understand the impacts of the OPR and the EXR.

The results of the present study have useful insights for investors and decision-makers including investment consultancy firms and traders. For instance, investment decision-making needs to keep an eye on OPR shocks and EXR, particularly while
long-term planning is concerned. Although, the case of causality between OPR and EXR, according to earlier empirical findings, shows conflated findings for oil importing and exporting countries, however, the case of ASEAN countries should be separately considered in isolation, given the geographical, resource endowment and trade policies. As our results have found that the ASEAN economies are more sensitive to shocks during certain point of event and to overcome this sensitivity, the ASEAN nations need to take the following steps. First, there is urgent need of robust policy to regulate the internal and external shocks during the time of crisis. Second, the central banks of the ASEAN nations may develop a back-up strategy to stabilize exchange rate during the crisis by maturing the monetary policies. Moreover, our findings calls for a special strategy for investment decisions related to the ASEAN region while considering multiple EXR. In addition, for sectors including oil, and currency exchange, a differentiated strategy should be applied to the region and companies and trade firms related to oil and portfolio investment.

Author contributions MK: Conceptualization, Visualization, Investigation, Writing—Original Draft, Formal Analysis, Review and Editing, Software and Methodology, Supervision, Validation, Project Administration. PK, AA & SYL: Review and Editing, Supervision, Resources, Data Curation and Investigation.

Funding There is not involvement of funding in this research.

Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethical approval No human data are involved in this research.

Consent for publication It is not applicable to this study, as there is no human data involved in it.

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