Movements of oil prices and exchange rates in China and India: New evidence from wavelet-based, non-linear, autoregressive distributed lag estimations

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Abstract: This paper contributes to the existing literature by investigating the impact of oil prices on real exchange rates in China and India. We employ the non-linear, autoregressive-distributed lag model advanced by Shin et al. (2014), which allows both short-run and long-run asymmetry pass-through to a variable of interest. Oil prices and exchange rates are frequently found to be noisy. In order to detect the accurate relationship between oil prices and exchange rates, the maximum overlap, discrete-wavelet transformation is used to remove noise from the original series. The dynamic relationship between the original and de-noised series is compared. Our empirical findings suggest only long-run asymmetric effects of oil prices on exchange rates for both countries; however, after time-series noise removal, the asymmetric long-run effect becomes symmetric for India. Policy implications also are included.

JEL: C13, C22, C51, F31, Q40
Keywords: Oil price shocks, asymmetric effects, exchange rates, India, China**,** NARDL

1. Introduction

Oil plays a significant role in the world energy market. With globalisation and economic reform, demand for oil has been increasing in developing countries. Changes in oil prices may have direct and indirect effects on the aggregate level of output, affecting investment in production and other economic activities.[1] Supply-side effects cause rising oil prices, with lower output production in the economy. Therefore, the cost of production escalates, resulting in higher prices. This process becomes a source of instability both for producers and investors, resulting in lower demand for goods and services.

There is a vast literature relating supply-side channels through which positive oil price shocks can hinder economic activities (Bruno and Sachs, 1982; Hooker, 1996; Brown and Yucel, 2002; Hamilton, 2009; Tang et al. 2010; Ghosh, 2011). Moreover, rising oil prices may create demand-side imbalances within an economy. For example, higher oil prices may lead to inflationary pressures, particularly in oil-importing countries, and reduce real income, resulting in lower consumer spending and thus lower aggregate demand (see, for instance, Huang and Guo, 2007). Furthermore, an increase in energy prices (including oil prices) discourages business activity by raising costs of production. This lowers profitability and investment, leading to a lower level of economic growth in the long-run (Brown and Yucel, 2002; Tang et al. 2010).[2] In this scenario, energy is considered to be one of the less desirable factors of production for business firms, motivating firms to substitute energy with other factor inputs, such as capital-intensive or labor-intensive inputs into the production process (Broadstock et al. 2007; Zhang et al. 2008; Bhattacharyya et al. 2011).

Other channels through which oil price shocks can affect the performance of macroeconomic variables include the wealth transfer effect, the inflation effect, the role of monetary policy, and the sector adjustment effect through oil use (Brown and Yucel,

[1] Roberts and Ryan (2015) identify factors affecting speculation of oil prices in the world market.

[2] This is discussed in greater details for the Chinese context by Zhang et al. (2008).

2002).[3] Either supply- or demand-side effects of oil prices on an economy (which result in higher production prices) may also influence its exchange rate. This is significant for commodity-exporting countries, such as China and India.

Understanding the link between oil prices and exchange rates is vital for emerging economies. Both China and India are rapidly moving towards a higher degree of economic integration, and are among the top net oil-importing countries in the world. This is also indicative of the fact that in both economies, energy consumption, production and business activities are increasing over time. Since both China and India are major players in the international energy and foreign exchange markets, the issue of the link between oil price and real exchange rates has become a perennial policy topic. The fact is that large fluctuations in both oil price and real exchange rates could be detrimental to international trade and the smooth operation of financial markets and macroeconomic activity. International oil shocks could play an increasingly important role in movements of domestic price levels and domestic currencies for both countries.[4]

According to Cheng et al. 2007 and Basher et al. 2012, emerging economies will account for 50% of global GDP by 2050. These markets have the potential capacity for expanding economic growth, creating employment opportunities, enhancing human capital formation and reducing poverty levels, e.g., in the Asia region. Recent statistics from the International Energy Agency (IEA, 2018) predict that China and India will contribute more than 50% of global oil demand by 2023. Both China and India are accumulating large reserves of foreign currency (mostly in USD), thus becoming key players in the international commodity and energy transaction markets.

In this era of growing demand for oil and other energy sources, with trade liberalisation, it is believed that these two ‘Asian Tigers’ will create tremendous pressure on the world

[3]See Tang et al. (2010) for a detail theoretical discussion on the macroeconomic effects of oil price changes.

[4] Shahbaz et al. (2018) covers recent financial developments of China and India.

economy, particularly in commodity, currency and international oil markets. Therefore, there is a need for further analysis of oil price and exchange rate movements of these two countries. This has significance in developing a policy agenda for both countries.

With the development of non-linear estimation techniques, there is empirical evidence of asymmetric effects of oil price on economic activity (see Huang et al. 2005). The literature on the asymmetric effects of oil prices on the exchange rate for China and India is scant. We contribute to the existing literature with two methodological improvements. First, we employ a recently developed wavelet-based, non-linear, auto-regressive distributed lag econometric technique by Shin et al. (2014). This model allows for both short-run and long-run asymmetries to pass through from one variable to another variable of interest. In doing so, we employ monthly data for oil price and the exchange rate both for China and India to examine the asymmetric effects of oil prices on exchange rates.

Second, given that oil price and exchange rate series usually contain high noise, we use the maximum overlap, discrete wavelet transformation to remove noise from the original series. Our empirical findings reflect the long-run asymmetric effect of oil prices on exchange rates for both countries. After time series noise removal, the long-run effect becomes symmetric for India. Finally, we shed new light on the policy implications of insulating the domestic currency of China and India against volatile imported oil prices shocks.

The remainder of the paper is structured as follows. Section 2 covers a brief review of related literature. Section 3 analyzes the data sources and estimation steps. Section 4 presents a discussion of empirical results. The final section summarizes our major findings with a discussion of policy implications.

2. General literature review

The oil crisis of the 1970s and the subsequent recent global financial crisis of 2008-09 have motivated researchers to examine the relationship between real exchange rates and oil price shocks, particularly in developed economies. There is much theoretical literature that has provided evidence, since the 1980s, linking between oil prices and exchange rates (Krugman, 1980; Golub, 1983).

Increasing oil prices generates a current account surplus for oil exporters, and current account deficits for oil importers, resulting in a reallocation of wealth that may impact exchange rates. For example, Krugman (1980) argues that oil price plays a vital role for both oil-exporting and oil-importing countries, in the sense that an oil price increase will eventually lead to a transfer of wealth from the oil importing countries to the oil exporting ones. Subsequently, Golub (1983) supports the findings by Krugman; in this case, the dynamic behaviour of exchange rates depends on the distribution of oil imports across importing countries and portfolio preferences of oil importing and exporting countries. For instance, a rise in oil prices reduces demand for foreign currency (usually the USD) by domestic players (e.g., consumers, business firms, governments, oil refiners, and producers) due to the rising costs of imported commodities from other countries. This has the further effect in lowering demand for foreign currency, thereby creating excess demand, that has detrimental effects on its own. There is a possibility of depreciation of foreign currency against domestic currency, and export demand from international buyers is expected to be lower for commodity-exporting countries. In this case, oil-importing countries are worse-off in of terms of commodity trade due to the appreciation of domestic currency against foreign currency.

This argument is consistent with Chen and Chen (2007), who emphasise that for countries heavily dependent on imported oil, a rise in real oil price may increase the price of tradable goods in the home country by a greater proportion than in the foreign country, thereby resulting in a real depreciation of the home currency. Given the sequence of these events, Mcguirk (1983) suggests that oil-importing countries need to improve their competitive position for tradable commodities only by depreciating domestic currency against international currency (usually USD). Furthermore, it is often assumed that in order to improve trade competitiveness of a country in the international commodity market in response to rising oil prices, the home country would have to raise the nominal exchange rate leading, to a further real depreciation of the oil-importing country.

Furthermore, it has been maintained that both monetary and real economy shocks are primary sources of real exchange rate fluctuations. Dornbusch (1973) argues that money market shocks induce excessive volatility of real exchange rates in an environment of sluggish price adjustments. Transitory shocks play a pivotal role in driving real exchange rate dynamics, as is suggested by various studies (Chen, 2004; Evans and Lothian, 1993; Frankel and Rose, 1996). Following Stockman (1980), real economic shocks such as changes in productivity, government spending and labor supply, may be contributing factors in changing real exchange rates. This has been supported by other researchers (Bjornland, 2004; MacDonald, 1998; Zhou, 1995).

Rafiq et al. (2009) provide an extensive survey of the literature, linking oil price and exchange rate. Oil price shocks have a significant effect on the output of an economy. Moreover, they find that the impact of oil price changes on the economy is asymmetric. In particular, the negative impact of increased oil prices is found to be higher for economic activity than the positive impact of decreased oil prices.

Amano and Van Norden (1998) report an appreciation of the US dollar due to oil price rises. Using a panel of G7 countries, Chen and Chen (2007) find that the real price of oil is the dominant source of real exchange rate changes. Olomola and Adejumo (2006) investigate the relationship between real oil prices and real exchange rates, incorporating macroeconomic variables, such as output, inflation and the money supply in Nigeria; they find that an oil price shock has significant positive effects on the exchange rate and money supply in the long-run, but not on the output and inflation. In an extensive empirical analysis, using energy- and commodity-exporting countries, Dauvin (2014) examines the link between energy prices and real exchange rate. A strong positive relationship is established between real exchange rate and energy prices via terms of trade channels. This positive association mainly occurs for both energy- and commodity-exporting countries beyond a certain threshold level.

On the other hand, deprecation of exchange rates due to oil price rises has been found in G7 countries (Darby, 1982), and in Kazakhstan (Kutan and Wyzan, 2005). Zhang (2013) notes that cointegration between oil prices and the USD does not exist without controlling for structural breaks. Beckmann and Czudaj (2013) apply the Markov-switching-vector error-correction model to investigate the relationship between oil prices and exchange rates. Their results show that an oil price increase leads to the appreciation of the real effective exchange rate in oil-exporting countries. Aloui et al. (2013) apply the copula-GARCH approach to examine the dependence between oil price and exchange rate, confirming the findings reported by Beckmann and Czudaj (2013). For the Romanian economy, Tiwari et al. (2013a) use the wavelet approach to assess the relationship between oil price and exchange rate, noting that a neutral effect exists between the variables.

Furthermore, for South Africa, Fowowe (2014) examines the association between oil prices and exchange rate over the period of $2003M_2$-$2012M_1$, and confirms that an oil price rise leads to depreciation of the South African exchange rate relative to the USD. Similarly, Brahmasrene et al. (2014) examine the short-run and long-run dynamic relationship between the US imported crude oil prices and exchange rate, finding that exchange rate Granger-caused crude oil price changes in the short-run, and crude oil prices also Granger-caused exchange rate changes in the long-run. Moreover, they found that exchange rate shocks had a significant negative impact on crude oil prices. [5] More recently, Bouoiyour et al. (2015) examine the determining factors of real effective exchange rates by applying the wavelet method to the Russian economy, and found that oil prices drove the real effective exchange rate. Shahbaz et al. (2015) examined the relationship between oil price and exchange rate by applying the time-frequency approach in Pakistan— they found oil price drove the exchange rate. Jammazi et al. (2015), using a wavelet-based, nonlinear, autoregressive distributed lags model (W-NARDL), for a panel of 18 currencies, find evidence of significant and asymmetric pass-through of exchange rates to crude oil prices in both the short- and long-run. Wątorek et. al. (2019) examine cross-correlations of multifractality between Crude oil futures and currencies expressed in USD, gold futures and S&P 500. The strongest correlations are established between oil, S&P500 and the currencies of the oil producing countries.

[5] Another branch of literature has also examined the effect of exchange rate on oil prices and found significant effects of exchange rates (Hong, 2002; Sadorsky, 2010; Zhang et al. 2008; Novotny, 2012).

2.1. Brief overview of literature on the oil price-exchange rate nexus in China

A handful of studies have examined the impact of oil prices on Chinese exchange rate. For example, Huang and Gou (2007) examine the impact of oil prices on the real exchange rate and found that real demand and supply shocks play a vital role in driving the changes. They also found minimal influence of real oil price shocks on exchange rate appreciation in the long-run, due to the low dependence on imported oil and government energy regulations. In a similar fashion, Benassy-Quere et al. (2007) test cointegration and causality between the real oil price and real effective exchange rate with annual data from 1974-2004, and find unidirectional causality running from oil price to real effective exchange rate. Moreover, they also establish that the USD is positively linked with the oil price in China, indicating that a rise in oil price leads to an appreciation of the USD in the long-run. Recently, De Vita, and Trachanas (2016) find no evidence of cointegration or any non-linear causality for the Chinese economy. Li et al. (2017), using a Bayesian MCMC approach to estimate the stochastic volatility, establish strong evidence for jump spill-over effects between oil prices and exchange.[6]

2.2. Brief overview of literature on the oil price-exchange rate nexus in India

Due to the limited availability of daily and monthly data, research on the association between oil prices and exchange rates in India is limited. Ghosh (2011) considers daily data to examine the crude oil price-exchange rate nexus for India during a period of extreme oil price volatility, finding that a positive oil price change leads to deprecation of the Indian rupee (INR) against the USD. The research established that the oil price shock has permanent effects on exchange rate volatility, and that both positive and negative oil price shocks have similar effects on the exchange rate in India. Similarly, Tiwari et al. (2013b) examine the linear and non-linear Granger causalities between oil price and the real effective exchange rate of the INR. For this empirical effort, they employ wavelet-based, non-linear, causality tests in the time- and frequency-domain approaches, with a view to revisiting the relationships among the decomposed series on a scale-by-scale basis. They did not find any causal relationship between oil price and exchange rate at the

[6] The volatility spill over between OPEC oil price and Chinese
sectoral stock returns is examined by Kirkulak-Uludag and Safarzadeh (2018).

shorter time scales (e.g. three months). Nevertheless, they did find evidence of bidirectional causality between them when using longer time scales only (e.g. more than 32 months). Recently, Kaushik et al. (2014) examine the relationship between oil price and exchange rate by incorporating real GDP, real money balances and interest rates as additional determining factors. Their analysis corroborated the findings of Tiwari et al. (2013b). Finally, De Vita and Trachanas (2016) find no evidence of cointegration or any non-linear causality for the Indian economy.

2.3. Oil pricing in China

China is markedly different from India in terms of its gradual process of market liberalization, price regulations and transparency in the oil pricing system. With the foundation of the People's Republic of China in 1949, and economic reforms initiated in 1979, economic growth in China has increased dramatically. With high-paced economic growth, in combination with liberalization, industrialization and urbanization in China, the demand for energy consumption has increased significantly (Du et al. 2010). The rising energy demand is driven by economic players including consumers, firms, governments and oil producers. China has been a net importer of oil for many years, and is already among the top three global importers of oil, with 68% of total oil consumed in 2010 being from outside markets. China accounts for 10% of the world's total oil consumption. Following the energy outlook (2019) by the British Petroleum, oil is the second most energy sources next to coal accounts 17% of total energy demand in 2017. This suggests an oil supply gap in China that continues to grow and, at the same time, domestic oil markets in China are expected to be greatly influenced by international energy markets (Zhang et al. 2008).

In China, the oil pricing system has played an increasing role in inducing stable economic growth, ensuring protection for oil producers and helping domestic consumers. Due to this strategic importance, the oil sector in China has experienced a series of deregulation reforms. Before 1980, the oil sector in China was under the central planning system. In this phase, oil field development and the price of oil were primarily financed and controlled by the central government. Both wholesale and retail prices of crude oil and petroleum products were solely determined by the central and local governments, leaving no scope for world oil price shocks to pass through to China's macro-economy (Wang, 1995). Eventually, oil prices in China began to correlate with those of world oil markets when China initiated market-oriented reforms in 1979. From 1981 to 1998, a 'dual-track pricing' system for the oil sector was introduced by the State Council of China, in which domestic oil producers were required to sell their base level of oil (100 million tonnes) at a regulated low price in the domestic market, and additional production beyond this base level enabled oil producers to sell at higher prices in international markets. This 'dual-pricing' system seems to have two major implications: it provides protection for domestic oil producers to help them establish and grow; and it regulates the oil sector to some extent, implying that the correlation between domestic oil price in China and world oil prices is expected to be low. In 1998, the central government further deregulated its domestic oil-pricing mechanism and abolished the dual-track pricing system to the extent of providing a platform to domestic oil producers in selling oil at international market-determined prices. From June 1998 to 2001, the Singaporean market price was used as the benchmark to peg Chinese domestic prices. In 2008, the linking of Chinese domestic prices has been extended towards European Brent, Dubai and Indonesian oil prices which further indicates that the crude oil prices of China depend on the dynamics of world oil markets (Zhang et al. 2008, Du et al. 2010).

2.4. Oil pricing in India

Prior to Independence, oil pricing was market-driven in India. Despite the initiation of economic policy reforms in early 1990s, a market determined oil pricing system prevailed from 1974-1998. Eventually, the Indian economy followed the administrative oil price mechanism between 1998 and 2006. In order to boost exploration and production of hydrocarbons, the Indian government introduced the 'New Exploration Licensing Policy' to provide an equal platform and 'level playing field' for both public and private sector companies. From 2006 onwards, India decided to use a trade parity (import plus export) oil price mechanism. The practice of using trade parity by the Indian government initiated when investors in India began importing oil from other oil-importing countries to cope with increasing energy demand. Producers in oil refineries also started to export surplus oil to other oil-importing countries. Drastic oil price changes mainly occurred in India due to the advancement of reform policies since the early 1990s. A major development towards an energy pricing system in India was to monitor growing demand for oil and simultaneously extend the use of other non-renewable energy sources to compensate for the excess demand for energy.

Being an emerging economy, the unprecedented growth for the last 25 years has led to a significant surge in demand for imported oil and gas from the rest of the world. Due to rapid economic expansion, India became the world's fourth-largest oil consumer in 2013, consuming 3.7 million barrels a day (mb/d). By 2020, India is projected to consume 4.7 (mb/d), overtaking Japan as the third-largest global consumer of oil (and almost 5% of total demand for oil in the global market). This growth in oil demand has made India the fourth largest oil importer since 2011. Oil production also plays a significant role in the expansion of consumption and production of economic activities (International Energy Agency, 2014). Following the World Energy Outlook (2013), oil production growth is expected to decline at an annual average rate of 1.4% from 2011 to 2035 for India.

3. Data and econometric steps

3.1. Data

We use monthly observations covering the period 1990M_1–2019M_{12}. These data are the closing prices for Brent crude oil and USD exchange rates of the Chinese and Indian currencies. Oil price data are extracted from the US Energy Information Administration database and exchange rate data are sourced from the Central Bank of China and the Reserve Bank of India. The bilateral real exchange rate reflects the change in the exchange rate of two currencies (INR/USD or RMB/USD), which are measured by the relative prices of two countries. The crude oil price is expressed in real terms. We take the first difference of the logarithmic transformation of real oil prices (ROP) and exchange rate (RER).[7] Table 1 reports summary statistics of the variables we use. There

[7] Monthly data on Brent Crude oil, INR/USD and RMB/USD bilateral exchange rates have been collected from the websites of Energy Information Administration (EIA), (www.eia.doe.gov) Reserve Bank of India (www.rbi.org.in) and Data Stream.

seems to be evidence of significant volatility in real oil prices expressed in local currencies; however, the magnitude of fluctuations in exchange rate appears less volatile when compared to standard deviations associated with real oil prices. Jarque-Bera statistics indicate that we cannot reject the null of normal distribution for all series. The real exchange rate is constructed aligning with the changes in exchange rates of two currencies (India-US and China-US) which were determined by the relative prices in these countries. The real oil price is defined as the US D price of oil converted to the domestic currency and then deflated by the domestic consumer price index.

Table-1: Descriptive Statistics

Countries	India		China	
Variable	RER	ROP	RER	ROP
Mean(x100)	0.132	0.723	-0.247	0.452
Std. Dev.(x 100)	5.434	11.269	4.256	9.823
Maximum (x 100)	12.721	38.828	58.469	48.257
Minimum (x 100)	-17.357	-34.311	-6.584	-36.548
Skewness	0.122	-0.658	11.527	0.1125
Kurtosis	6.523	2.587	31.422	8.2634
Jarque-Bera	65.487 [0.000]	25.204 [0.000]	87.326 [0.000]	78.29 [0.000]

3.2. Econometric steps

3.2.1 Unit root

We employ the Narayan and Popp (2010) unit root test which allows for two endogenous structural breaks under null and alternative hypotheses. This test has better size properties and identifies breaks more accurately than the Lumsdaine and Papell (1997) and Lee and Strazicich (2003) tests.

3.2.2 Wavelet based approach

Before examining the exchange rate pass-through to oil prices within the NARD model, we employ the Discrete Wavelet Transform (DWT) in order to extract the smoothed parts of the time series. The DWT is an efficient tool of decomposition that used the dyadic scales and position. Thus, we started by extracting the smoothed parts of our underlying time series[8]. Therefore, it is important to apply wavelet-based noise removal techniques which perform a multi-resolution analysis by decomposing the original time series into a scale as father wavelets and mother wavelets, without loss of temporal information. The mother wavelets are suitable for describing the detail and high-frequency components, and the father wavelets are useful in representing the smooth and low-frequency parts of the time series. Father $\phi(t)$ and mother $\psi(t)$ wavelets are defined as:

$$\phi(t) = \sqrt{2}\sum_k l_k \, \phi(2t-k) \quad (1)$$

$$\psi(t) = \sqrt{2}\sum_k h_k \, \phi(2t-k) \quad (2)$$

Where the father wavelet integrates to one and mother wavelet integrates to zero. The coefficients l_k and h_k are, respectively, the low-pass and the high-pass filter:

$$l_k = \frac{1}{\sqrt{2}}\int \phi(t)\phi(2t-k)dt \quad (3)$$

$$h_k = \frac{1}{\sqrt{2}}\int \psi(t)\phi(2t-k)dt \quad (4)$$

The wavelet representation of time series $X(t)$ can be expressed as follows:

$$X(t) = \sum_k S_{j,k}\phi_{j,k}(t) + \sum_k d_{j,k}\psi_{j,k}(t) + \sum_k d_{j-1,k}\psi_{j-1,k}(t) + \cdots + \sum_k d_{1,k}\psi_{1,k}(t) \quad (5)$$

Where $S_{j,k}$ and $d_{j,k}$ are wavelet transform coefficients given by projection onto father and mother wavelets over scaling and translation:

[8] We remove the noise (extract the smoothed part) in order to estimate the accurate relationships between the underlying variables (crude oil price and exchange rate). The denoised data is independent and identically distributed with mean zero and each value in the same time series has a zero correlation with others (Fig-3).

$$S_{j,k} = \int \phi_{j,k}(t)X(t)dt \qquad (6)$$

$$d_{j,k} = \int \psi_{j,k}(t)X(t)dt \quad \text{for } j = 1,2, \ldots J \qquad (7)$$

The approximating wavelet functions $\phi_{j,k}$ and $\psi_{j,k}(t)$ are defined as scaled and translated decompositions of ϕ and ψ, with scale factor 2^j and translation parameter $2^j k$:

$$\phi_{j,k} = 2^{\frac{-j}{2}}\phi\left(\frac{t-2^j k}{2^j}\right) \qquad (8)$$

$$\psi_{j,k} = 2^{\frac{-j}{2}}\psi\left(\frac{t-2^j k}{2^j}\right) \qquad (9)$$

There are many wavelet families, and the discrete wavelet transform (DWT) is one of the most useful tools for time series analysis. The objective of a DWT is to transform the time series to wavelets to provide us with an exact analytic view of the analyzed variable over time. When the length of the time series is N, the DWT is applied to data defined over a range of integers $t = 0,1 \ldots, T-1$. The jth level wavelet $\{h_{j,l}\}_{l=0}^{L_j-1}$ and scaling $\{g_{j,l}\}_{l=0}^{L_j-1}$ coefficients may be linked directly to the time series $X(t)$ and must fulfill the following conditions:

$$\sum_{l=0}^{L_j-1} g_{j,l} = 2^{\frac{-j}{2}}; \sum_{l=0}^{L_j-1} g_{j,l}^2 = 1; \sum_{l=0}^{L_j-1} g_{j,l}h_{j,l} = 0; \sum_{l=0}^{L_j-1} h_{j,l} = 0\ ; \sum_{l=0}^{L_j-1} h_{j,l}^2 = 1.$$

These proprieties imply that wavelet filter coefficients must sum to zero (Ramsey, 2002).

DWT has deficiencies, such as the dyadic length requirements and its non-shift invariant characteristics. These disadvantages can be overcome by applying the maximal overlap discrete wavelet transformation, which can handle any sample size and can produce a more asymptotically efficient wavelet variance estimator than the DWT (Percival and

Walden, 2000; Gencay et al. 2002).[9] The MODWT wavelet and scaling coefficients $\widetilde{\omega}_{j,t}$ and $\tilde{\upsilon}_{j,t}$ are given by:

$$\widetilde{\omega}_{j,t} = 2^{\frac{-j}{2}} \sum_{l=0}^{L_j-1} \tilde{h}_{j,l} X_{t-l} \qquad (10)$$

and

$$\tilde{\upsilon}_{j,t} = 2^{\frac{-j}{2}} \sum_{l=0}^{L_j-1} \tilde{g}_{j,l} X_{t-l} \qquad (11)$$

Where $\tilde{h}_{j,l}$ and $\tilde{g}_{j,l}$ are the MODWT wavelet and scaling filters obtained by rescaling the DWT filters as follows:

$$\tilde{h}_{j,l} = 2^{\frac{-j}{2}} h_{j,l}$$

and (12)

$$\tilde{g}_{j,l} = 2^{\frac{-j}{2}} g_{j,l}$$

The MODWT has a number of coefficients equal to the sample size for each scale and thus the DWT coefficients may be considered a subset of the MODWT coefficients.

3.2.3 The NARDL approach

We examine both long- and short-run asymmetries between exchange rate and oil price using the nonlinear, autoregressive-distributed lag approach (Shin et al. 2014) with positive and negative partial-sum decompositions of the real oil price.[10] This approach has the advantage of discriminating between the short- and long-run asymmetric response of the real effective exchange rate to both positive and negative changes in real oil prices. The change in the concerned variable (real oil price or real exchange rate) is expressed as the first difference in logarithmic transformation of this variable. The asymmetric cointegrating relationship can be expressed as follows:

[9]The MODWT has synonyms within the wavelet literature, viz. the 'non-decimated DWT', 'stationary DWT' (Nason and Silverman, 1995), 'translation-invariant DWT' (Coifman and Donoho, 1995) and 'time-invariant DWT'.
[10]The model is an extension of linear ARDL proposed by Pesaran et al. (2001).

$$RER_t = \beta^+ ROP_t^+ + \beta^- ROP_t^- + \mu_t \qquad (13)$$

Where RER_t is the change in real exchange rate and ROP_t represents the change in real oil price, defined as $ROP_t = ROP_0 + ROP_t^+ + ROP_t^-$, where ROP_0 is the initial value and ROP_t^+ and ROP_t^- are partial sum processes of positive and negative changes in ROP_t. β^+ and β^- are the associated asymmetric long-run parameters. The extension of the ARDL model proposed by Shin et al. (2014) yields the following asymmetric error correction model:

$$\Delta RER_t = \vartheta + \rho REER_{t-1} + \theta^+ ROP_{t-1}^+ + \theta^- ROP_{t-1}^- + \sum_{i=1}^{p-1} \gamma_i REER_{t-i} + \sum_{i=0}^{q-1} (\varphi_i^+ \Delta ROP_{t-i}^+ + \varphi_i^- \Delta ROP_{t-i}^-) + \epsilon_t \qquad (14)$$

Where p and q denote the lag orders for RER_t and ROP_t, respectively. The equation (14) can be estimated by the standard OLS, as we are able to decompose the regressor in its positive and negative partial sums. We test the long-run relationship between the levels of RER_t, ROP_t^+ and ROP_t^- ($i.e.$ $\rho = \theta^+ = \theta^- = 0$) by using the F_{PSS} statistics suggested by Pesaran et al. (2001) and Shin et al. (2014). The t_{BDM} test advanced by Banerjee et al. (1998) tests the null hypothesis $\rho = 0$ against the alternative $\rho < 0$. We can compute the asymmetric long-run coefficients as follows: $L_{mi^+} = \hat{\theta}^+/\rho$ and $L_{mi^-} = \hat{\theta}^-/\rho$. We use the standard Wald test to examine the long-run symmetry $\theta = \theta^+ = \theta^-$ and short-run symmetry which can take either of two forms: $\varphi_i^+ = \varphi_i^-$ for all $i = 1, \dots, q-1$ or $\sum_{i=0}^{q-1} \varphi_i^+ = \sum_{i=0}^{q-1} \varphi_i^-$. The asymmetric dynamic multiplier effects of a unit change of mi_t^+ and mi_t^-, respectively, on cr_t can be expressed as follows:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial cr_{t+j}}{\partial mi_t^+} \text{ and } m_h^- = \sum_{j=0}^{h} \frac{\partial cr_{t+j}}{\partial mi_t^-} \text{ for } h = 0,1,2 \dots$$

As $h \to \infty$, then $m_h^+ \to L_{mi^+}$ and $m_h^- \to L_{mi^-}$.

To test the short-run symmetry, we use the Wald test and, if the symmetry is not rejected, then equation (14) simplifies to NARDL with long-run asymmetry:

$$\Delta RER_t = \vartheta + \rho RER_{t-1} + \theta^{+} ROP_{t-1}^{+} + \theta^{-} ROP_{t-1}^{-} + \sum_{i=1}^{p-1} \gamma_i RER_{t-i} + \sum_{i=0}^{q-1} \varphi_i \Delta ROP_{t-i} + \epsilon_t \quad (15)$$

If long-run symmetry is not rejected, then equation-14 simplifies to NARDL with short-run asymmetry:

$$\Delta RER_t = \vartheta + \rho RER_{t-1} + \theta ROP_{t-1} + \sum_{i=1}^{p-1} \gamma_i RER_{t-i} + \sum_{i=0}^{q-1} (\varphi_i^{+} \Delta ROP_{t-i}^{+} + \varphi_i^{-} \Delta ROP_{t-i}^{-}) + \epsilon_t \quad (16)$$

3.2.4 The asymmetric causality test

The presence of cointegration between real oil price and real exchange rate implies a causal relationship must exist. In order to examine the directional relationship between variables, we apply the recent asymmetric panel causality tests developed by Hatemi-J (2012).[11] The Hatemi-J (2012) approach, which is based on the Toda-Yamamoto (1995) causality test, accounts for nonlinear effects in the sense that the impact of negative shocks might be different from the impact of positive shocks. According to Hatemi-J (2012), the integrated variable real exchange rate and real oil price can be defined as a random walk process as follows:

$$RER_t = RER_{t-1} + e_{1t} = RER_0 + \sum_{i=1}^{t} e_{1i} \quad \text{and} \quad ROP_t = ROP_{t-1} + e_{2t} = ROP_0 + \sum_{i=1}^{t} e_{2i} \quad (17)$$

where $t = 1,2, \dots, T$, $REER_0$ and ROP_0 are the initial values and e_{1t} and e_{2t} are the white noise error terms. Positive and negative shocks can be defined as the following: $e_{1i}^{+} = max(e_{1i}, 0)$, $e_{2i}^{+} = max(e_{2i}, 0)$, $e_{1i}^{-} = min(e_{1i}, 0)$ and $e_{2i}^{-} = min(e_{2i}, 0)$. It follows that: $RER_t = RER_{t-1} + e_{1t} = RER_0 + \sum_{i=1}^{t} e_{1i}^{+} + \sum_{i=1}^{t} e_{1i}^{-}$ and $ROP_t = ROP_{t-1} + e_{2t} = ROP_0 + \sum_{i=1}^{t} e_{2i}^{+} + \sum_{i=1}^{t} e_{2i}^{-}$. Consequently, since there is a permanent effect of negative and positive components on the underlying variables, the negative and positive shocks of real exchange rate and real oil price can be defined in a cumulative form with $RER_t^{+} = \sum_{i=1}^{t} e_{1i}^{+}$, $RER_t^{-} = \sum_{i=1}^{t} e_{1i}^{-}$, $ROP_t^{+} = \sum_{i=1}^{t} e_{2i}^{+}$ and $ROP_t^{-} = \sum_{i=1}^{t} e_{2i}^{-}$. According to Hatemi-J (2012), we can use the negative and positive components to examine the

[11] The authors are grateful to A. Hatemi-J for making his Gauss code available.

asymmetric causality between RER_t and ROP_t. This test can be implemented by estimating the following vector autoregressive model of order p: $Y_t^+ = \vartheta + A_1 Y_{t-1}^+ + \cdots + A_p Y_{t-p}^+ + u_t^+$ where Y_t^+ is the 2×1 vector of the variable, ϑ is the 2×1 vector of intercepts (corresponding to each of the variables representing the cumulative sum of positive shocks). The matrix A_r is a 2×2 matrix of parameters for lag order r ($r = 1, \ldots, p$). The optimal lag order p is selected using the following information criteria suggested by Hatemi-J (2003, 2008):

$$\mathrm{HJC} = \ln\left(\left|\widehat{\Omega}_{\mathrm{j}}\right|\right) + j\left(\frac{\mathrm{n^2 lnT + 2n^2 ln(lnT)}}{2\mathrm{T}}\right), j = 0, \ldots, \mathrm{p} \qquad (18)$$

Where $\left|\widehat{\Omega}_j\right|$ is the determinant of the estimated variance-covariance matrix of the error terms in the VAR model based on lag order j, n is the number of equations in the VAR model and T is the number of observations. The null hypothesis that the kth element ROP_t^+ does not cause the ωth RER_t^+ is defined as:

H_0: the row ω, column k element in A_r equals zero for $r = 1, \ldots,$ p.

According to Hatemi-J (2012), the null hypothesis can be tested using a Wald test[12].

4. Empirical findings and discussion

4.1. Unit root tests

We begin by presenting the initial findings of the time series properties of the series. We consider the possibility of structural breaks in the time series by applying the Narayan and Popp (2010) unit root test with two structural breaks. We present the results for both the break in the intercept (M1) and break in the intercept and trend (M2) in Table 2. In both cases, the Narayan and Popp (2010) unit root test results reveal that the unit root null is rejected for the series. This result suggests that oil price shocks will have transitory effects on the real exchange rate. Furthermore, Figure 1 indicates that the rates of change between the real oil price and real exchange rate of both countries are nonlinear.

[12] For technical details see Hatemi-J (2012).

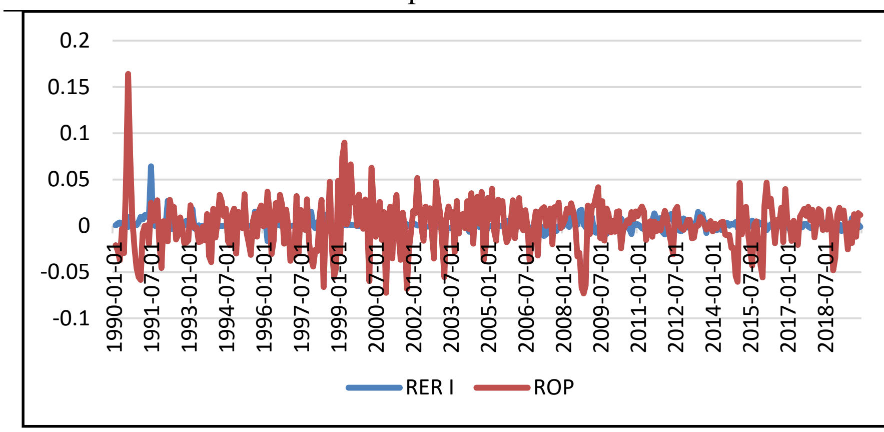
Table-2: Narayan and Popp (2010) Unit Root Test with Two Structural Breaks

		Break in Intercept			Break in Intercept and Trend		
Country	**Series**	**Test statistic**	**TB_1**	**TB_2**	**Test statistic**	**TB_1**	**TB_2**
INDIA	ROP	-8.114*	2004: 11	2009: 06	-7.356*	2005: 07	2008: 07
	RER	-7.522*	2001: 07	2002: 05	-6.283*	2001: 06	2002: 11
CHINA	ROP	-5.138*	2005: 08	2007: 09	-8.256*	2000: 05	2004: 07
	RER	-6.492*	1999: 11	2002: 06	-5.316*	1999: 05	2002: 03

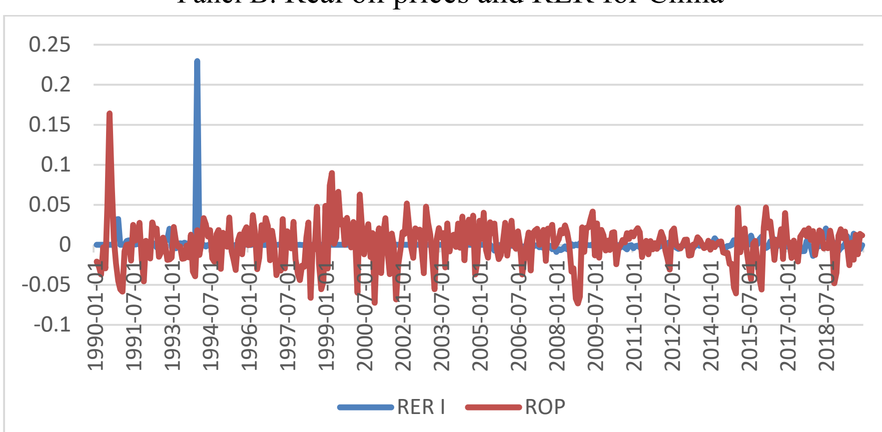
Note: The critical values are taken from Narayan and Popp (2010). TB_1 and TB_2 are the dates of the structural breaks. * denotes statistical significance at the 1%.

Figure-1: Real Oil Prices and RER for India and China

Panel A: Real oil prices and RER for India



Panel B: Real oil prices and RER for China



4.2. Impact of oil prices on the real exchange rates (considering original series)

To capture both short- and long-run dynamics between oil price and exchange rate, we use the nonlinear, autoregressive-distributed lag proposed by Shin et al. (2014). This approach is among the simplest in the class of nonlinear error correction models and is applicable even if the variables are found to be I(0) or I(1). Furthermore, it can be estimated using the ordinary least squares method. With the purpose of selecting the best fitting models, we perform Wald tests for identifying the existence of short-run (W_{SR}) and long-run (W_{LR}) symmetries[13]. The results of Wald tests are reported in Table 3.

Table-3: Results of Short-Run and Long-Run Symmetry Tests

	Original Series			De-noised Series		
	Long run W_{LR}	Short run W_{SR}	Conclusion	Long run W_{LR}	Short run W_{SR}	Conclusion
India	6.896 [0.04]	0.351 [0.416]	NARDL with LR asymmetry	2.847 [0.142]	0.057 [0.674]	Symmetric ARDL
China	4.361 [0.072]	0.354 [0.678]	NARDL with LR asymmetry	4.652 [0.047]	3.453 [0.179]	NARDL with LR asymmetry

Note: W_{LR} refers to the Wald test of long-run symmetry while W_{SR} denotes the Wald test of the additive short-run symmetry condition. The associated p-values are given in brackets.

In the case of India, the null hypothesis of long-run symmetry is rejected at the 5% level, but the null of short-run symmetry cannot be rejected. These findings suggest that NARDL with long-run asymmetry is a suitable model to describe the dynamic interaction between oil prices and exchange rates. In the long-run, the real exchange rate responds asymmetrically to real oil price changes. For China, the symmetry is accepted only in the short-run, highlighting that the preferred model is NARDL with long-run asymmetry. This means that the real oil price reacts asymmetrically to positive and negative shocks in oil prices. As a result, the use of a linear symmetric model for these countries may bias estimation of the error correction model dynamics.

In the second step, we estimate the best specifications for each country. Table 4 reports findings from long-run asymmetric effects of real oil prices on the real exchange rate. We present results for the NARDL model which capture the long-run asymmetric

[13]The optimal number of lags for the two models is selected by using the SIC criterion.

transmission of real oil price changes to the real exchange rate. The Breusch-Godfrey serial correlation, heteroscedasticity and Jarque-Bera normality tests were performed on the estimated residuals show that our model is accurately specified. Furthermore, F_{PSS} and t_{BDM} statistics reject the null of long-run symmetry, which supports the Wald test results.

Table-4: The NARDL Pass-through Analysis

Original Series			
India		China	
NARDL with LR asymmetry		NARDL with LR asymmetry	
Constant	0.413 (0.237)	Constant	0.382 (0.293)
RER_{t-1}	-0.714*** (0.076)	RER_{t-1}	-0.694*** (0.084)
ROP^{+}_{t-1}	0.038 (0.051)	ROP^{+}_{t-1}	0.072* (0.046)
ROP^{-}_{t-1}	0.034 (0.027)	ROP^{-}_{t-1}	0.062* (0.031)
ΔRER_{t-1}	-0.023 (0.053)	ΔRER_{t-1}	-0.096 (0.187)
ΔROP_{t}	0.077*** (0.036)	ΔROP_{t}	0.152*** (0.031)
ΔROP_{t-1}	0.038 (0.047)	ΔROP_{t-1}	0.023 (0.068)
$L_{ROP^{+}}$	0.182	$L_{ROP^{+}}$	0.382***
$L_{ROP^{-}}$	-0.197	$L_{ROP^{-}}$	-0.389***
Adj. R^2	0.56	Adj. R^2	0.49
χ^2_{SC}	11.981 [0.681]	χ^2_{SC}	8.114 [0.697]
χ^2_{HET}	47.712 [0.000]	χ^2_{HET}	65.285 [0.000]
JB	92.487 [0.000]	JB	36.29 [0.000]
t_{BDM}	-7.24	t_{BDM}	-8.14
F_{PSS}	9.14	F_{PSS}	17.27

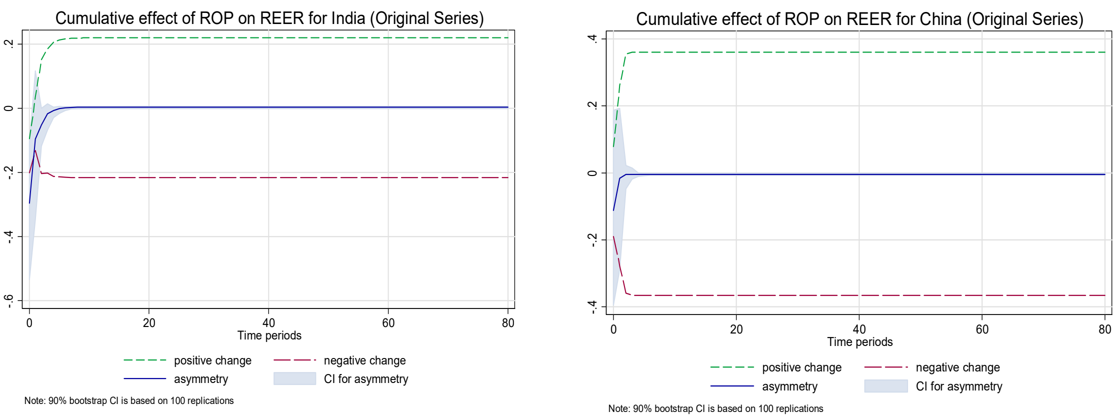
Note: The Schwarz Info Criteria (*SIC*) is *used* to *select* the *optimal lag length*. $L_{ROP^{+}}$ and $L_{ROP^{-}}$ denote the long-run coefficients associated with positive and negative change of oil price.$t_{BDM}$is the BDM t-statistic while F_{PSS} denotes the PSS F-test of the null hypothesis of no-long run levels relationship. Pesaran, Shin and Smith (2001) tabulate the 5% critical values of t_{BDM} as -3.53 and -3.22 for k = 2 and k = 1, respectively, while the equivalent values for F_{PSS} are 4.85 and 5.73.χ^2_{SC}, χ^2_{HET} and JBdenote the Breusch-Godfrey serial correlation, heteroscedasticity and Jarque-Bera normality tests respectively. Standard errors of the estimated coefficients are in parenthesis. The *p*-values of statistical tests are in brackets. *, ** and *** denote significance at the 10%, 5%, and 1% levels respectively.

Results for India show positive short- and long-run relationships between real oil prices and the real exchange rate. Moreover, there is evidence of significant short-run effects of actual changes in real oil prices, but the long-run coefficients are not statistically significant. The positive relationship between underlying variables implies that the real exchange rate tends to depreciate when real oil prices increase over the short-run.[14] This finding is consistent with Ghosh (2011), reflecting that an increase in oil price leads to depreciation in the INR, vis-à-vis the USD, and oil shocks (positive and negative) have similar effects in terms of magnitude on exchange rate volatility in India. Our findings are different from Tiwari et al. (2013) and Kaushik et al. (2014) who establish a neutral effect between the variables; Bal and Rath, (2015) report a feedback effect between oil price and exchange rate.

Our analyses reveal that long-run coefficients carry a positive sign, but are statistically insignificant. This result suggests that real oil prices, although seeming to have asymmetric depreciating long-run effects on the real exchange rate between the INR and USD, these effects may be imperceptible. One plausible explanation for this result could be that oil pricing in India has long been under the administered regime and energy remains largely subsidized. Ghosh (2011) uses data for a single year, therefore not reflecting the long-run relationship between oil prices and exchange rates. The dynamic multiplier for nonlinear adjustment of real effective exchange rate to real oil price is plotted in Figure 2. Lower and upper bands for asymmetry indicate the 90% confidence interval.

[14] This further reflects that increasing oil prices will add to the deterioration of domestic INR value against the foreign currency. As a result, it not only enables Indian exporters to export a higher volume of goods in the international trading market, but also attracts foreign importers to buy Indian commodities as it appears to be less expensive for them compared to availability of other items which are priced at higher rate. This also benefits the Indian economy in earning greater amounts of foreign exchange reserves which could be beneficial for mitigating growing demand for oil.

Figure-2: Real Exchange Rate-Brent Oil prices dynamic multipliers for China and India



Our findings suggest the real exchange rate reacts almost symmetrically to negative and positive real oil price shocks in the long-run (as indicated by the statistically insignificant long-run coefficients). The speed of adjustment to the long-run equilibrium is relatively high (80.2% per month). The asymmetric oil price pass-through is not persistent over time and converges rapidly to the long-run level. The rapid adjustment of real oil prices and real exchange rates from their initial equilibrium to their new equilibrium over time can be explained by the centrally administered retail price of petroleum products which is protected from international oil price volatility.

For China, the NARDL with long-run asymmetry is selected to be the best suited model; thus, the results support evidence of long-run asymmetric effects of real oil prices on real exchange rates. The asymmetric long-run coefficients are positive and significant at the 1% level, highlighting that both negative and positive oil price shocks lead to depreciation of the Chinese RMB relative to USD. This result can be potentially explained by the managed floating exchange rate regime that China follows. In other words, given the elastic labor supply in China, the increase in oil prices will harm China's export capacity less than that of its competitors.[15] These findings are not in

[15] It is worth noting that export growth in China is less prone to external oil price increases due to the cheap labour force, and exposure to new technology embodied in the production process that ultimately allow producers to reduce the cost of production. The lower cost of production helps Chinese exporters to access

agreement with Huang and Gou (2007), who note that oil prices have an appreciating effect on the exchange rate (but minimally so). Bal and Rath (2015) report that oil prices cause exchange rates and exchange rates cause oil prices—a feedback effect. Our results show that real oil price shocks lead to a minor appreciation of the real exchange rate in the long-run. The findings also indicate the existence of significant short-run positive effect of actual changes in real oil prices on the real exchange rate. This implies that, in addition to the asymmetric long-run positive relationship, the positive symmetric short-run influence of real oil price changes is captured.

We further evaluate the short-run and long-run cumulative dynamic multipliers of real oil price changes on the real exchange rate. These are presented in Figure 2. We find a high speed of adjustment of 80.6% per month. One possible explanation for this rapid adjustment is that Chinese exports are not energy intensive, so the dynamic multipliers converge rapidly to the long-run equilibrium between real oil prices and real effective exchange rates.[16]

4.3. The impact of oil prices on real exchange rates (de-noised series)

The aim of the wavelet noise removal technique is to preserve useful information from the original series. De-noising is required when time series are not smooth and contain high volatility or regime shifts. The crude oil price becomes more volatile and responsive to increasingly different influencing factors with higher levels of speculation worldwide. We examined the dynamic relationship between real oil prices and real effective exchange rates based on a wavelet NARDL model. We remove noise in the first step with the MODWT transformation technique to obtain a de-noised time series, which serves as input data in the next step. Figures 3-5 depict these series. After filtration, a nonlinear ARDL model is applied to examine whether the previous results of the short- and long-run symmetry tests prevail or not.

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international market with lower prices. This phenomenon also indicates that an adverse impact of rising oil prices has less of an impact on Chinese exports in the international market.

[16]Xiaodi and Xiaozhong (2004) show that labour-intensive products form the largest share of Chinese exports.

Figure-3: Real Oil Prices (ROP) Series for India (original and de-noised series)

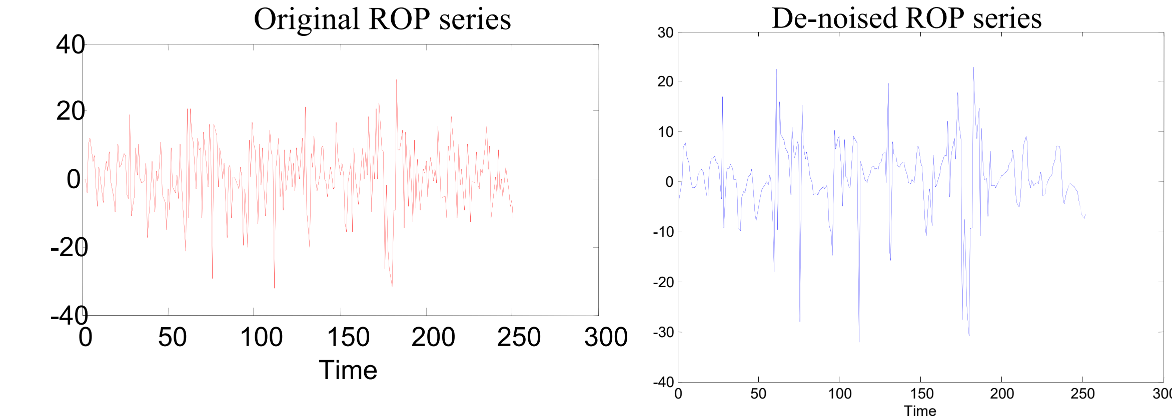
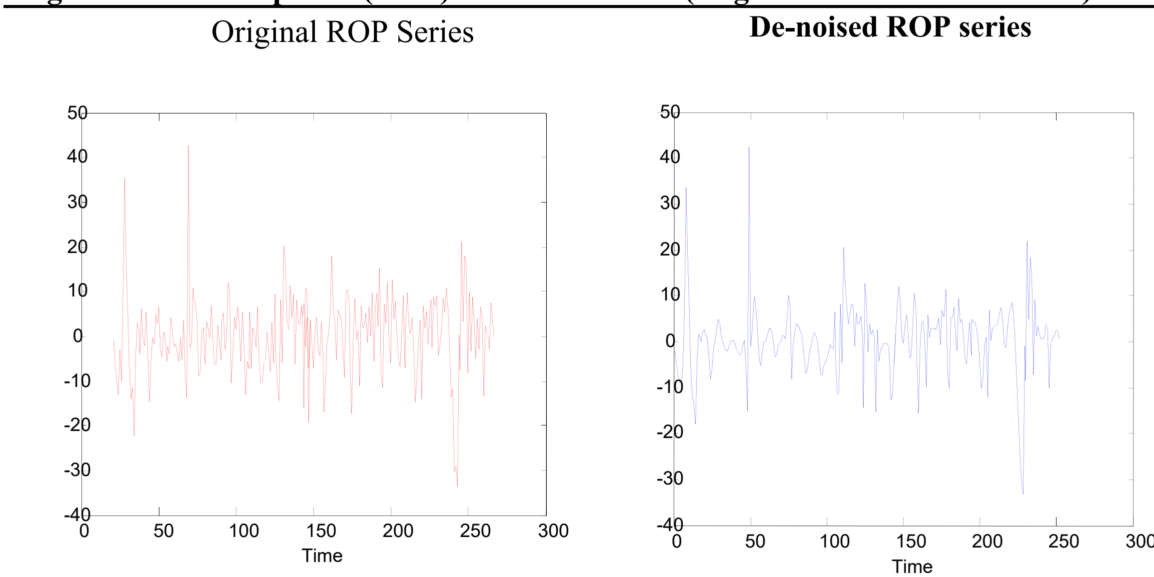


Figure 4: Real Oil prices (ROP) series for China (original and de-noised series)



In order to select the best fitted NARDL model, we perform the Wald test for detecting short- and long-run symmetries. Table-5 reveals that for India, a standard symmetric ARDL is selected because both short- and long-run symmetry cannot be rejected; this implies that real exchange rates react symmetrically to positive and negative oil price shocks. The symmetric long-run coefficient defining the equilibrium between the real oil prices and real exchange rates is always positive, and significant at the 1% level. This finding suggests that an increase in real oil price induces a depreciation of the real exchange rate in the long-run. There is also evidence of positive short-run effects of actual and lagged changes in real oil price on the real exchange rate. Therefore, the increase in real oil price seems to have a significant short- and long-run depreciating effect on the INR. Crude oil imports continue to rise, which contributes to the strengthening of the USD against the INR.

Table-5: The NARDL Pass-through Analysis

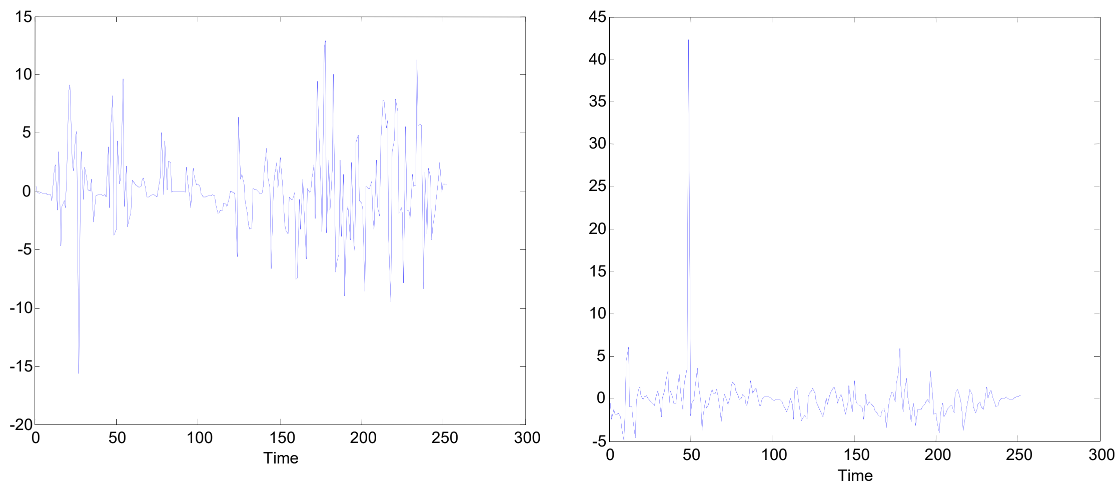
De-noised Series			
India		China	
Symmetric ARDL		NARDL with LR asymmetry	
Constant	0.213 (0.118)	Constant	0.367 (0.258)
RER_{t-1}	-0.876*** (0.058)	RER_{t-1}	-0.787*** (0.063)
ROP_{t-1}	0.057 (0.042)	ROP_{t-1}^{+}	0.057 (0.038)
ΔRER_{t-1}	-0.043 (0.093)	ROP_{t-1}^{-}	0.057 (0.036)
ΔROP_{t}	0.081** (0.041)	ΔRER_{t-1}	0.074 (0.083)
ΔROP_{t-1}	0.086** (0.047)	ΔROP_{t}	0.213*** (0.029)
		ΔROP_{t-1}	-0.091*** (0.037)
L_{ROP}	0.237* [0.082]	$L_{ROP^{+}}$	0.287**
		$L_{ROP^{-}}$	0.293**
Adj. R^2	0.51	Adj. R^2	0.57
χ^2_{SC}	14.328 [0.389]	χ^2_{SC}	15.457 [0.392]
χ^2_{HET}	34.18 [0.064]	χ^2_{HET}	68.52 [0.000]
JB	11.372 [0.000]	JB	9.587 [0.000]
F_{PSS}	21.286	t_{BDM}	-11.138
		F_{PSS}	28.786

Note: L_{ROP} denotes the long-run effect of crude oil prices on exchange rates.

In the case of China, after removing noise from the original data, a NARDL with long-run asymmetry is selected. The asymmetric long-run coefficients are positive and significant at the 1% level; however, the short-run lagged effect is negative and significant at the 1% level, highlighting that a positive shock of real oil price change induces an appreciation in Chinese RMB. Intuitively, the oil price increase has no negative impact on China's export expansion because the products made in the country high international competitiveness.

Figure-5: Real Exchange Rate-Brent Oil Prices Dynamic Multipliers for China and India (De-noised Series)

De-noised REE I series (India) De-noised REE I Series



4.4 The asymmetric causality between oil prices and real exchange rates

Results of asymmetric causality tests are presented in Table 6. We find evidence that the positive and negative cumulative oil shocks do not Granger-cause the exchange rate, and cannot be rejected at any conventional significance level for India. Conversely, for China, findings of the asymmetric Granger causality test confirmed the finding of the NARDL test for cointegration. We found that the null hypothesis of non-Granger causality from real oil price to real exchange rate can be rejected at the 5% level of significance, reflecting positive and negative shocks in oil price drive the real exchange rate in China. The null hypothesis of no causality from positive and negative shocks to the real exchange rate is accepted for both China and India.

Table-6: Results of Hatemi-J Asymmetric Causality Test

Country	Null hypothesis	Test value	Bootstrap CV at 1%	Bootstrap CV at 5%	Bootstrap CV at 10%	Lag length
Original Series						
INDIA	$ROP^{+} \nRightarrow RER^{+}$	0.052	8.124	4.112	2.760	1
	$ROP^{-} \nRightarrow RER^{-}$	4.657	12.972	6.853	4.838	2
	$ROP^{+} \nRightarrow RER^{-}$	1.524	10.454	6.220	4.682	2
	$ROP^{-} \nRightarrow RER^{+}$	3.523	10.069	6.107	4.668	2
CHINA	$ROP^{+} \nRightarrow RER^{+}$	6.364**	11.849	3.619	2.183	1
	$ROP^{-} \nRightarrow RER^{-}$	0.826	13.008	3.895	2.252	1
	$ROP^{+} \nRightarrow RER^{-}$	1.582	12.987	6.131	4.472	2
	$ROP^{-} \nRightarrow RER^{+}$	8.574**	13.085	6.352	4.474	2
De-noised Series						
INDIA	$RER^{+} \nRightarrow ROP^{+}$	0.872	7.971	3.908	2.669	1
	$RER^{-} \nRightarrow ROP^{-}$	0.547	12.007	6.625	4.815	2
	$RER^{+} \nRightarrow ROP^{-}$	8.657	16.940	11.665	9.410	2
	$RER^{-} \nRightarrow ROP^{+}$	0.836	9.811	6.135	4.563	2
CHINA	$RER^{+} \nRightarrow ROP^{+}$	0.741	13.599	3.798	2.217	1
	$RER^{-} \nRightarrow ROP^{-}$	0.247	14.674	3.800	2.199	1
	$RER^{+} \nRightarrow ROP^{-}$	3.642	11.502	6.223	4.643	2
	$RER^{-} \nRightarrow ROP^{+}$	4.117	16.278	6.731	4.451	2

Notes: The optimal lag-length is 6 based on HJC criterion. The symbol $A \nRightarrow B$shows that A does not Granger-cause B. Bootstrap CV means critical value. ** shows significant at 5% level.

5. Concluding remarks and policy implications

Given the significant role of oil in both the Chinese and Indian economies, it is imperative that economic planners understand the relationship between oil prices and exchange rates. Our study identifies asymmetric short- and long-run relationships between real oil prices and real exchange rates in China and India by employing a non-linear, autoregressive-distributed lag model developed by Shin et al. (2014). Using monthly observations covering the period 1990–2019, we find that real oil prices have a long-run asymmetric effect on real exchange rates both for China and India. This effect is positive for China regardless of whether shocks are positive or negative, implying that both negative and positive oil price shocks lead to depreciation of Chinese RMB against the USD. For India, the asymmetric long-run coefficients were statistically insignificant, suggesting that the long-run effects of both positive and negative oil price shocks on real effective exchange rates are imperceptible.

For robustness checks, results of the wavelet based NARDL cointegration model are compared with those obtained from original data. This model has the advantage of using de-noised data, as crude oil becomes more volatile and sensitive to increasingly diversified influencing factors. We are not able to reject the null hypothesis of short- and long-run symmetries for India. Therefore, a standard, symmetric ARDL is best suited for examining the dynamic interaction between real oil prices and the real effective exchange rate in India. The symmetric long-run coefficient defining the equilibrium between real oil prices and real exchange rates is always positive, suggesting a significant depreciation of the INR against the USD. This finding is interesting, and consistent with results of NARDL employed on the original data (recall we found non-significant asymmetric long-run coefficients). For China, after removing noise, a NARDL with long-run asymmetry is also selected; the asymmetric long-run coefficients are still positive and significant at the 1% level. For both countries, an increase in oil price causes depreciation of currency, but in different magnitudes.

From policy perspectives, our findings add new evidence towards the existing empirical literature. In the case of India, a long-run, symmetric effect of oil price shocks is established on the real exchange rate, considering the original data series with and without noise. This reflects equal long-run impacts of both negative and positive real oil price shocks on the real exchange rate. Oil prices further reflect the depreciation of the INR against the USD in the long-run.

From a policy perspective, findings of our research suggest a necessary intervention by the Reserve Bank of India (RBI) in the foreign exchange market to protect the value of the INR against the USD. In addition, the Indian government and the RBI need to take necessary action in reducing the demand for imported oil. Otherwise, this will jeopardise the credit rating of INR by accumulating higher foreign exchange reserves. The consequences of having lower foreign exchange reserve, due to the depreciation of INR, will have long-run effects on aggregate economic activities. We also suggest the adverse long-run depreciating impact of oil price changes could be minimized by the collective action from both the central bank and governments. We suggest co-ordination of monetary and fiscal policies are necessary to minimise the adverse effects of real oil prices on real exchange rates in India.

Policy implications of our findings for China are different. We establish a significant long-run asymmetric effect of real oil prices on the real exchange rate in China. This finding is consistent across two different models when we use the data original series with and without noise. This result implies that the long-run depreciation of the Chinese RMB against the USD occurs predominantly due to the asymmetric effects of positive and negative real oil price shocks. Two interesting inferences arise here. First, the Chinese RMB depreciates in the long-run. Second, there are asymmetric effects of real oil prices. It is easier for the central bank and government in China to deal with the first inference. But, as long as the second inference remains, it is challenging to isolate the relative asymmetric depreciating effects of both positive and negative real oil price shocks on the Chinese RMB. From a policy perspective, we suggest that higher veto power should be provided to the central bank in order to allow for effective intervention in the international foreign exchange market while dealing with domestic currency fluctuations. Without this, China will be on the brink of losing major producers and exporters in the international market and, eventually, greater loss of foreign exchange reserves is expected in future. This can act as a barrier for China in becoming the next super-power in general, and specifically in the oil and foreign exchange markets. Apart from this constraint, we believe that dangers of oil price changes on the exchange rate are expected to be reduced due to the emergence of China as a major player both in the oil and foreign exchange markets.

On a final note, this comparative study confirms the existence of asymmetric short- and long-run relationships between the real oil prices and real exchange rates for China and India. Future research may include the role of financial crises to examine the asymmetric short- and long-run effects of real oil price on the real effective exchange rate for these countries, and their indirect effects on sectoral output. Our findings emphasise to policy-advisers and Central Banks to protect the value of the domestic currency against the USD in the international trade and foreign exchange markets. Identifying factors related to financial speculation in world oil markets in both countries will bring currency stability for both countries.

In an era of sustainable development, energy-saving technological changes with renewable energy sources will help to ensure stability in exchange rates in relation to changes in oil prices. The role of renewable energy sources will be significant in future for both countries in capturing some of the effects of oil shocks and the consequences on the economy including the trade sector.

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