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# Dynamic linkage between oil prices and exchange rates: new global evidence

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## Abstract

This paper examines the dynamic linkage between crude oil prices and exchange rates from a global perspective. Unlike the conventional cointegration specification used in earlier works, we evaluate long- and short-run relations based on the pooled mean group approach. Taking monthly data of real oil prices and real exchange rates from the period January 1997 to July 2015, we classify 81 countries by their net oil import status (i.e., oil-importing and oil-exporting) and exchange rate arrangement systems (i.e., free-floating and managed floating), presenting results that the long-run relationship between oil prices and exchange rates depends on country-specific circumstances. For countries adopting free-floating systems, oil importers reveal a significantly negative bidirectional correlation, while oil exporters show no correlation between oil prices and exchange rates. As for managed floating systems, only exchange rates have predictive content for oil prices no matter in the cases of oil importers or exporters. Knowledge of these relationships can guide government policy development to prevent sudden and substantial shocks from crude oil price and exchange rate movements.

**Keywords** Crude oil price · Exchange rate · Exchange rate systems · Pooled mean group

**JEL Classification** C33 · G15 · Q43

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## 1 Introduction

The frequent episodes of crude oil prices' boom and bust in recent decades have attracted intense interest in their potential determinants (Hamilton 2009) and their macroeconomic impacts (e.g., Narayan et al. 2014; Narayan and Gupta 2015; Ghosh and Kanjilal 2016; Lee et al. 2017, 2019; Lee and Lee 2019). Without a doubt, there is an extensive amount of theoretical and empirical research exploring the linkage between crude oil prices and exchange rates, but lacks a clear understanding due to the mixed results therein. From a theoretical standpoint, the relationship between oil prices and exchange rates may run in either or both directions through multiple channels. The influence of oil prices on exchange rates can be transmitted through the terms of trade channel, the wealth effect channel, and the portfolio reallocation channel (Golub 1983; Krugman 1983; Amano and van Norden 1998), while the opposite relation is derived from the asset pricing theory (Bloomberg and Harris 1995; Chen et al. 2010).

Empirical works analyzing bidirectional spillovers are of importance for market participants, because they point out the direction of relationship and its determinants. However, the findings of empirical inquiries into this issue are somewhat mixed. Some previous studies, for example, consider the role oil prices have in explaining exchange rates (e.g., Bénassy-Quéré et al. 2007; Chen and Chen 2007; Narayan et al. 2008; Lizardo and Mollick 2010; Al-mulali and Sab 2012; Buetzer et al. 2016), while others find either the importance of exchange rates in affecting oil price movements (e.g., Sadorsky 2000; Yousefi and Wirjanto 2004; Zhang et al. 2008; Akram 2009) or no correlation between the two variables (e.g., Aleisa and Dibooglu 2002; Breitenfeller and Cuaresma 2008). Different findings on the perceptions of relationship depend on diverse sample selection (with a specific time frame or sample countries), different methodology, and the choice of variables.

It is also worth noting that there might be divergent responses for oil-importing and oil-exporting countries since their energy policies are disparate with regard to the nature of economic swings. The terms of trade channel mentioned above suggest that increases in real oil prices lead to real exchange appreciation in net oil-exporting countries (Sadorsky 2000; Chen and Chen 2007; Lizardo and Mollick 2010; Basher et al. 2016; Buetzer et al. 2016; Yang et al. 2017) and depreciation in oil-importing countries (Chen and Chen 2007; Lizardo and Mollick 2010; Buetzer et al. 2016). Reboredo (2012) and Yang et al. (2017) also show that the co-movements of oil price and exchange rate are more pronounced for oil-exporting countries.

While the connections between oil prices and exchange rates have been broadly analyzed in the empirical literature, an essential influencing factor, like the exchange rate arrangement system, has not yet received attention. Husain et al. (2005) assess the influence of an exchange rate regime on its macroeconomic performance for a wide range of developing and advanced economies. Their results indicate that exchange rate flexibility is likely to spur higher inflation in developing countries, while it is associated with lower inflation in advanced countries. Based on these observations, Narayan et al. (2019) expect that the price impact is stronger in the float regime than the managed float regime when they evaluate the influence of oil prices on Indonesia's exchange rate. They indicate that previous findings on the disconnection between exchange rates and oil prices can be attributed to the exchange rate regimes, revealing results that a long-run relation exists in float exchange rate regimes, but not in managed float regimes. Following this vein, our paper takes a fresh look at the long-run relationship between oil prices and exchange rates from the perspective of exchange rate system.

There are several contributions from the present research. First, we assess the long-run relationship between oil prices and exchange change rates from a global perspective, which has been less involved in existing empirical research. Reviewing the existing literature, while some studies address the issue within a multi-country context, most others are country-specific and difficult to generalize. Based on a comparative analysis on 81 countries, our findings complement the existing research by considering heterogeneities across countries, which are arguably essential to analyzing the global oil and exchange rate markets. In addition, to provide more useful information, we categorize 8 subpanels based on their average annual oil net import and exchange rate arrangement systems and thus identify distinct connectedness scenarios and divergent relations between oil prices and the exchange rates for these groups. Second, the use of pooled mean group (PMG) approach introduced by Pesaran et al. (1999) allows short-run dynamics to differ across countries and enables valid inferences for short-run and long-run relationships, no matter whether the included variables are integrated of order one or zero. Hence, the PMG estimators offer more flexibility over the alternative standard cointegration tests that heavily rely on the pretesting problems of the order of integration for the system. To the best of our knowledge, Chen and Chen (2007) are the first at dealing with the relationship between real oil prices and real exchange change rates for G7 countries by employing the PMG approach. Following this vein, we evaluate long- and short-run relations using the pooled mean group approach on a global scale under the consideration of heterogeneities across countries.

The rest of the paper runs as follows. Section 2 provides a brief review of the relevant literature concerning the relationship between oil prices and exchange rates. Section 3 introduces the methodology used herein. Section 4 provides data descriptions, sources, and variable definitions. Section 5 discusses the results of analyses. Section 6 draws some conclusions and outlines implications.

## 2 Theoretical foundations and related literature

A massive amount of theoretical and empirical research has analyzed the linkage between oil prices and exchange rates, because they are closely connected with the economy. Theoretically, oil prices affect exchange rates via three particular channels: the terms of trade channel, wealth effect channel, and portfolio reallocation channel. The trade channel stresses that oil price plays a peripheral role that affects trade conditions. Amano and van Norden (1998) construct a simple two-sector model for tradable and non-tradable goods and show that oil prices are a major cause of persistent shocks on exchange rates. For the wealth effect and the portfolio reallocation channel, Golub (1983) and Krugman (1983) provide a theoretical basis to state that oil price movement results in a wealth transfer from oil-importing to oil-exporting countries. Specifically, the aforementioned wealth and portfolio channels signal the short-run and long-sun effects of this transfer, respectively. On the other hand, the potential importance of exchange rates in explaining oil price variations is also theoretically investigated. Based on the law of one price, for example, Bloomberg and Harris (1995) provide some useful insights on the effects of exchange rates on oil prices. Given that crude oil is a primary energy source traded internationally in US dollars, a relatively weak US dollar, ceteris paribus, reduces the cost to international buyers and increases the demand for oil, thereby leading to a rise in oil prices. Using the present-value model, Chen et al. (2010) offer a theoretical resolution to show that exchange rates have remarkable predictive power in explaining commodity prices.

Based on the aforementioned theoretical foundations, a large amount of research effort has been devoted to discussing the bidirectional relationship between oil prices and exchange rates. One main strand of the literature discusses the long-run interaction mechanism between oil prices and exchange rates. Amano and van Norden (1998), for example, use the cointegration and vector error correction model to examine the relationship between the US real exchange rate and real oil prices. The results suggest that oil prices are a major source of exchange rate shocks. Using monthly panel data for the G7 countries and a panel cointegration technique, Chen and Chen (2007) also show the preeminent role of oil prices in forecasting exchange rates in G7 countries. Based on cointegration analysis, Lizardo and Mollick (2010) provide evidence that a rising real oil price is associated with a real appreciation (depreciation) in the exchange rate of oil-exporting (oil-importing) countries. Focusing on 12 oil-exporting countries, Al-mulali and Sab (2012) apply fixed and random effects models to detect the oil price-exchange rate relation, showing results that an increase in oil prices leads to a real exchange rate appreciation in these countries. Using a Markov-switching approach, Buetzer et al. (2016) show oil price changes originating from global economic demand shocks affect a country's terms of trade, thereby causing changes in exchange rates in both oil-exporting and oil-importing countries. By contrast, other studies suggest that exchange rates matter to oil prices. Using vector error correction models, Sadorsky (2000) investigates the interaction between energy futures prices (including crude oil) and trade-weighted US exchange rates. Their empirical results indicate that exchange rates have predictive content for energy futures prices. Zhang et al. (2008) also reach similar results in the long run based on varied econometric techniques, but the short-term effect of the US dollar exchange rate is quite limited.

Another strand of contemporary literature aims at the short-run dynamics between oil prices and exchange rates (Narayan et al. 2008; Reboredo 2012). Narayan et al. (2008), for example, use the GARCH and exponential GARCH models to examine the influence of oil prices on the nominal exchange rate. Their results indicate that oil price shocks lead to exchange rate appreciation in Fiji Islands. Reboredo (2012) further employ a copula-based GARCH model to explore the co-movements of oil prices and exchange rates. Results show that the oil price and exchange rate co-movements are more pronounced for oil-exporting countries like Canada, Norway, and Mexico and less severe for the oil-importing countries, like Japan. Some recent studies also consider wavelet approaches to study the relationship among series (Reboredo and Rivera-Castro 2013; Tiwari et al. 2013; Bouoiyour et al. 2015; Yang et al. 2017).

Based on the wavelet coherence framework, Yang et al. (2017) find the relationship between crude oil prices and exchange rates is negative for oil-exporting countries, while the linkage is unclear for oil-importing countries.

In contrast to the aforementioned works, little is known about how exchange rate restrictions shape the relation between oil prices and exchange rates. Since exchange rate policy has sustained or persistent effects on the behavior of exchange rates (as noted by Akram 2004), detailed knowledge on the role of exchange rate systems is required to shed light on this issue. According to our understanding, Lv et al. (2018) are the only researchers examining whether and how exchange rate mechanisms may alter the relationship between oil prices and exchange rates. They distinguish free-floating, managed floating, and soft-pegged arrangement systems for 17 oil-exporting countries. Their empirical results show that countries with free-floating exchange rate systems show a significantly negative bidirectional correlation between oil prices and exchange rates. They also find that the correlation between oil prices and exchange rates turns weak with high government restrictions. However, the relationship in either direction cannot be fully ruled out no matter for managed exchange rate systems or for pegged exchange rate systems.

## 3 Empirical model and methodology

### 3.1 Basic framework

To simplify the exposition, this research first considers the following simple relation between real oil prices and real exchange rates. We define the real exchange rate ($\mathrm{REXCH}_t$) as the nominal exchange rate deflated by a ratio of domestic to foreign price levels.

$$\mathrm{REXCH}_t = \frac{\mathrm{EXCH}_t \times P_t^*}{P_t}, \tag{1}$$

where $\mathrm{EXCH}_t$ is the nominal exchange rate defined in local currency units per US dollar; $P_t^*$ and $P_t$ are the domestic and foreign price levels, respectively. The logarithm of the real exchange rate ($\mathrm{rexch}_t$) can be written as the nominal exchange rate adjusted for changes in the home and foreign price levels.

$$\mathrm{rexch}_t = \mathrm{exch}_t + p_t^* - p_t, \tag{2}$$

where $\mathrm{exch}_t$ is the logarithm of the nominal exchange rate; and $p_t^*$ and $p_t$ are the logarithm of the domestic and foreign price levels, respectively.

Following Chen and Chen (2007), Narayan (2013), and Kisswani et al. (2019), the real oil price ($\mathrm{ROILP}_t$) is defined as the nominal price of WTI crude oil expressed in US dollars converted to domestic currency price, using the exchange rate ($\mathrm{EXCH}_t$), and then deflated by domestic consumer price index ($P_t^*$).

$$\mathrm{ROILP}_t = \frac{\mathrm{EXCH}_t \times \mathrm{OILP}_t}{P_t^*} \tag{3}$$

The logarithm of the oil price is then expressed as the nominal oil price adjusted for the exchange rate and home price levels.

$$\mathrm{roilp}_t = \mathrm{oilp}_t + \left(\mathrm{exch}_t - p_t^*\right) \tag{4}$$

### 3.2 Panel unit root test with cross-sectional dependence

In the context of an increasingly integrated global financial market, it is crucial to consider the persistence of cross-sectional dependence through potential spatial and spillover effects or as a result of unobserved common factors (Asafu-Adjaye et al. 2016). To deal with the above problems, we first apply the cross-sectional dependence (CD) test of Pesaran (2004) to examine whether there is cross-sectional dependence across countries for each variable.

We then conduct Pesaran's (2007) cross-sectionally augmented Im-Pesaran-Shin (CIPS) test of cross-sectional dependence. A one-factor model with heterogeneous loading factors for residuals is used here. The Pesaran's CIPS test statistic for a null of unit root against a heterogeneous alternative is given by,

$$\mathrm{CIPS}(N,\ T) = \frac{1}{N}\sum_{i=1}^{N} t_i(N, T), \tag{5}$$

where $t_i(N, T)$ is the $t$-ratio given by the ADF regression on cross section $i$. The null hypothesis of a unit root can be rejected if the statistic is lower than the critical value tabulated in Pesaran (2007).

### 3.3 The pooled mean group (PMG) estimator

The modeling approach in this paper follows the analytical framework of Chen and Chen (2007), Narayan (2013), and Kisswani et al. (2019) in hypothesizing the nexus between real oil prices and real exchange rates that appears in Eq. (6),

$$\mathrm{rexch}_{it} = \alpha_i + \beta \mathrm{roilp}_{it} + \varepsilon_{it}, \tag{6}$$

where $i = 1, \ldots, N$ identifies the cross-sectional unit, and subscript $t = 1, \ldots, T$ denotes the time period. The dependent variable $\mathrm{rexch}_{it}$ is the logarithm of real exchange rates, and the explanatory variable $\mathrm{roilp}_{it}$ is the logarithm of real oil prices.

To examine the relationship between the two, we start with a simple panel autoregressive distributed lag (ARDL) by assuming a symmetric response of real oil prices to changes in real exchange rates. Following Pesaran et al. (1999), an ARDL $(p, q)$ dynamic panel specification of Eq. (6) is presented as Eq. (7),

$$\mathrm{rexch}_{it} = \sum_{j=1}^{p} \lambda_{ij}\mathrm{rexch}_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}\mathrm{roilp}_{i,t-j} + \mu_i + \varepsilon_{it}, \tag{7}$$

where $\lambda_{ij}$ are scalars, $\delta_{ij}$ are estimated coefficients, and $\mu_i$ represents fixed effects. Equation (7) can be rearranged as in Eq. (8),

$$\begin{aligned}\Delta \text{rexch}_{it} &= -\phi_i \text{rexch}_{i,t-1} + \beta_i \text{roilp}_{i,t-1} \\ &\quad + \sum_{j=1}^{p-1} \lambda_{ij} \Delta \text{rexch}_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij} \Delta \text{roilp}_{i,t-j} + \mu_i + \varepsilon_{it},\end{aligned} \tag{8}$$

where $\phi_i = (1-\sum_{j=1}^{p} \lambda_{ij})$, $\beta_i = \sum_{j=0}^{q} \delta_{ij}$, $\lambda_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}$ for $j = 1, \ldots, p-1$, and $\delta_{ij} = -\sum_{m=j+1}^{q} \delta_{im}$ for $j = 1, \ldots, q-1$. Equation (7) can be reparametrized into an error correction form as in Eq. (9),

$$\begin{aligned}\Delta \text{rexch}_{it} &= -\phi_{1i}(\text{rexch}_{i,t-1} - \theta_{10} - \theta_{11}\text{roilp}_{i,t-1}) \\ &\quad + \sum_{j=1}^{p_1-1} \lambda_{1ij} \Delta \text{rexch}_{i,t-j} + \sum_{j=0}^{q_1} \delta_{1ij} \Delta \text{roilp}_{i,t-j} + \varepsilon_{1it},\end{aligned} \tag{9}$$

where $\text{rexch}_{i,t-1} - \theta_{10} - \theta_{11}\text{roilp}_{i,t-1}$ is the error correction term for each unit; $\theta_{11}$ denotes the long-run coefficient, while $\lambda_1$ and $\delta_1$ are the short-run coefficients. In a similar manner, the impact of real oil prices on real exchange rates can be expressed as,

$$\begin{aligned}\Delta \text{roilp}_{it} &= -\phi_{2i}(\text{roilp}_{i,t-1} - \theta_{20} - \theta_{21}\text{rexch}_{i,t-1}) \\ &\quad + \sum_{j=1}^{p_2-1} \lambda_{2ij} \Delta \text{roilp}_{i,t-j} + \sum_{j=0}^{q_2} \delta_{2ij} \Delta \text{rexch}_{i,t-j} + \varepsilon_{2it}\end{aligned} \tag{10}$$

where $\text{roilp}_{i,t-1} - \theta_{20} - \theta_{21}\text{rexch}_{i,t-1}$ is the error correction term for each unit; $\theta_{21}$ denotes the long-run coefficient, while $\lambda_2$ and $\delta_2$ are the short-run coefficients.

The PMG estimator allows for cross-sectional heterogeneity in its short-run coefficients, speed of adjustment, and error variances, but imposes homogeneity on long-run coefficients. The long-run equilibrium relationships between real oil prices and real exchange rate can be specified in Eqs. (11) and (12),

$$-\phi_1(\text{rexch}_{t-1} - \theta_{10}^* - \theta_{11}^*\text{roilp}_{t-1}) \tag{11}$$

$$-\phi_2(\text{roilp}_{t-1} - \theta_{20}^* - \theta_{21}^*\text{rexch}_{t-1}) \tag{12}$$

The coefficients of the error correction term $\phi_1$ and $\phi_2$ represent the speed of adjustment toward its long-run equilibrium. The inverse of the absolute value of these coefficients provides a measure for speed of adjustment. The significance of the long-run coefficients $\theta_{11}$ and $\theta_{21}$ indicates a valid long-run relationship between the associated variable and the dependent variable. In addition, a significantly negative associated error correction term suggests a valid long-run relationship.

## 4 Data description

Our sample employs monthly data of oil prices, consumer price index, and nominal exchange rates for 81 countries. Data for WTI crude oil prices (in US dollars per barrel) are obtained from the website of the US Energy Information Administration (EIA),[1] while the data for consumer price index (2010 = 100) and nominal exchange rates (defined as national currency per US dollar) are extracted from the International Financial Statistics (IFS). Based on data availability of all the variables, the total sample contains a balanced panel of 3942 observations over the period from January 1997 to July 2015.

To provide more informative disclosures, this study divides a global sample of 81 countries (*All*) into several meaningful subsample groups. Table 1 lists the countries and the abbreviations used and provides detailed descriptions of the individual exchange rate systems and net crude oil imports. We first collect data on crude oil imports and exports, which are expressed in thousand tons of oil equivalent, ktoe, from the website of the International Energy Agency (IEA). Column 4 summarizes the average annual oil net imports within a country. The positive numbers show net imports, while the negative numbers present net exports. Based on these numbers, we classify the sample into oil-importing and oil-exporting countries.

We identify the exchange rate regimes indicated by the numbers 1–9 for each country by using the information from International Monetary Fund (IMF 2015). A higher number assigned for an exchange rate regime imply a more free-floating exchange rate system (1 = no legal tender of their own, 2 = currency board, 3 = conventional peg, 4 = stabilized arrangement, 5 = crawling peg, 6 = craw-like arrangement, 7 = other, 8 = floating, 9 = free-floating). To get a better insight into the role of exchange rate systems, we classify the countries into free-floating countries (numbers 8–9) and managed floating countries (numbers 1–7).

In summary, this paper conducts a comparative analysis for 81 countries and 8 subpanels based on their importer or exporter status and exchange rate systems. These subpanels included in our analysis are 56 oil-importing countries (*oilimp*), 25 oil-exporting countries (*oilexp*), 46 free-floating countries (*float*), 35 managed floating countries (fix), 37 oil-importing countries with a free-floating system (*impfloat*), 19 oil-importing countries with a managed floating system (*impfix*), 9 oil-exporting countries with a free-floating system (*expfloat*), and 16 oil-exporting countries with a managed floating system (*expfix*). Table 7 of "Appendix" provides information on the countries covered.

## 5 Empirical results

### 5.1 Preliminary tests

Many econometric modeling tasks require knowledge on the stationarity properties of the respective variables used in the analysis (Lee et al. 2013; Liu et al. 2016; Gupta et al.

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[1] Available at http://www.eia.gov.

**Table 1** The oil import status and exchange rate systems for sample countries

| Countries | Code | EX systems | Oil net imports | |
|---|---|---|---|---|
| | | | Mean | Median |
| *Panel A: 56 oil-importing countries* | | | | |
| Australia | AUS | 9 | 7074 | 7363 |
| Austria | AUT | 9 | 8235 | 8192 |
| Bangladesh | BGD | 4 | 1221 | 1219 |
| Belgium | BEL | 9 | 32500 | 32725 |
| Brazil | BRA | 8 | 3286 | − 139 |
| Bulgaria | BGR | 2 | 6198 | 6103 |
| Chile | CHL | 9 | 9858 | 9872 |
| China | CHN | 6 | 152445 | 138838 |
| Croatia | HRV | 6 | 3780 | 3969 |
| Cyprus | CYP | 9 | NA (2440)[c] | NA |
| Czech Republic | CZE | 4 | 6936 | 7004 |
| El Salvador | SLV | 1 | 773 | 901 |
| Estonia | EST | 9 | NA (550)[c] | NA |
| Finland | FIN | 9 | 11813 | 11914 |
| France | FRA | 9 | 75375 | 81170 |
| Germany | DEU | 9 | 102440 | 104337 |
| Ghana | GHA | 8 | 177 | 1567 |
| Greece | GRC | 9 | 20624 | 20218 |
| Haiti | HTI | 6 | NA (980)[c] | NA |
| Honduras | HND | 5 | NA (2380)[c] | NA |
| Hong Kong | HKG | 2 | NA (28890)[c] | NA |
| Hungary | HUN | 8 | 5915 | 5800 |
| Iceland | ISL | 8 | NA (950)[c] | NA |
| India | IND | 8 | 122611 | 113955 |
| Ireland | IRL | 9 | 3151 | 3041 |
| Israel | ISR | 8 | 12238 | 12023 |
| Italy | ITA | 9 | 83768 | 87770 |
| Jamaica | JAM | 6 | 988 | 1066 |
| Japan | JPN | 9 | 200453 | 208273 |
| Jordan | JOR | 3 | 3741 | 3633 |
| Kenya | KEN | 8 | 1587 | 1651 |
| Korea/South | KOR | 8 | 121981 | 121216 |
| Luxembourg | LUX | 9 | NA (4020)[c] | NA |
| Morocco | MAR | 3 | 6273 | 6398 |
| Nepal | NPL | 3 | NA (1950)[c] | NA |
| New Zealand | NZL | 8 | 3436 | 3472 |

**Table 1** continued

| Countries | Code | EX systems | Oil net imports | |
|---|---|---|---|---|
| | | | Mean | Median |
| Pakistan | PAK | 7 | 7229 | 7676 |
| Panama | PAN | 1 | NA (6580)$^{c}$ | NA |
| Peru | PER | 8 | 3293 | 3546 |
| Philippines | PHL | 8 | 10791 | 9706 |
| Poland | POL | 9 | 20484 | 20701 |
| Portugal | PRT | 9 | 13202 | 13487 |
| Romania | ROM | 8 | 6481 | 6153 |
| Singapore | SGP | 4 | 49121 | 47584 |
| Slovak Republic | SVK | 9 | 5597 | 5614 |
| South Africa | ZAF | 8 | 18800 | 18857 |
| Spain | ESP | 9 | 60214 | 60118 |
| Sri Lanka | LKA | 4 | 2011 | 1990 |
| Sweden | SWE | 9 | 19523 | 19523 |
| Switzerland | CHE | 6 | 4876 | 5033 |
| Taiwan | TWN | 8 | 45165 | 45923 |
| Thailand | THA | 8 | 37839 | 38337 |
| Trinidad and Tobago | TTO | 4 | 1366 | 1253 |
| Turkey | TUR | 8 | 21709 | 23077 |
| Uruguay | URY | 8 | 1808 | 1890 |
| Zambia | ZMB | 8 | 471 | 489 |
| *Panel B: 25 oil-exporting countries* | | | | |
| Algeria | DZA | 7 | – 43854 | – 39955 |
| Angola | AGO | 4 | – 64220 | – 69360 |
| Argentina | ARG | 8 | – 7235 | – 4680 |
| Bolivia | BOL | 4 | – 119 | – 94 |
| Canada | CAN | 9 | – 56138 | – 50398 |
| Colombia | COL | 8 | – 21013 | – 18250 |
| Denmark | DNK | 3 | – 6088 | – 5635 |
| Egypt | EGY | 4 | – 5904 | – 5836 |
| Gabon | GAB | 3 | – 12580 | – 12156 |
| Guatemala | GTM | 6 | – 539 | – 534 |
| Indonesia | IDN | 8 | – 5050 | – 1350 |
| Iran | IRN | 6 | – 108996 | – 118508 |
| Kazakhstan | KAZ | 4 | – 48028 | – 52008 |
| Kuwait | KWT | 3 | – 77669 | – 73367 |
| Malaysia | MYS | 7 | – 8504 | – 9150 |
| Mexico | MEX | 9 | – 86396 | – 89760 |
| Nigeria | NGA | 7 | – 111532 | – 111004 |
| Norway | NOR | 9 | – 106501 | – 101134 |

**Table 1** continued

| Countries | Code | EX systems | Oil net imports | |
|---|---|---|---|---|
| | | | Mean | Median |
| Paraguay | PRY | 8 | NA (– 1660)$^{c}$ | NA |
| Russian Federation | RUS | 8 | – 212119 | – 240309 |
| Saudi Arabia | SAU | 3 | – 337776 | – 350954 |
| Sudan | SDN | 7 | – 9049 | – 9107 |
| Tunisia | TUN | 6 | – 1912 | – 1788 |
| UK | GBR | 9 | – 3787 | 6297 |
| Vietnam | VNM | 4 | – 13490 | – 14102 |

According to the list of countries by exchange rate regime in IMF (2015), the exchange rate systems are specified as follows: 1 = no legal tender of their own, 2 = currency board, 3 = conventional peg, 4 = stabilized arrangement, 5 = crawling peg, 6 = craw-like arrangement, 7 = other, 8 = floating, 9 = free-floating. NA = not available. Superscript c denotes average annual oil net imports within a country are unavailable, and net imports of the country in 2015 are therefore indicated in parentheses

2018). Before conducting further estimations, it is meaningful to assess the order of integration of the series. While the PMG estimation is applicable no matter whether the variables are integrated of order zero or one, one must conduct unit root tests to make sure that no higher degree of integration variable is involved in the system. To address the concern of cross-sectional dependence, the left panel of Table 2 reports the CD test results for the global panel and each of the eight subpanels. Evidence shows that the null hypothesis of cross-sectional independence is strongly rejected at the 1% significance level, supporting the use of the cross-sectional dependent panel unit root test.

The right panel of Table 2 summarizes the results of CIPS statistics for the constant only models and the constant and time trend models. Given that real oil prices generally exhibit a clear time trend, we choose the model with intercepts and time trends. Results reveal that the null hypothesis of a unit root for *rolip* is not rejected in level, but is rejected when the data are in first and second differences, suggesting that real oil prices are $I(1)$ series. For those of *rexch*, evidence shows that real exchange rates are integrated of order zero, $I(0)$, no matter which model specification is used.

The literature has documented that traditional regression systems involving a mixture of stationary and non-stationary variables could lead to spurious results, because the test statistics no longer follow standard distributions (Granger and Newbold 1974; Phillips 1986). In the case of PMG estimation, the variables must not be integrated of order two, $I(2)$; otherwise, the results will lead to misleading inferences. The results of these tests indicate that none of the variables are $I(2)$, and thus, the underlying framework for the PMG estimation is valid for our analyses.

### 5.2 PMG estimation results

Table 3 summarizes the parameter estimation results for the long-run and short-run coefficients using the PMG method. At the bottom of the table, we further conduct the Hausman test in order to justify the use of the pooled mean group approach.

**Table 2** Cross-dependence test and CIPS unit root test

| Cross-dependence test | | | CIPS unit root test | | | |
|---|---|---|---|---|---|---|
| | | | Levels | | First difference | Second difference |
| Panel | Variables | Test statistics | Constant | Constant and trend | Test statistics | Test statistics |
| All | roilp | $779.01^{***}$ | $-2.03^{*}$ | $-2.19$ | $-6.07^{***}$ | $-6.12^{***}$ |
| ($N = 81$) | rexch | $420.66^{***}$ | $-2.98^{***}$ | $-3.29^{***}$ | $-5.73^{***}$ | $-6.07^{***}$ |
| oilimp | roilp | $547.17^{***}$ | $-2.02$ | $-2.18$ | $-6.09^{***}$ | $-6.11^{***}$ |
| ($N = 56$) | rexch | $323.12^{***}$ | $-2.68^{***}$ | $-2.91^{***}$ | $-5.75^{***}$ | $-6.12^{***}$ |
| oilexp | roilp | $228.26^{***}$ | $-2.18^{**}$ | $-2.25$ | $-6.08^{***}$ | $-6.12^{***}$ |
| ($N = 25$) | rexch | $100.08^{***}$ | $-2.76^{***}$ | $-3.48^{***}$ | $-5.38^{***}$ | $-6.05^{***}$ |
| float | roilp | $452.63^{***}$ | $-2.28^{***}$ | $-2.45$ | $-6.12^{***}$ | $-6.11^{***}$ |
| ($N = 46$) | rexch | $252.44^{***}$ | $-2.72^{***}$ | $-3.08^{***}$ | $-6.01^{***}$ | $-6.01^{***}$ |
| fix | roilp | $323.71^{***}$ | $-2.28^{***}$ | $-2.37$ | $-5.96^{***}$ | $-6.12^{***}$ |
| ($N = 35$) | rexch | $189.58^{***}$ | $-2.87^{***}$ | $-3.29^{***}$ | $-5.46^{***}$ | $-6.07^{***}$ |
| impfloat | roilp | $367.94^{***}$ | $-2.17^{**}$ | $-2.35$ | $-6.10^{***}$ | $-6.12^{***}$ |
| ($N = 37$) | rexch | $227.88^{***}$ | $-2.58^{***}$ | $-2.98^{***}$ | $-5.98^{***}$ | $-6.09^{***}$ |
| impfix | roilp | $175.64^{***}$ | $-2.40^{**}$ | $-2.37$ | $-6.11^{***}$ | $-6.11^{***}$ |
| ($N = 19$) | rexch | $108.52^{***}$ | $-2.95^{***}$ | $-2.97^{***}$ | $-5.53^{***}$ | $-6.03^{***}$ |
| expfloat | roilp | $79.78^{***}$ | $-2.57^{***}$ | $-2.58$ | $-6.12^{***}$ | $-6.12^{***}$ |
| ($N = 9$) | rexch | $22.74^{***}$ | $-2.90^{***}$ | $-3.29^{***}$ | $-6.12^{***}$ | $-6.03^{***}$ |
| expfix | roilp | $143.58^{***}$ | $-2.11$ | $-2.25$ | $-6.12^{***}$ | $-6.11^{***}$ |
| ($N = 16$) | rexch | $78.90^{***}$ | $-2.32^{***}$ | $-3.23^{***}$ | $-5.61^{***}$ | $-6.01^{***}$ |

The variables include real crude oil prices (roilp) and real exchange rates (rexch). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively

Here, the null hypothesis is the homogeneity of long-run coefficients against the alternative hypothesis of heterogeneity. Evidence shows that, with some exceptions, all panels pass the test confirming that our PMG estimators are valid.[2] Column 1 in the table shows the results for the full sample when treating *rexch* and *rolip* as dependent variables, respectively. The results show that oil prices and exchange rates exhibit bidirectional correlations, which is in line with theoretical expectations of trade effect, wealth and portfolio channel, as well as asset pricing (Golub 1983; Krugman 1983; Bloomberg and Harris 1995; Amano and van Norden 1998; Chen et al. 2010). More specifically, the estimated long-run coefficients are significantly negative in each case, suggesting a higher oil price is associated with real exchange depreciation and vice versa. For example, a 1% increase in real oil price predicts a 0.27% decrease in real exchange rate (currency depreciation), while a 1% increase in real exchange rate predicts a 0.53% decrease in real oil price. In addition, the coefficients of error correction

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[2] In the case of the long-run coefficients being large but insignificant, the test statistics are negative. This result is the same as those reported in Asafu-Adjaye et al. (2016).

terms are also significantly negative, confirming the existence of long-run relationship among variables for the consideration of both cases. The resulting estimates of the speed of adjustment are 4.78 and 2.91 years, respectively, meaning that each variable in the system responds quite fast to deviations from the long-run equilibrium. Regarding the short-run dynamics, evidence shows a positive bidirectional correlation between real oil prices and real exchange rates in both cases, suggesting that higher oil prices are associated with real exchange appreciations and vice versa.

With reference to the next two columns of Table 3, we report the estimation results for oil-importing and oil-exporting countries. The long-run coefficients and the error correction term provide evidence of a significantly negative bidirectional correlation between oil prices and exchange rates in oil-importing countries. This result suggests that a higher oil price is associated with a real exchange depreciations and vice versa, which is consistent with some previous findings (e.g., Sadorsky 2000; Chen and Chen 2007; Lizardo and Mollick 2010; Basher et al. 2016; Buetzer et al. 2016; Yang et al. 2017). For oil-exporting countries, only a positive unidirectional correlation running from exchange rate to oil price is observed, indicating that exchange rates have predictive power for oil prices. An increase in real exchange rate (currency appreciation) is associated with an increase in real oil price. However, oil price changes have no explanatory power for exchange rates. When the results of oil-importing countries and oil-exporting countries are compared, evidence shows that oil prices are a significant determinant of oil-exporting countries' exchange rates. Rising oil prices is associated with real exchange rate depreciations in oil-importing countries. As noted by Narayan et al. (2019), since the US dollar is used as a major settlement currency in international trade and financial transactions, high energy prices increase US dollar demand, resulting in the depreciation of oil-importing countries' currencies. Regarding the short-run dynamics, there is a bidirectional correlation between real oil prices and real exchange rates, and they impact each other with a positive effect on both oil-importing and oil-exporting countries. When comparing the magnitudes of the elasticity coefficients, we find that the short-run correlation for oil-exporting countries is higher than that for oil-importing countries, which is in line with the findings of Reboredo (2012) and Yang et al. (2017).

Columns 4 and 5 provide the estimation results when free-floating countries and managed floating countries are considered. From the results of long-run coefficients and the error correction term, we find a significantly negative bidirectional correlation between oil prices and exchange rates in free-floating countries, while a significantly negative correlation runs from real exchange rates to real oil prices in managed floating countries. The results for the countries with managed floating exchange systems indicate that rigid restrictions lessen or even vanish the predictive power of oil prices for exchange rates. As far as short-run relation is concerned, evidence shows a positive bidirectional correlation between real oil prices and real exchange rates in both cases. The elasticity coefficients for managed floating countries are higher than those of free-floating countries.

To provide some useful insight on the relationships between real oil prices and exchange rates, Table 4 shows the parameter estimation when a country's oil net imports and exchange rate arrangement systems are simultaneously incorporated. The results show that the long-run relationships depend on a country's specific circum-

**Table 3** Parameter estimation using the PMG method

| Panel | All ($N = 81$) | | oilimp ($N = 56$) | | oilexp ($N = 25$) | | float ($N = 46$) | | fix ($N = 35$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dependent | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp |
| ARDL Model | (2, 2) | (3, 2) | (2, 2) | (3, 2) | (2, 3) | (3, 2) | (2, 2) | (3, 2) | (3, 2) | (3, 2) |
| *Long-run coefficients* | | | | | | | | | | |
| rexch | | $-0.5287^{***}$ | | $-0.6090^{***}$ | | $0.4964^{*}$ | | $-0.6358^{***}$ | | $-0.3667^{**}$ |
| roilp | $-0.2747^{***}$ | | $-0.2140^{***}$ | | 84.9842 | | $-0.0885^{***}$ | | 74.5094 | |
| ecm $_{t-1}$ | $-0.0174^{***}$ | $-0.0286^{***}$ | $-0.0193^{***}$ | $-0.0327^{***}$ | $4.35\text{E}{-}05^{***}$ | $-0.0200^{***}$ | $-0.0233^{***}$ | $-0.0324^{***}$ | $5.03\text{E}{-}05^{***}$ | $-0.0233^{***}$ |
| *Short-run coefficients* | | | | | | | | | | |
| $\Delta\text{rexch}_t$ | | $0.9866^{***}$ | | $0.9423^{***}$ | | $1.0785^{***}$ | | $0.6478^{***}$ | | $1.4074^{***}$ |
| $\Delta\text{rexch}_{t-1}$ | $0.1538^{***}$ | $-0.4218^{***}$ | $0.1701^{***}$ | $-0.3929^{***}$ | $0.1027^{***}$ | $-0.4890^{***}$ | $0.1996^{***}$ | $-0.3831^{***}$ | $0.0869^{***}$ | $-0.4597^{***}$ |
| $\Delta\text{rexch}_{t-2}$ | | | | | | | | | $-0.0436^{***}$ | |
| $\Delta\text{roilp}_t$ | $0.1101^{***}$ | | $0.0908^{***}$ | | $0.1524^{***}$ | | $0.1037^{***}$ | | $0.1139^{***}$ | |
| $\Delta\text{roilp}_{t-1}$ | $-0.0358^{***}$ | $0.2224^{***}$ | $-0.0332^{***}$ | $0.2242^{***}$ | $-0.0399^{***}$ | $0.2181^{***}$ | $-0.0450^{***}$ | $0.2194^{***}$ | $-0.0286^{***}$ | $0.2262^{***}$ |
| $\Delta\text{roilp}_{t-2}$ | | $0.1081^{***}$ | | $0.1128^{***}$ | $-0.0239^{***}$ | $0.0950^{***}$ | | $0.0989^{***}$ | | $0.1205^{***}$ |
| Hausman test [*p* value] | 0.6442<br>[0.4222] | 0.0819<br>[0.7748] | 0.0643<br>[0.7998] | 0.1245<br>[0.7242] | − 0.0030<br>[NA] | 0.2279<br>[0.6331] | 0.0528<br>[0.8183] | 0.2556<br>[0.6132] | − 0.0043<br>[NA] | 0.4717<br>[0.4922] |

The variables include real crude oil prices (roilp) and real exchange rates (rexch). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The lag parameters of the ARDL model are selected based on Akaike information criterion (AIC) with maximum lag set at 4

**Table 4** Parameter estimation using the PMG method

| Panel | impfloat ($N = 37$) | | impfix ($N = 19$) | | expfloat ($N = 9$) | | expfix ($N = 16$) | |
|---|---|---|---|---|---|---|---|---|
| Dependent | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp |
| ARDL model | (2, 2) | (3, 2) | (3, 2) | (3, 2) | (2, 3) | (3, 3) | (2, 3) | (3, 2) |
| *Long-run coefficients* | | | | | | | | |
| rexch | | $-0.6955^{***}$ | | $-0.5180^{***}$ | | 0.0620 | | $1.6479^{***}$ |
| roilp | $-0.0985^{***}$ | | 40.5913 | | 0.0357 | | 83.0451 | |
| $\text{ecm}_{t-1}$ | $-0.0225^{***}$ | $-0.0341^{***}$ | $3.57\text{E}{-}05^{**}$ | $-0.0297^{***}$ | $-0.0318^{***}$ | $-0.0259^{***}$ | $6.81\text{E}{-}05^{***}$ | $-0.0161^{***}$ |
| *Short-run coefficients* | | | | | | | | |
| $\Delta\text{rexch}_t$ | | $0.6617^{***}$ | | $1.4183^{***}$ | | $0.5438^{***}$ | | $1.3650^{***}$ |
| $\Delta\text{rexch}_{t-1}$ | $0.2021^{***}$ | $-0.3663^{***}$ | $0.0941^{***}$ | $-0.4489^{***}$ | $0.1705^{***}$ | $-0.4505^{***}$ | $0.0769^{***}$ | $-0.4968^{***}$ |
| $\Delta\text{rexch}_{t-2}$ | | | $-0.0582^{***}$ | | | $-0.2533^{***}$ | | |
| $\Delta\text{roilp}_t$ | $0.0965^{***}$ | | $0.0716^{***}$ | | $0.1324^{***}$ | | $0.1625^{***}$ | |
| $\Delta\text{roilp}_{t-1}$ | $-0.0416^{***}$ | $0.2234^{***}$ | $-0.0220^{***}$ | $0.2253^{***}$ | $-0.0565^{***}$ | $0.1803^{***}$ | $-0.0315^{**}$ | $0.2240^{***}$ |
| $\Delta\text{roilp}_{t-2}$ | | $0.1050^{***}$ | | $0.1290^{***}$ | $-0.0301^{***}$ | $0.1007^{***}$ | $-0.0203^{***}$ | $0.1040^{***}$ |
| Hausman test [$p$ value] | 0.0290 [0.8647] | 0.1274 [0.7211] | − 0.0024 [NA] | 0.0093 [0.9230] | 0.2799 [0.5967] | 0.0193 [0.8894] | − 0.0024 [NA] | 2.2739 [0.1316] |

The variables include real crude oil prices (roilp) and real exchange rates (rexch). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The lag parameters of the ARDL model are selected based on Akaike information criterion (AIC) with maximum lag set at 4

stances. Even though the findings are quite diverse, some clear patterns have emerged and can be summarized as below. Evidence shows that there exists a bidirectional correlation relationship between real oil prices and real exchange rates for oil-importing countries with free-floating exchange rate arrangements, thus confirming our previous findings. For countries with exchange rate management, the results reveal that exchange rates have predictive power for oil prices no matter in the case of oil-importing or oil-exporting countries. Increases in real exchange rates are associated with decreases (increases) in real oil prices of oil-importing (oil-exporting) countries. Put differently, we find that oil prices play a minor role in shaping exchange rates in countries that have imposed tight restrictions on exchange rates. These results confirm the findings of Narayan et al. (2019) who find little evidence of the connection between oil prices and exchange rates. In addition, no correlation between the variables exists for oil-exporting countries with free-floating exchange rate arrangements, indicating oil prices do not correlate with exchange rates. Therefore, policies aiming at exchange rate control may not influence oil prices and vice versa.

### 5.3 Robustness test

This section offers some robustness checks to the main findings. Given that the exchange rate arrangement system plays an essential role in shaping the relation between oil prices and exchange rates, we first test whether the findings vary with different classifications of exchange rate systems. In our prior work, we classify the countries into managed floating countries (numbers 1–7) and free-floating countries (numbers 8–9) by using the information of IMF (2015). However, lumping categories 1–7 into managed floating may raise concern about the variations between countries. In this regard, we divide the 35 managed floating countries (fix) into 21 hard-pegged countries (numbers 1–4, labeled fix1) and 14 soft-pegged (numbers 5–7, labeled fix2) countries and then replicate the analysis with these subsamples.

Table 5 reports the results for the associated subsamples. As shown in Columns 1 and 2, we find a significantly negative correlation runs from real exchange rates to real oil prices in hard-pegged countries, which is consistent with our earlier findings. In addition, compared with soft-pegged countries, the results of hard-pegged countries show that strong restriction weakens or even eliminates the explanatory power of oil prices for exchange rates. The results of Columns 3 and 4 also reach the same conclusion for oil-importing countries with hard- and soft-pegged exchange rate arrangements. As to the oil-exporting countries, the results of Columns 5 and 6 still reveal that increases in real exchange rates predict increases in real oil prices. However, the effect of exchange rate on oil price is insignificant in hard-pegged countries, implying that countries with rigid restrictions on exchange rates have the capability to eliminate the influence of oil prices on exchange rates. Overall, the aforementioned results essentially remain unchanged compared with our previous ones.

To account for the cross-sectional dependence of the error terms, we then test our findings by adopting Pesaran's (2006) common correlated effect mean group (CCEMG) approach, which allows cross-sectional dependence and time-variant unobservables to have heterogeneous impacts across panel members. This method deals

**Table 5** Robust checks: parameter estimation using the PMG method for two subsamples of managed floating system

| Panel | fix1 ($N = 21$) | | fix2 ($N = 14$) | | impfix1 ($N = 12$) | | impfix2 ($N = 7$) | | exfix1 ($N = 9$) | | exfix2 ($N = 7$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dependent | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp |
| ARDL model | (3, 2) | (3, 2) | (2, 2) | (3, 2) | (3, 2) | (3, 2) | (2, 2) | (3, 2) | (2, 3) | (3, 2) | (2, 2) | (3, 2) |
| *Long-run coefficients* | | | | | | | | | | | | |
| rexch | | − 0.4444*** | | 1.4116*** | | − 0.5148*** | | − 0.5414 | | 0.6340 | | 1.8314*** |
| roilp | 50.3661 | | − 0.3203*** | | 30.4848 | | 91.5521 | | 52.4295 | | − 0.1312*** | |
| ecm $_{t-1}$ | 7.07E−05*** | − 0.0237*** | − 0.0159*** | − 0.0183*** | 5.22E−05 | − 0.0303*** | 1.34E−05* | − 0.0289 | 0.0001*** | − 0.0180*** | − 0.0247*** | − 0.0176*** |
| *Short-run coefficients* | | | | | | | | | | | | |
| $\Delta$rexch$_t$ | | 1.5515*** | | 1.2044*** | | 1.3488*** | | 1.5274*** | | 1.7268*** | | 0.8728*** |
| $\Delta$rexch$_{t-1}$ | 0.0684*** | − 0.4721*** | 0.1116** | − 0.4431*** | 0.0678** | − 0.3482*** | 0.1269* | − 0.6072*** | 0.0724*** | − 0.6564** | 0.1050*** | − 0.2738*** |
| $\Delta$rexch$_{t-2}$ | − 0.0453** | | | | − 0.0765*** | | 0.0650*** | | | | | |
| $\Delta$roilp$_t$ | 0.0896*** | | 0.1498*** | | 0.0759*** | | − 0.0176** | | 0.1070** | | 0.2313** | |
| $\Delta$roilp$_{t-1}$ | − 0.0197*** | 0.2219*** | − 0.0373*** | 0.2275** | − 0.0247** | 0.2222*** | | 0.2302*** | − 0.0104 | 0.2220*** | − 0.0616*** | 0.2302*** |
| $\Delta$roilp$_{t-2}$ | | 0.1224*** | | 0.1087*** | | 0.1256*** | | 0.1343*** | − 0.0138* | 0.1168*** | | 0.0926*** |
| Hausman test [$p$ value] | − 0.0067<br>[NA] | 1.2608<br>[0.2615] | 0.0572<br>[0.8110] | 3.8870<br>[0.0500] | − 0.0036<br>[NA] | 1.1504<br>[0.2835] | − 0.0001<br>[NA] | 2.5618<br>[0.1095] | − 0.0049<br>[NA] | 1.4131<br>[0.2345] | 0.4737<br>[0.4913] | 2.4221<br>[0.1196] |

The variables include real crude oil prices (roilp) and real exchange rates (rexch). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The lag parameters of the ARDL model are selected based on Akaike information criterion (AIC) with maximum lag set at 4

with the problem of cross-sectional dependence by adding the cross-sectional averages of the dependent and independent variables as additional regressors when applying OLS to each unit. Table 6 shows the parameter estimations when net oil import status and the exchange rate arrangement system are simultaneously considered. The results are qualitatively similar to those reported in Table 4, with only minor changes in significance and intensity. Evidence still favors a bidirectional relationship for oil-importing countries with free-floating exchange rate arrangements. For countries with exchange rate management, oil prices still have no significant effect on real exchange rates. Our findings are thus robust to controlling for cross-sectional dependence.

## 6 Conclusions and implications

Even if the relationship between oil prices and exchange rates has been a recurring subject of debate in the literature, there have been few attempts to identify the role of exchange rate policy. This study thus conducts an investigation into the long- and short-run relationships between oil prices and exchange rates using the PMG approach for 81 countries by considering the net oil import status (i.e., oil-importing and oil-exporting) and the exchange rate arrangement system (i.e., free-floating and managed floating) during the period from January 1997 to July 2015. Overall, our results indicate that the long-run relationships between real oil prices and real exchange rates are country-specific. Even though our full sample results reveal a significantly negative bidirectional correlation between the variables and confirm the findings of most previous studies based on the assumption of free-floating conditions, their direction, impact, intensity, and significance are not the same for different countries in terms of the net oil import status or the exchange rate system.

For free-floating systems, oil importers reveal a significantly negative bidirectional correlation, while oil exporters show no correlation between the variables in either direction. The former results suggest that oil prices and exchange rates mutually interact with each other, and their reinforcements may have considerable implications for policy development and intervention practice. Given that exchange rates are sensitive to changes in oil price, investors in these countries have to implement effective hedge strategies. However, the latter results show that oil price increases may not influence the exchange rate and vice versa in oil-exporting countries with a managed floating system. On the contrary, for managed floating systems, only a unidirectional correlation from exchange rates to oil prices is found no matter for oil importers or exporters. These results indicate that the movement in the exchange rate has predictive power on oil prices. In addition, evidence also shows that when government restrictions are enhanced, oil prices may not influence exchange rates. Therefore, adequate attention should be paid to exchange rate movements in these countries.

Finally, while the question regarding other theoretically relevant determinants of exchange rates is beyond the scope of the current study, plausible extensions for future research might cover the influence of productivity, inflation, and interest rates on the relationships between real oil prices and real exchange rates. To our knowledge, Narayan et al. (2019) are the researchers who account for these important determinants. This extension looks interesting and worth analyzing in future research.

**Table 6** Robust checks: parameter estimation using the CCEMG method

| Panel | impfloat ($N = 37$) | | impfix ($N = 19$) | | expfloat ($N = 9$) | | expfix ($N = 16$) | |
|---|---|---|---|---|---|---|---|---|
| Dependent | rexch | roilp | rexch | roilp | rexch | roilp | rexch | roilp |
| ARDL model | (2, 2) | (3, 2) | (3, 1) | (3, 2) | (2, 3) | (3, 3) | (2, 3) | (3, 2) |
| *Long-run coefficients* | | | | | | | | |
| rexch | | $-1.2961^{***}$ | | $-0.5011$ | | $30.5028^{**}$ | | 0.2829 |
| roilp | $-0.1374^{***}$ | | 0.0009 | | 0.5087 | | $-0.3730$ | |
| $\text{ecm}_{t-1}$ | $-0.0199^{***}$ | $-0.0502^{***}$ | $-0.0094^{***}$ | $-0.0532^{***}$ | $-0.0130$ | $-0.0047$ | $-0.0122^{**}$ | $-0.0291^{***}$ |
| *Short-run coefficients* | | | | | | | | |
| $\Delta\text{rexch}_t$ | | $0.0040^{***}$ | | $0.0149^{***}$ | | $0.0019^{***}$ | | $0.0156^{***}$ |
| $\Delta\text{rexch}_{t-1}$ | $0.0026^{***}$ | $-0.0077^{***}$ | $0.0013^{***}$ | $-0.0071^{***}$ | $0.0009^{***}$ | $-0.0062^{***}$ | $0.0007^{***}$ | $-0.0094^{***}$ |
| $\Delta\text{rexch}_{t-2}$ | | | $-0.0012^{***}$ | | | $-0.0053^{***}$ | | |
| $\Delta\text{roilp}_t$ | $0.0001^{***}$ | | $0.0002^{***}$ | | $0.0001^{***}$ | | $0.0003^{***}$ | |
| $\Delta\text{roilp}_{t-1}$ | $-0.0001^{***}$ | $0.0020^{***}$ | | $0.0023^{***}$ | $-0.0002^{***}$ | $0.0015^{***}$ | $0.00006^{**}$ | $0.0023^{***}$ |
| $\Delta\text{roilp}_{t-2}$ | | $0.0011^{***}$ | | $0.0014^{***}$ | $-0.0001^{***}$ | $0.0006^{***}$ | $-0.00004^{***}$ | $0.0014^{***}$ |

The variables include real crude oil prices (roilp) and real exchange rates (rexch). ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The lag parameters of the ARDL model are selected based on Akaike information criterion (AIC) with maximum lag set at 4

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**Data availability** The datasets are available from the corresponding author on reasonable request.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

# Appendix

See Table 7.

**Table 7** List of 81 countries classified into subsamples

| oilimp panel | oilimp panel | oilexp panel | float panel | float panel | fix panel | fix panel |
|---|---|---|---|---|---|---|
| Australia | Japan | Algeria | Argentina | Kenya | Algeria | #Jordan |
| Austria | Jordan | Angola | Australia | Korea/South | Angola | Kazakhstan |
| Bangladesh | Kenya | Argentina | Austria | Luxembourg | #Bangladesh | Kuwait |
| Belgium | Korea/South | Bolivia | Belgium | Mexico | Bolivia | Malaysia |
| Brazil | Luxembourg | Canada | Brazil | New Zealand | #Bulgaria | #Morocco |
| Bulgaria | Morocco | Colombia | Canada | Norway | China | #Nepal |
| Chile | Nepal | Denmark | Chile | Paraguay | Croatia | Nigeria |
| China | New Zealand | Egypt | Colombia | Peru | #Czech Republic | Pakistan |
| Croatia | Pakistan | Gabon | Cyprus | Philippines | Denmark | #Panama |
| Cyprus | Panama | Guatemala | Estonia | Poland | Egypt | Saudi Arabia |
| Czech Republic | Peru | Indonesia | Finland | Portugal | #El Salvador | #Singapore |
| El Salvador | Philippines | Iran | France | Romania | Gabon | #Sri Lanka |
| Estonia | Poland | Kazakhstan | Germany | Russian Federation | Guatemala | Sudan |
| Finland | Portugal | Kuwait | Ghana | Slovak Republic | Haiti | Switzerland |
| France | Romania | Malaysia | Greece | South Africa | Honduras | #Trinidad and Tobago |
| Germany | Singapore | Mexico | Hungary | Spain | #Hong Kong | Tunisia |
| Ghana | Slovak Republic | Nigeria | Iceland | Sweden | Iran | Vietnam |
| Greece | South Africa | Norway | India | Taiwan | Jamaica | |
| Haiti | Spain | Paraguay | Indonesia | Thailand | | |
| Honduras | Sri Lanka | Russian Federation | Ireland | Turkey | | |
| Hong Kong | Sweden | Saudi Arabia | Israel | UK | | |
| Hungary | Switzerland | Sudan | Italy | Uruguay | | |
| Iceland | Taiwan | Tunisia | Japan | Zambia | | |
| India | Thailand | UK | | | | |

**Table 7** continued

| oilimp panel | oilimp panel | oilexp panel | float panel | float panel | fix panel | fix panel |
|---|---|---|---|---|---|---|
| Ireland | Trinidad and Tobago | Vietnam | | | | |
| Israel | Turkey | | | | | |
| Italy | Uruguay | | | | | |
| Jamaica | Zambia | | | | | |

| impfloat panel | impfloat panel | impfix panel | expfloat panel | expfix panel |
|---|---|---|---|---|
| Australia | Japan | #Bangladesh | Argentina | Algeria |
| Austria | Kenya | #Bulgaria | Canada | Angola |
| Belgium | Korea/South | China | Colombia | Bolivia |
| Brazil | Luxembourg | Croatia | Indonesia | Denmark |
| Chile | New Zealand | #Czech Republic | Mexico | Egypt |
| Cyprus | Peru | #El Salvador | Norway | Gabon |
| El Salvador | Philippines | Haiti | Paraguay | Guatemala |
| Estonia | Poland | Honduras | Russian Federation | Iran |
| Finland | Portugal | #Hong Kong | UK | Kazakhstan |
| France | Romania | Jamaica | | Kuwait |
| Germany | Slovak Republic | #Jordan | | Malaysia |
| Ghana | South Africa | #Morocco | | Nigeria |
| Greece | Spain | #Nepal | | Saudi Arabia |
| Hungary | Sweden | Pakistan | | Sudan |
| Iceland | Taiwan | #Panama | | Tunisia |
| India | Thailand | #Singapore | | Vietnam |
| Ireland | Turkey | #Sri Lanka | | |
| Israel | Uruguay | Switzerland | | |
| Italy | Zambia | #Trinidad and Tobago | | |

Countries are classified by their average annual oil net import and exchange rate arrangement systems. # denotes the subsample of fix1 in robustness test section

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