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## Nonlinear causality between crude oil price and exchange rate: A comparative study of China and India - A Reassessment

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## Abstract

De Vita and Trachanas's (hereafter DV-T, 2016) paper published in (Energy Economics, Volume 56, May 2016, pages, 150-160) criticizes Bal and Rath's paper (Energy Economics, Volume 51, September 2015, pages, 149-156) (hereafter, BR, 2015) by undertaking a 'pure replication' and a 'reanalysis' using (BR, 2015) data set. The aim of this paper is to reassess (BR, 2015) by providing comments and additional evidence. We revisit (BR, 2015) with the aim of applying additional unit root, cointegration and nonlinear causality tests. The results derived from these supplementary tests clearly reveal that the oil price series is non-stationary at level. The bivariate noisy Mackey-Glass model proposed by Kyrtsou and Terraza (2003) reveals bi-directional non-linear causality exists between real oil price and exchange rate in case of China, whereas for India, only unidirectional nonlinear causality running from oil price to exchange rate.

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**Nonlinear causality between crude oil price and exchange rate: A comparative study of China and India - A Reassessment**

## 1. Introduction

The aim of this paper is to comment on Bal and Rath's (BR, 2015) and provide additional evidence by reassessing the linkage between oil price and exchange rate by considering two emerging countries, China and India.

First, we proceed by reviewing De Vita and Trachanas's (DV-T, 2016) paper published in *Energy Economics*. Second, we provide comments on BR (2015). Third, we apply additional unit root, nonlinear causality, and cointegration tests to draw the inference. In this paper we apply degree of non-stationary DNS (ω) unit root test. It shows the real oil price series and exchange rate are non-stationary at level. Finally, we further employed additional econometrics tools such as Bayer and Hanck (BH) (2013) cointegration test, bivariate noisy Mackey-Glass model developed by Kyrtsou and Terraza (2003) for examining non-linear causality test. Our reassessment does not fully support the findings of BR (2015) or DV-T (2016). We conclude that the linear or nonlinear causality between oil prices and exchange rate are sensitive to different econometrics techniques along with their underlying properties and therefore leave this research question to the readers for further investigation.

The remainder of this paper structured as follows. Section 2 summarizes DV-T (2016) and provides comments on BR (2015). Section 3 provides additional results by revisiting casual linkage between oil price and exchange rate by comparing China and India. Section 4 concludes.

## 2. Summary of De Vita and Trachnas (2016) analytical steps

DV-T (2016) revisits (BR, 2015) by undertaking a 'pure replication' and 'reanalysis' of BR (2015). They offer additional results using battery of unit root tests and causality tests. First, DV-T (2016) examines the stationary property of real oil price and real exchange rate for China and India using the Ng-Perron (2001) unit root test. Their study has found different results by doing an "exact replication". They discovered that the real oil price is I(0) at level. Additionally, they apply both the ARDL and the NARDL models to examine the linear and nonlinear long run relationship between the real oil price and real exchange rate. Finally, to check the robustness, they apply the Hiemstra and Jones (1994) and Diks and Panchenko (2006) nonlinear causality tests by considering oil price as I(0) and exchange rate I(1). Their results confirm the absence of any nonlinear causality between oil price and exchange rates for both the countries.

While we appreciate the replication works done by DV-T (2016), but we revisit our earlier work, BR (2015) through estimating Ng-Perron (2001) unit root test for real oil price by taking both drift and trend. First, we found that real oil price is non-stationary at level, i.e. I(1) with drift only, whereas, stationary at level I(0) when trend term is added with drift. Although we admit that it was our mistake by not reporting these results in BR (2015), however, inference draw about the non-stationarity of real oil price is based on results Ng-Perron (2001) with drift and without trend only. Second, there are several studies published both in energy economics and other journals which show that oil price is non-stationary at level, i.e. I(1) (for example, see: Chaudhuri and Daniel, 1998; Amano and Norden, 1998; Chen and Chen, 2007; Bénassy-Quéré, Mignon, and Penot, 2007; Benhmad, 2012; Tiwari, Dar, and Bhanja, 2013; Narayan, Sharma, Poon, and Westerlund, 2014). These studies have considered data either over different time periods or various unit root tests. Further, different unit root tests either include the constant only or both the constant and time trend. There is an absence of guiding theory on the choice of models, hence the flexibility in these selections. The variables have taken either raw form or natural log form. Again, no theory guides this choice. Finally, BR (2015) decision for considering real oil price series as I(1) at level was based on the results derived from Narayan and Popp (2010) unit root test with two structural breaks at level and slope (see, BR, 2015, Table 2, pp.153).

What message draws from the linear cointegration tests done by BR (2015)? BR used the Johansen and Juselius (1990) cointegration test and found one cointegrating vector between real oil price and exchange rate for both China and India. DV-T (2016) study shows that there is absence of any cointegrating relatonship between real oil price and exchnage rate for China and India. Additionally, they have detected that the procedure for estimating the cointegration test by BR (2015) was incorrect. Again, we admit our slipup while selecting the optimum lag.

Finally, with regard to results of nonlinear causality between oil price and real exchange rate, BR(2015) apply the Himestra and Jones (1994) by considering both oil price and real exchange rate series as I(1), whereas DV-T (2016) consider real oil price as I(0) and real exchange rate as I(1). Therefore, the results drawn from both the papers are different. Therefore, in our opinion DV-T (2016) identifies the limitation of BR (2015) by carefully examining the same research question using much robust techniques, which we appreciate.

But to our knowledge, pure replication implies that one need to use exactly same data set and follow the exact steps with accurate codes used by BR (2015).

In the following section, we provide additional results to the findings of Bal and Rath (2015).

## 3. Additional Evidence

### *3.1. Data Sources*

This study uses monthly data covering the period from January 1994 to March 2013. Exchange rate is measured by real effective exchange rate of India (RIX) which is obtained from the Reserve Bank of India published by Hand book of Statistics on Indian economy and the real effective exchange rate of China (RCX) is collected from CEIC data base. The West Texas Intermediate (WTI) as crude oil price which is deflated by United States consumer price index by following (Faria et.al. 2009) for real term. So the WTI and United State consumer price index data is obtained from CEIC data base.

### *3.2. Unit Root Test*

This study further examines the stationarity property using degree of non-stationary DNS(w) method. The examination of unit root through DNS(w) method is well executed in the area of mathematics, physics, engineering sciences and applied geophysics (see, for example, Huang et al. 1998 and Barman et al. 2016). The merit of this method over other traditional methods is that stationary of any data can be checked accurately without destroying the nonlinear and non-stationary features of the data. Some statistically significant and useful quantities, namely mean marginal spectrum, $h(\omega)$, degree of non-stationary ($DNS(\omega)$) and instantaneous energy *IE(t)* can also be derived from Hilbert Huang Transformation (HHT) [Huang et al., 2015]. The mean marginal spectrum$h(\omega)$ is defined as$h(\omega) = \frac{1}{T}\int_0^T H(t,\omega)\, dt$. $DNS(\omega)$ can be used to quantify the degree of non-stationary of a time series. There is high likelihood of the presence of nonlinearity in high frequency data such as oil price and exchange rate, therefore, DNS method is also appropriate to check the stationarity. An index of non-stationary can be derived from the Hilbert spectrum in order to check how far the process deviates from the stationary. This index is termed as $DNS(\omega)$ and defined as

$$DNS(\omega) = \frac{1}{T}\int_0^T [1 - \frac{H(t,\omega)}{h(w)}]\, dt \tag{1}$$

Where [0, T] is the chosen time window.

**<INSERT FIGURE 1>**

In the figures, (a), (c) and (e) represent the DNS (ω) at the level form of oil price, exchange rate of China and exchange rate of India respectively. It clearly shows that the frequencies are oscillating and hence non stationary at the level from. Whereas, the figure (b), (d) and (f) shows the DNS (ω) at the first order difference and clearly observed that the frequency are mean revering and mean are moving toward zero in case of oil price, exchange rates of China and India respectively. Therefore, all the variables are stationary at the first difference (Dash et al., 2017; Huang et al., 2005).

*3.3. Cointegration Results*

Then we use the Bayer and Hanck (BH) (2013) cointegration test to investigate the long run relationship between oil price and exchange rate. BH cointegration test is efficient, robust and has certain advantages over other traditional cointegration tests such as Engle and Granger (1987), Johansen and Juselius (1990) as well as Pesaran et al. (2001) [1]. The BH (2013) test ignores the multiple testing procedures through combining the statistical significance level by following Fisher's (1932) critical values. Therefore, the results derived from BH test are efficient and robust. The probability values of each cointegration test such as Engle and Granger (1987); Johansen (1991); Banerjee et al. (1998) and Boswijk (1994) are denoted by $P_{EG}$ , $P_J$ , $P_{Ba}$ , and $P_{Bo}$ , respectively.

**<INSERT TABLE 1>**

The BH cointegration results are presented in Table 1. Our result shows that there is no cointegration relationship between oil price and exchange rate for both the countries. The results from BH test suspected about the linear association between oil price and exchange rate in case both the countries. So, we decompose the time series data through Hilbert-Huang (1998) transformation (HHT) approach. The main aim to use this approach is to remove the noise and short term trend that presence in the data. HHT preserved the nonlinear and no-stationary features of the variable which is the main advantage over other approach such as wavelet transformation method, which destroy the nonlinear properties and leads to erroneous results (Huang, et al, 1998). HHT decompose the data into two steps. First, it decomposes into a set of intrinsic mode function (IMF) through empirical mode decomposition (EMD)

[1] For detail, see: Shahbaz et al. (2016)

approach. Second, it extracts the energy-frequency-time spectrum by using Hilbert transformation approach on the generated IMF. EMD has been applied to decompose the oil price and exchange rate of both the countries into IMF. The decomposition of oil price is presented in figure 2. Similarly, figures 3 and 4 show the decomposed of exchange rate of India and China, respectively. After removing the noisy components in the data, we further apply BH (2013) cointegration test and results are presented in Table 2. The result shows an existence of long run relationship between real oil price and exchange rate for both China and India. We reject the null hypothesis of no long run relationship at 1 percent level in both ways in case of both the countries. The results of Table 2 further reveal that the original data on real oil price and exchange rate without removing the noisy components are heavily contain non-linearity. Further, we use Hodrick-Prescott filter for oil price and exchange rate and use BH (2013) test for those filter series for robustness of the results. The results of BH (2013) test based on Hodrick-Prescott filter process are presented in Table 3. The results suggest that there are having long run relationship among oil price and exchange rate for both India and China respectively.

**<INSERT FIGURE 2>**

**<INSERT FIGURE 3>**

**<INSERT FIGURE 4>**

*3.4. Non-linear Granger causality results*

With regard to examining the non-linear Granger causality test between oil price and exchange rate, we further use the bivariate noisy Mackey-Glass model proposed by Kyrtsou and Terraza (2003). Hiemstra and Jones (1994) and Diks and Panchenko (2006) test for nonlinear Granger causality between $\{X_t\}$ and $\{Y_t\}$ is applied to the filter series that has extracted from VAR residuals. But, the VAR framework is a linear method and can able to confer the linear residuals based on time. Whereas, Mackey-Glass framework is nonlinear time delay differential equation and can able to filter the nonlinear residuals of the variable, which can be directly use in Hiemstra and Jones (1994) Granger causality test to capture the nonlinear causality between the variables without losing any important information that present in the data. Further, Mackey-Glass method can able to show the nonlinear feedback of the interdependent variable in the time series (Kyrtsou and Labys, 2006). The non-linear causality between the two variables can be explained in equations (2) and (3) by quoting from Kyrtsou and Labys (2006, p. 262):

$$X_t = \alpha_{11}\frac{X_{t-\tau_1}}{1+X_{t-\tau_2}^{C_1}} - \delta_{11}X_{t-1} + \alpha_{12}\frac{Y_{t-\tau_2}}{1+Y_{t-\tau_2}^{C_2}} - \delta_{12}Y_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim N(0,1) \tag{2}$$

$$Y_t = \alpha_{21}\frac{X_{t-\tau_1}}{1+X_{t-\tau_2}^{C_1}} - \delta_{21}X_{t-1} + \alpha_{22}\frac{Y_{t-\tau_2}}{1+Y_{t-\tau_2}^{C_2}} - \delta_{22}Y_{t-1} + \mu_t, \qquad \mu_t \sim N(0,1) \tag{3}$$

Where α and δ are the parameters to be estimated; $\tau$ is the time delay and $C_1$ and $C_2$ are constants. X and Y are oil price and exchange rate, respectively. The best parameter of the model is estimated through ordinary least squares (OLS) method and the delay parameter has been chosen following Schwarz and Hannan-Quinn criterions. The results of nonlinear Granger causality are presented in Tables 4 and 5.

The column 2 and column 3 of Table 4 represent results for both India and China respectively. All the coefficients related to α demonstrate the nonlinear causality between oil price and exchange rate, whereas, all coefficients related to δ indicate the linear causality between oil price and exchange rate. The coefficients of equations 2 and 3 can be interpreted as follows. $\alpha_{11}$ represents the nonlinear effect of lag period oil price on current period of oil price, $\delta_{11}$ reveals the linear effect of lag period oil price on current period oil price, $\alpha_{12}$ is nonlinear effect of lag period exchange rate on current period oil price, $\delta_{12}$ shows the linear effect of lag period exchange rate on current period oil price, $\alpha_{21}$ represents the nonlinear effects of lag period oil price on current period exchange rate, $\delta_{21}$ is the linear effect of lag period oil price on current period exchange rate, $\alpha_{22}$ represents the nonlinear effect of lag period exchange rate on current period exchange rate, and $\delta_{22}$ indicates the linear effects of lag period exchange rate on current period exchange rate.

The results of the Table 4 can be summarized as follows. First, there is an existence of nonlinear and linear effects of lag period oil price on current period oil price in case of India, whereas, a weak nonlinear effect in case of China. Second, there is no nonlinear impact of exchange rate on oil price for India and weak nonlinear effect of exchange rate on oil price. Third, strong evidence of linear and nonlinear effects of lag oil price on exchange rate for China, but in case of India, the nonlinear effect of lag period oil price on exchange rate is weak. Finally, there is evidence of linear and non-linear effect of lag period exchange rate on current period exchange rate for both China and India. Although some of the coefficients in Table 3 are very large, but it is because of by nature of the Mackey-Glass framework, which not only takes the lag period effects of oil and exchange rate together but also built the linear and nonlinear relationship within the model. Further, the results in Table 5 show that there exits unidirectional nonlinear Granger causality between oil price and exchange rate in the case of India, whereas bi-directional Granger causality found between oil price and exchange rate in the case of China.

**<INSERT TABLE 2>**

**<INSERT TABLE 3>**

**<INSERT TABLE 4>**

**<INSERT TABLE 5>**

## 4. Conclusions

De Vita and Trachanas's paper (*Energy Economics, Volume 56, May 2016, pages, 150-160)* reevaluate Bal and Rath's paper (*Energy Economics, Volume 51, September 2015, pages, 149-156)* by undertaking a 'pure replication' and a 'reanalysis' using Bal and Rath, 2015 data set. The aim of this paper was to reexamine our work (Bal and Rath, 2015) by supporting additional evidence. We revisited (BR, 2015) with the aim of applying additional unit root, cointegration and nonlinear causality tests. The unit root based on DNS (ω) method shows that the real oil price series is non-stationary at level, i.e. I(1). Then we used the Bayer and Hanck (BH) (2013) cointegration test to investigate the long run relationship between real oil price and exchange rate. Our results revealed that presence of long run relationship between real oil price and exchange rate after removing the noisy components from the original data. Further, the bivariate noisy Mackey-Glass model proposed by Kyrtsou and Terraza (2003) discovered bi-directional non-linear Granger causality exists between real oil price and exchange rate in case of China, whereas, only unidirectional non-linear causality running from real oil price to exchange rate in case of India.

Thus, in our opinion, DV-T (2016) identified the limitation of BR (2015) by carefully examining the same research question using various robust techniques in their 'reanalysis' section. We conclude by saying that the stationary property of oil price and nonlinear causality between oil prices and exchange rate are sensitive to different econometrics techniques based on their underlying properties.

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Figure 1: The Degree of Non-Stationary Spectrum DNS(ω)

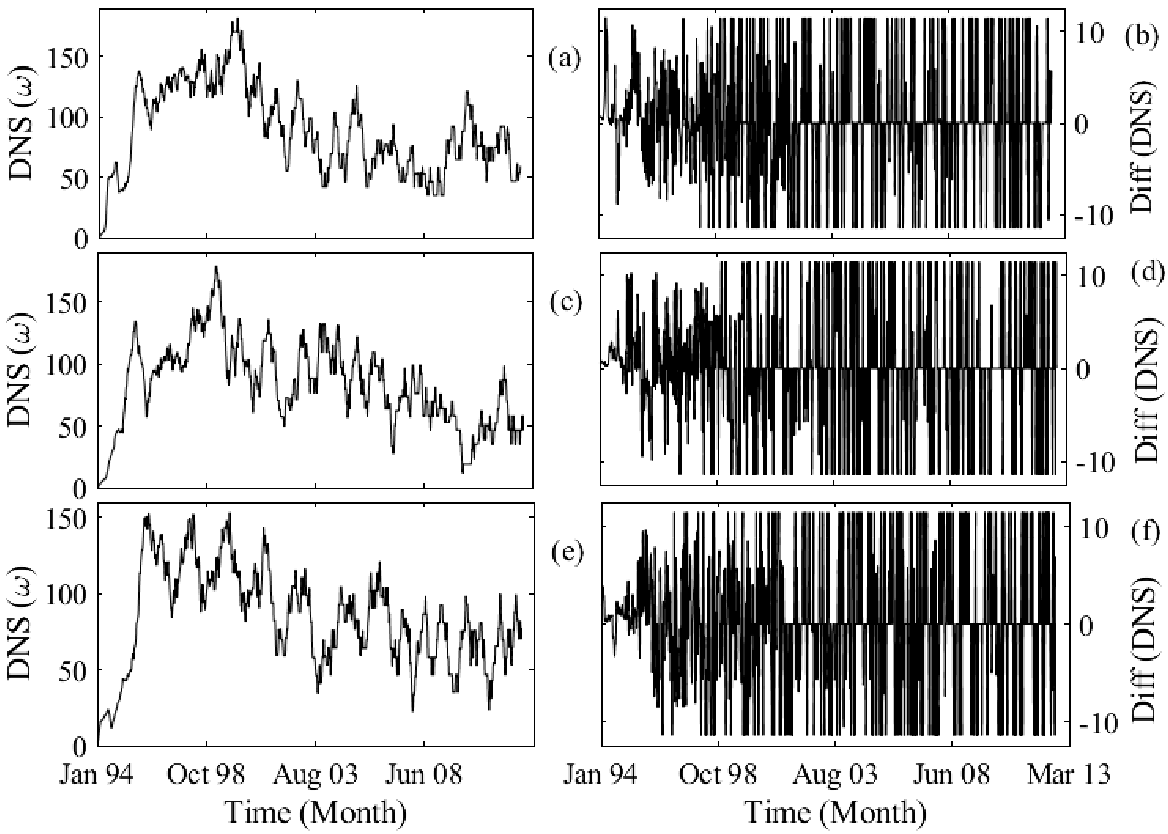

Figure 2: IMFs (a-f) of Oil Price

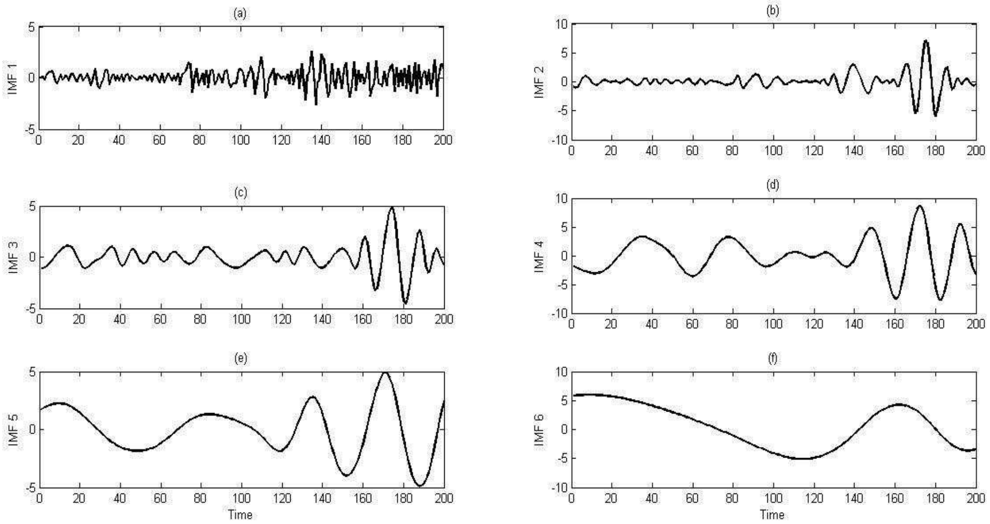


Figure 3: IMFs (a-f) of Exchange Rate of India

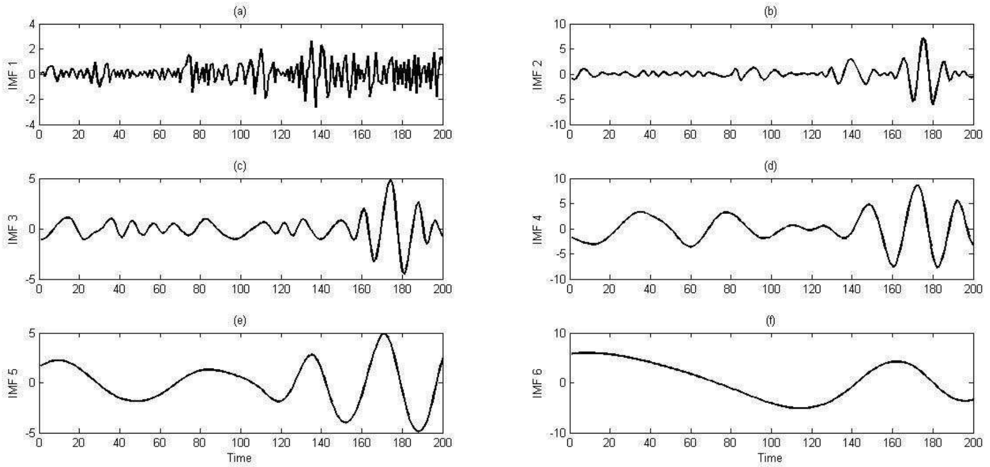

Figure 4: IMFs (a-f) of Exchange Rate of China

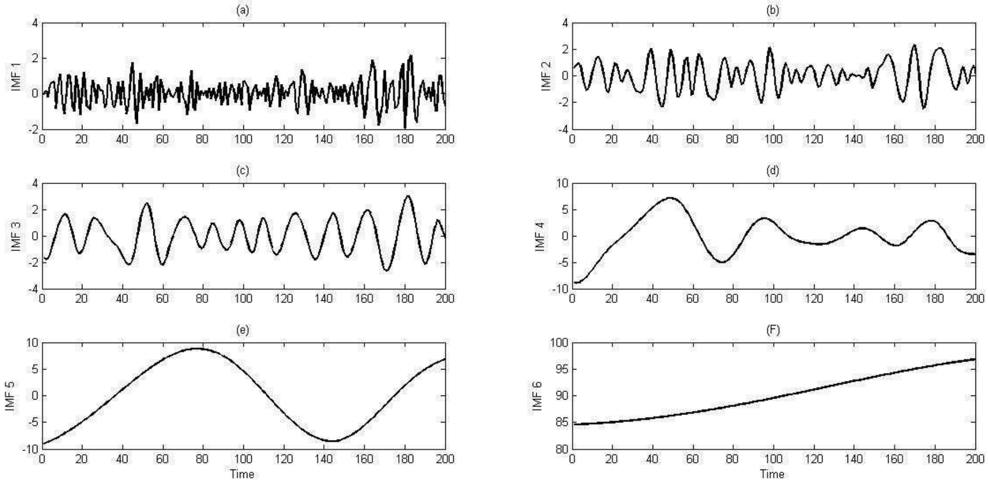


Table 1: Bayer-Hanck cointegration test

| Parameter | EG-J | EG-J-Ba-Bo | Lag | Inferences |
|---|---|---|---|---|
| Test Statistics | | | | |
| India | | | | |
| ROL-RIX | 4.57 | 8.17 | 2 | No long run Relationship |
| RIX-ROL | 8.10 | 19.98 | 2 | No long run Relationship |
| China | | | | |
| ROL-RCX | 7.83 | 9.30 | 2 | No long run Relationship |
| RCX-ROL | 7.10 | 18.06 | 2 | No long run Relationship |

The critical value of the Bayer-Hanck test at 5% level of significance is 11.22 and 21.93 respectively.

Table 2: Bayer-Hanck cointegration test from HHT transformation

| Parameter | EG-J | EG-J-Ba-Bo | Lag | Inferences |
|---|---|---|---|---|
| Test Statistics | | | | |
| India | | | | |
| ROL-RIX | 57.79 | 70.86 | 2 | Existence of long run Relationship |
| RIX-ROL | 55.64 | 111.85 | 2 | Existence of long run Relationship |
| China | | | | |
| ROL-RCX | 110.52 | 221.05 | 1 | Existence of long run Relationship |
| RCX-ROL | 110.52 | 221.05 | 1 | Existence of long run Relationship |

The critical value of the Bayer-Hanck test at 1% and 5% level of significance are 17.30, 33.969, 11.22 and 21.93 respectively.

Table 3: Bayer-Hanck cointegration test based on Hodrick-Prescott filter series

| Parameter | EG-J | EG-J-Ba-Bo | Lag | Inferences |
|---|---|---|---|---|
| Test Statistics | | | | |
| India | | | | |
| ROL-RIX | 70.46 | 77.88 | 2 | Existence of long run Relationship |
| RIX-ROL | 70.68 | 80.66 | 2 | Existence of long run Relationship |
| China | | | | |
| ROL-RCX | 110.52 | 111.09 | 2 | Existence of long run Relationship |
| RCX-ROL | 110.52 | 165.78 | 2 | Existence of long run Relationship |

The critical value of the Bayer-Hanck test at 1% and 5% level of significance are 17.30, 33.969, 11.22 and 21.93 respectively.

Table 4: Results for the bivariate noisy Mackey-Glass model

| Parameter | India | China |
|---|---|---|
| $\alpha_{11}$ | $-2.03^{**}$ (0.03) | $15.54^{*}$ (0.08) |
| $\delta_{11}$ | $-0.99^{***}$ (0.00) | $-0.96^{***}$ (0.00) |
| $\alpha_{12}$ | $1.24E+14$ (0.11) | $-582.47^{*}$ (0.10) |
| $\delta_{12}$ | $-0.02^{*}$ (0.08) | $0.08^{*}$ (0.09) |
| $\alpha_{21}$ | $8.31^{*}$ (0.09) | $-16.53^{***}$ (0.00) |
| $\delta_{21}$ | 0.02 (0.69) | $-0.05^{***}$ (0.00) |
| $\alpha_{22}$ | $9.32E+13^{*}$ (0.10) | $762.14^{***}$ (0.00) |
| $\delta_{22}$ | $-0.93^{***}$ (0.00) | $1.07^{***}$ (0.00) |

***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively. The value in parentheses shows the p-value. The values of $\tau_1 = \tau_2 = 2$; $C_1 = 1$ and $C_2 = 8$ in case of India; $\tau_1 = 1$, $\tau_2 = 2$; $C_1 = 1$ and $C_2 = 2$ in case of China. The delay parameter is chosen on the basis of Schwarz and Hannan-Quinn criterion.

Table 5: Results of nonlinear Granger causality test.

| India | | | |
|---|---|---|---|
| $H_{0I}$ : $ROL_t$ does not cause $RIX_t$ | | $H_{0I}$ : $RIX_t$ does not cause $ROL_t$ | |
| F-statistics | P-value | F-statistics | P-value |
| $9.33^{***}$ | 0.00 | 0.0001 | 0.99 |
| China | | | |
| $H_{0C}$ : $ROL_t$ does not cause $RCX_t$ | | $H_{0C}$ : $RCX_t$ does not cause $ROL_t$ | |
| F-statistics | P-value | F-statistics | P-value |
| $9.05^{***}$ | 0.00 | $2.67^{*}$ | 0.10 |

*** and * denotes 1% and 10% level of significance respectively. The values of $\tau_1 = \tau_2 = 2$; $C_1 = 1$ and $C_2 = 8$ in case of India; $\tau_1 = 1$, $\tau_2 = 2$; $C_1 = 1$ and $C_2 = 2$ in case of China. The delay parameter is chosen on the basis of Schwarz and Hannan-Quinn criterion.