EMPIRICAL ANALYSES OF THE RELATIONSHIP BETWEEN REAL EXCHANGE RATE AND REAL INTEREST RATE DIFFERENTIALS IN INFLATION TARGETING COUNTRIES

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Abstract

This study empirically tests the long-run relationship between real exchange rate and real interest rate (RERI) differentials using quarterly panel data over the period 1993- 2018 employing cointegration methods for a panel of 12 inflation targeting countries. The theoretical relationship of a long-run equilibrium relationship between real exchange rates and interest rate differentials is essentially derived from the Purchasing Power Parity (PPP) and uncovered interest parity theories. This theoretical relationship has become a standard and acceptable theory in open economy macroeconomics. Even so, empirical evidence on this long-run relationship has been mixed. Our study differs from previous studies in two respects. First, we investigate this relationship only for countries that have the same monetary policy framework (inflation targeting) (interest rates and exchange rates are theoretically important in the transmission of monetary impulses to the real economy). Second, we use both multivariate and panel cointegration methods in our investigation. The results show some evidence of cointegration in the country-by-country cases that we investigated using multivariate cointegration tests and weak evidence of cointegration between real exchange rate and real interest rate differentials for the sample of inflation targeting countries using panel cointegration tests. The findings in this study corroborates early works and recent studies on the long-run relationship between real exchange rate and real interest rate differentials. The empirical evidence from this study conclude that there is no clear evidence that the real interest rate – real exchange rate relationship in inflation targeting countries are different from other countries with well-developed financial markets.

Keywords: real exchange rates, inflation, interest rate differentials, inflation targeting, panel model, co-integration

JEL Classification: E43, E52, F31

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1. Introduction

This study examines the long-run relationship between real exchange rate and real interest rate differentials (RERI) for a panel of 12 inflation targeting countries[2] over the period 1993- 2018 using cointegration methods. Many studies in the literature support the essential role played by real interest rate differentials in the determination of the real exchange rate. The flexible-price monetary model (Frankel, 1976; Bilson, 1979), the sticky-price monetary model (Dornbush, 1976; Frankel, 1979, 1981), the sticky-price asset (Hooper and Morton, 1982) and the optimizing models (Grilli and Roubini, 1992; Obstfeld and Rogoff, 1996) underline this important relationship known as the real exchange rate - real interest rate (RERI) model. Interest differentials, which is the difference in the interest rate between interest-bearing assets in two corresponding countries, can be used to form expectations of future exchange rates between two currencies. Many studies have investigated the RERI relationship using samples of industrialised countries.

Our study differs from previous studies in two respects: First, we investigate this relationship only for countries that have the same monetary policy framework (inflation targeting) (interest rates and exchange rates are theoretically important in the transmission of monetary impulses to the real economy), and second, we use both multivariate and panel cointegration methods in our investigation. The motivation for this study is the quest to examine the dynamics between the long-run relationship between real exchange rate and real interest rate differentials for countries that have adapted inflation targeting monetary policy framework for relatively longer periods. We selected inflation targeting countries for our analysis following mounting evidence of the stability found in the responses to inflation and output gaps among countries that adopted inflation targeting (Barajas, 2014). Inflation targeting is a monetary policy framework in which central banks announce in advance the targeted level of inflation to achieve and commit to that goal. The public then form expectations based on the announced target.

The focus of in this study is analyzing the long-run relationship between the series rather than the short-run relationship. We use the MacDonald and Nagayasu (1999) approach but for a

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[2] Countries that have adopted inflation targeting monetary policy regime included in this study are Australia, Canada, Iceland, Israel, Korea, Mexico, New Zealand, Norway, South Africa, Sweden, Thailand, and United Kingdom. The countries were chosen based on the availability of data.

panel of countries which present different characteristics than the sample previously used by the authors. It is essential to see how the two series move together in the long run in the context of countries where the future targeted level of inflation is communicated in advance by the Central Bank as a tool to bring price stability in the economy. The findings in this study are in line with the early work by Meese and Rogoff (1998) and Edison and Pauls (1993) who found no strong support for the relationship between real interest differentials and real exchange rates in the long run and in contrast with findings by authors such as MacDonald and Nagayasu (1999) and Hoffman and MacDonald (2009) in the panel cointegration analysis. Our results in the country-by country case are supported by the findings of Khairman and Chinchwadkar (2015). The paper is structured as follows. Section 2 provides a literature review, section 3 describes the theoretical framework of the RERI relationship, section 4 describes the data and methodology, section 5 provides the results and interpretation of the results and the last section presents the concluding remarks.

2. LITERATURE REVIEW

Empirical research presents mixed evidence on the long run relationship between real exchange rate and real interest rate (RERI) differentials. Some studies failed or show weak evidence (Edison and Pauls, 1993; Meese and Rogoff, 1988), while other found a statistically significant long-run relationship for the RERI model (MacDonald, 1997; Edison and Melick, 1999; MacDonald and Nagayasu, 2000; Hoffmann and MacDonald, 2009).

Messe and Rogoff (1998) investigated the empirical relationship between major currency real exchange rates and real interest rates over the modern (post-March 1973) flexible exchange rate period considering both in-sample and out-of-sample tests. The authors found little evidence of a stable relationship between real interest rates and real exchange rates. However, Ronald and Nagayasu (2000) found evidence of a long run relationship between real exchange rates and real interest rate differentials over the recent floating exchange rate period using panel cointegration methods to a data set of 14 industrialised countries.

Hoffmann and MacDonald (2009) re-investigated the RERI relationship using bilateral US real exchange rate data spanning the period 1978-2007. Instead of testing one particular model, the authors build on the VAR-method of Campbelle and Shiller (1987) to propose a metric of the economic significance of the relationship. The results provide robust evidence that the RERI link is economically significant and that the real interest rate differential is a reasonable approximation of the expected rate of depreciation over longer horizons. More recently, Khairman and Chinchwadkar (2015), did a country-by-country cointegration analysis of India and a number of bilateral trade partners and found the RERI relationship not to hold, but after introducing structural breaks in the analysis, found robust results that support the RERI relationship in the long run.

3. Theoretical Real Exchange Rate and Real Interest Rate (RERI) Model

The traditional derivation of the RERI relationship (see Meese and Rogoff, 1988) using the uncovered interest parity condition (UIP):

$$E_t \Delta s_{it+1} = (i_{it} - i_{it}^{*}) \qquad (1)$$

Where $\Delta s_{it} = s_{it+1} - s_{it}, s_{it}$ is the log of the nominal exchange rate (domestic currency price in terms of a unit of foreign currency) for country *i* at period t, i_{it} is the nominal interest rate for country *i* in period t, an asterisk denotes a foreign magnitude, $E_t$implies the expected conditional operator and $(i_{it} - i_{it}^{*})$ is the interest rate differential. Equation (1) implies that the expected change in spot exchange rate equals the interest differentials of two countries. A percent change in expected nominal exchange rate is equal to the difference between the nominal interest rate in the domestic and foreign country, known as the relative purchasing power parity.

Expected changes in nominal exchange rate ($E_t \Delta s_{it} = s_{it+1} - s_{it}$) and interest rate differentials ($i_{it} - i_{it}^{*}$) are both assumed to be integrated of order zero (denoted as *I*(0)). The nominal exchange rate and nominal interest rate are both assumed to be an I (1) process meaning that both series contain unit roots. The series should become stationary after first difference (Campbell and Shiller, 1987).

The RERI relationship can be derived by combining the Fisher equation $i_{it} = r_{it} + E\pi_{it+1}$ and the expected model of the real exchange rate identity $E_t s_{it} = E_t q_{it} + (E_t \pi_{it} - E_t \pi_{it}^{*})$. Where r_{it} is real interest rate, π_{it} is inflation and q_{it} is the logarithm of real exchange rate.

$$q_{it} = E q_{it+1} - (r_{it} - r_{it}^{*}) \qquad (2)$$

Equation (2) represents the RERI model and shows that the real exchange rate is function of the expected exchange rate and interest rate differential. The real interest rate differential is assumed to be negatively correlated with the real exchange rate (Dornbusch 1976). The expected rate is assumed to be constant since it cannot be observed, and factors used by individuals to form expectations are unknown. The expectation of future rates varies among different individuals and cannot be determined in advance as it remains unknown. Expectations are based on risk factors and time value of money which do not have a mean to measure. However, the expected rate will vary across countries meaning that $Eq_{it+1} = \alpha$ in order to increase the power of the tests (MacDonald and Nagayasu, 1999).

The variant model below of the RERI relationship will be tested instead of using equation (2):

$$q_{it} = \sigma_t + \beta_i (r_{it} - r_{it}^*) + \varepsilon_{it} \qquad (3)$$

The RERI relationship from equation (3) considers the fact that countries in the sample have different characteristics such as the size of the economy, history, demography, etc. Thus $\sigma_t$captures the fixed effect specific to country I, and ε_{it} is the error term. The coefficient β_i is expected to be negative and allows for heterogeneous relationship between the real exchange rate and the real interest rate differential.[3]

4. Data and Methodology

4.1 Data

This paper uses quarterly data from the International Financial Statistics of the International Monetary Fund and the Central Bank of Israel over the period 1993 to 2018 for a panel of 12 countries that have adopted an inflation targeting framework: Australia, Canada, Iceland, Israel, Korea, Mexico, New Zealand, Norway, South Africa, Sweden, Thailand, and the United Kingdom. The nominal exchange rates are the bilateral US exchange rate (local currency per US dollar). However, we estimated the real bilateral exchange rates for South Africa and the UK using data from the South African Reserve Bank.

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[3] This study follows the methodology used by MacDonald and Nagayasu (1999).

The Government Bond yield over 10 years is used as a proxy for long-term nominal interest rates. Long-term real interest rates were calculated using the Fisher equation. The expected inflation rate was computed using a two-sided moving average. This means that the expectation of the inflation rate at time t is formed based on information from two periods before and two periods ahead. A traditional approach for smoothing quarterly data is given by: $(X_{t-2} + X_{t-1}$ $+X_t + X_{t+1} + X_{t+2})/5$. The moving average filter mitigates assumed random movements from economic series to highlight the underlying trends and cycles. This technique is mostly used to determine business cycle turning points and reduce random noise while retaining a sharp step response[4].

Empirical results are computed in two steps. The first step is to test for the presence of unit roots in order to determine if the series are stationary or non-stationary and the order of integration. The augmented Dickey-Fuller test is used to test for country-by-country unit root, with the null hypothesis that the series contains a unit root (non-stationary) against the alternative hypothesis that the series does not contain a unit root (stationary). Levin, Lin and Chu (LLC) and Im, Pesaran and Shin (IPS) tests are used for panel unit root tests. The null hypothesis for these two tests is that the series contains a unit root, but under the alternative hypothesis, the tests allow for different degrees of heterogeneity. After unit roots tests have indicated that the series contains a unit root, we test for cointegration. The Johansen methodology is used to analyse country-by-country cointegration and the Pedroni test is used to test for panel cointegration. The null hypothesis of both tests is no-cointegration against the alternative hypothesis of cointegration.

4.2 Methodology

4.2.1 Unit root and Cointegration Tests

Unit root tests are used to determine if variables in the economic model are integrated and what the order of integration is. Unit root tests detect if a data series is stationary or non-stationary before constructing an econometric model. A series is said to be stationary if the mean is constant over time and the autocovariances are time independent.

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[4] See http://www.eviews.com/eviews6/eviews6/eviews6.html

Different types of unit root tests are available for individual time series analysis and panel unit root tests. For individual time series, some of the available tests are the KPSS test with the null hypothesis that the process is $I(0)$, the Phillip Perron test with the null of $I(1)$, the DW test with the null of random walk and $I(1)$, the Dickey-Fuller and the augmented Dickey-Fuller tests with the null of a unit root. For panel unit root tests, the most used are Levin, Lin and Chu (LLC), Im, Pesaran and Shin (IPS) and the Maddala and Wu (MW) tests.

This section will essentially focus on the augmented Dickey-Fuller (ADF) test which is preferred to test for the presence of unit roots for each country; and Levin, Lin and Chu (LLC) and Im, Pesaran and Shin (IPS) tests are used for panel data unit root tests.

4.2.2 Cointegration tests

Cointegration tests are used to know if two series are correlated in the long run in order to determine if a model has an empirical meaningful relationship before making inferences.

There are many methodologies to analyse cointegration such as the Engle and Ganger's two-step procedure, Durbin-Watson (DW) test statistic, and the Phillip-Ouliaris test made from the residual, Pedroni and the Johansen methodology. However, the focus in this section will be on the Johansen methodology. The Pedroni tests are used in this study to analyse country-by-country and panel cointegration respectively.

Johansen methodology[5]

The Johansen test is commonly preferred because of its statistical properties. The test has high power. Starting from the vector auto regression (VAR) re-parameterising:

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \Gamma_2 \Delta X_{t-1} + \ldots + \Gamma_{p-1} \Delta X_{t-p+1} - \Pi X_{t-p} + \varepsilon_t \qquad (18)$$

Where $\Gamma_1 = \Pi_1 - I, \Gamma_2 = \Pi_2 + \Gamma_1, \Gamma_3 = \Pi_3 + \Gamma_2, \ldots..$

$\Pi_2 = I - \Pi_1 - \Pi_2 - \Pi_3 - \ldots - \Pi_p$

The row rank of Π will determine the number of distinct cointegrating vectors. The matrix Π determines the extent to which the system is cointegrated.

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[5] See Johansen, s (1998) and Johansen, S and Juselius, K. (1992).

From the re-parameterising, let consider the first equation of the system:

$$\varDelta X_{1t} = \gamma_{11}\varDelta X_{t-1} + \gamma_{12}\varDelta X_{t-2} + \ldots + \gamma_{1p}\varDelta X_{t-p+1} - \varPi_1 X_{t-p} + \varepsilon_t \qquad (19)$$

Where γ_{ij} is the first row of $\varGamma_1, j = 1, \ldots, p-1$ and $\varPi$ is the first row of $\varPi$. $\varDelta X_{1t}$ and all $\varDelta X_{1t-j}$ are I(0) and ε_t is assumed l(0).

$\varPi = \beta\alpha'$ for suitable m x r matrix $\beta\ and\ \alpha$.

Then $\varPi_1 X_{t-p} = \beta\alpha' X_{t-p}$ and all linear combinations of $\alpha' X_{t-p}$ are stationary.

Where:

$$\alpha' = \begin{bmatrix} \alpha'_1 \\ \cdots \\ \alpha'_p \end{bmatrix}; \beta = \left[\beta_{1,}\ \beta_1 \ldots \beta_t\right] \text{ and } \beta\alpha' = \textstyle\sum_{j=i}^{p} \beta_j\, \alpha'_j$$

Johansen estimates the VAR subject to $\varPi = \beta\alpha'$ for various values of r, using ML, assuming $\mathcal{E}_t \sim iid\ N(0, \varSigma)$:

$$\varDelta X_t = \varGamma_1 \varDelta X_{t-1} + \varGamma_2 \varDelta X_{t-1} + \ldots + \varGamma_{p-1} \varDelta X_{t-p+1} - \beta\alpha' X_{t-p} + \varepsilon_t \qquad (20)$$

The null hypothesis is nocointegration, against the alternative hypothesis of cointegration at same chosen order. If the null of cointegration of order zero (r=0) against cointegration of order one (r= 1) is rejected, one can test for cointegration of order 1 (r=1) against the alternative of cointegration of order 2 (r=2), and so on. The appropriate test statistic is:

$$\lambda_{max}(r,\ r+1) = -Tlog(1 - \tilde{\lambda}_{r-1})$$

Where $\tilde{\lambda}_r$is the r^{th} characteristic root (estimated of) $\varPi$. The asymptotic distribution is not standard (i.e. x^2). In case there is cointegration between the series, one can run a Vector Error Correction Model (VECM).

Pedroni methodology[6]

Pedroni is a residual cointegrated test which exploit the following model:

$$\text{ADF t} = \left(\hat{S}^2 \textstyle\sum_{i=1}^{p} \sum_{t=1}^{t} L_{11i}^{-2} \widehat{\mathcal{E}}_{it_{-1}}^{2}\right)^{-\mathbf{1/2}} \textstyle\sum_{i=1}^{p} \sum_{t=1}^{t} L_{11}^{-2} (\widehat{\mathcal{E}}_{it_{-1}}\, \varDelta\, \widehat{\mathcal{E}}_{it}) \qquad (21)$$

Where $\hat{S}^2$ is the long-run variance, $\widehat{\mathcal{E}}_{it}$ are estimates of $\mathcal{E}_{it}$ from equation (3), L_t is the lower triangle component ofΩ_i, where Ω_i is the long-run covariance matrix which is positive definite

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[6]See Pedroni (1997) and MacDonald and Nagayasu (1999).

$(I_N \otimes \Omega_i) > 0)$ and which can be obtained using $\widehat{\mathcal{E}}_{it}$. Pedroni (1997) shows that the level of distortion of the test become smaller when there are large observations (T), provided that the moving average coefficients are positive.

5. Empirical Results and Discussions

Unit root tests indicate if the process is stationary or non-stationary and determine the order of integration. We use the augmented Dickey-Fuller test for country-by-country unit root tests and Levin, Lin & Chu and Im, Pesaran &Shin for panel unit root tests. Three distinct choices of lag-lengths are used (lag 1, lag 3 and lag 5) in order to examine how they affect the power of the test. After controlling for the presence of unit roots in the process, cointegration analyses can now determine if the series are cointegrated or not. The Johansen and Pedroni tests are used to examine country-by-country and panel cointegration respectively. The Johansen approach for country-by-country cointegration analysis is applied only for countries which have unit root at lag 1 and are integrated of the same order I (1). Pedroni methodology is used to analyse cointegration for a full panel of 12 countries and then a panel of 7 countries, after removing countries which don't have unit root.

5.1 Unit root tests

5.1.1 Country-by-countryunit root tests

The augmented Dickey-Fuller test examines country-by-country unit roots. The null hypothesis of the test is that the process contains a unit root against the alternative that the process does not contain a unit root. The appropriate critical t-statistics values are from Mackinnon (1996). Critical values at 1%, 5% and 10% are respectively -3.51, -2.89 and -2.58. The test is performed for different lag-length for a constant and a constant and trend as well as at level and first difference to determine if the process is $I(1)$ or $I(2)$. Overall for the Real Exchange rate, the series contains a unit root (failed to reject the null) for the majority of countries in the sample at different chosen lag-lengths. Results are provided in Table 1. However, the series do not contain unit roots (stationary) for Iceland at lag 3 with a constant, for Mexico with a constant for lag 1, 3 and 5 and with a constant and trend for lag 3 and 5, and for United-Kingdom at lag 1with a constant.

ADF unit root test shows that the majority of countries are integrated of the same order $I(1)$. But the t-statistics for Israel, Sweden and UK are not significant at lag 5using first difference.

Results are provided in Table 2. The process does not contain a unit root (reject the null of non-stationary) for Israel at lag 1 with a constant and for lag 1 and 3 with a constant and trend; Mexico for lag 1, 3 and 5 with a constant; Norway for lag 3 and 5 with a constant and trend; Thailand at lag 1with a constant. The data series for the majority of countries are *I*(1) expect for Mexico for lag 3 and 5 with a constant; Norway at lag 3 with a constant and trend; and UK for lag 3 and 5 with both a constant and a constant and trend. Country-by-country cointegration tests using the multivariate Johansen methodology will be performed only for countries which are non-stationary at lag 1 and are *I* (1) process. The focus will be on results at lag 1 for cointegration analysis.

Table 1: Unit root tests for real exchange rates (q)

Lags	1		3		5	
Countries	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
			Level			
Australia	-1.28	-2.15	-0.93	-1.72	-0.94	-1.88
Canada	-1.32	-2.67	-1.04	-2.38	-0.61	-1.89
Iceland	-2.13	-2.12	-2.98**	-3.06	-2.20	-2.24
Israel	-1.61	-1.45	-1.21	-1.06	-1.17	-0.95
Korea	-2.66	-2.58	-2.52	-2.43	-2.38	-2.25
Mexico	-2.81***	-3.01	-3.18**	-3.50**	-2.89***	-3.33***
New Zealand	-1.51	-2.03	-1.29	-1.79	-1.45	-2.03
Norway	-2.14	-2.58	-1.55	-1.90	-1.39	-1.80
South Africa	-2.17	-2.11	-0.33	-2.29	-2.10	-2.06
Sweden	-2.56	-2.53	-1.79	-1.76	-2.00	-1.97
Thailand	-1.79	-1.72	-1.31	-1.20	-1.48	-1.36
United Kingdom	-3.10**	-3.07	-2.42	-2.41	-2.75***	-2.74
			First difference			
Australia	-6.16*	-6.15*	-4.82*	-4.89*	-3.34**	-3.42***
Canada	-6.35*	-6.41*	-4.90*	-4.960*	-3.64*	-3.67**
Iceland	-5.16*	-5.12*	-3.90*	-3.87**	-4.67*	-4.63*
Israel	-6.00*	-6.02*	-5.08*	-5.14*	-2.98**	-3.10
Korea	-6.65*	-6.65*	-4.94*	-4.98*	-3.54*	-3.62**
Mexico	-7.63*	-7.62*	-4.52*	-4.53*	-4.28*	-4.28*
New Zealand	-5.51*	-5.52*	-4.14*	-4.18*	-3.43**	-3.50**
Norway	-6.24*	-6.19*	-5.81*	-5.77*	-3.19**	-3.19***
South Africa	-5.82*	-5.80*	-4.22*	-4.21*	-3.29**	-3.30***
Sweden	-6.33	-6.3**	-4.48*	-4.51*	-2.89***	-2.92
Thailand	-5.27*	-5.36*	-4.41*	-4.61*	-3.75*	-4.10*
United Kingdom	-6.81*	-6.77*	-4.00*	-3.97**	-3.06**	-3.01

*, ** and *** show the significant level of acceptance or rejection at 1%, 5% and 10% respectively of the null hypothesis that the series contains a unit root.

Table2: Unit root tests for real interest rate differentials **(r-r*)**

Lags	1		3		5	
Countries	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
Australia	-0.81	-2.45	-0.53	-1.70	-0.35	-1.58
Canada	-0.46	-2.23	-0.21	-2.53	-0.11	-2.33
Iceland	0.75	-1.35	0.61	-1.59	0.69	-1.44
Israel	-2.69***	-3.18***	-2.57	-3.32***	-2.24	-2.75
Korea	-1.77	-3.04	-1.41	-1.90	-1.53	-1.78
Mexico	-3.00**	-1.53	-3.13**	-2.03	-2.88***	-2.42
New Zealand	-2.11	-1.66	-1.98	-1.45	-1.73	-0.99
Norway	-1.64	-2.80	-1.64	-3.70**	-1.41	-3.37***
South Africa	2.0	-1.33	1.90	-1.56	1.63	-0.85
Sweden	-1.11	-2.12	-1.43	-3.15	-0.89	-3.11
Thailand	-2.8***	-2.58	-2.05	-2.17	-1.72	-1.96
United Kingdom	-1.27	0.32	-1.43	-0.64	-1.51	-0.22
			First difference			
Australia	-5.34*	-5.57*	-4.18*	-4.26*	-3.95*	-4.11*
Canada	-5.76*	-5.73*	-3.64*	-3.69**	-3.61*	-3.65**
Iceland	-4.50*	-5.38*	-3.21**	-4.10*	-2.78***	-3.70*
Israel	-5.39*	-5.39*	-5.25*	-5.26*	-4.10*	-4.17*
Korea	-6.44*	-6.46	-5.33*	-5.38*	-3.50**	-3.66**
Mexico	-7.13*	-8.12*	-2.48	-3.20**	-2.34	-3.46***
New Zealand	-5.98*	-6.36*	-3.92*	-4.09*	-3.87*	-4.31*
Norway	-5.17*	-5.11*	-2.98***	-2.96	-3.90*	-3.84**
South Africa	-5.58*	-6.30*	-3.23**	-3.67**	-3.27**	-3.80**
Sweden	-5.08*	-5.03*	-3.47**	-3.55**	-3.86*	-3.94**
Thailand	-6.27*	-6.52*	-3.61*	-3.65**	-2.82***	-2.83
United Kingdom	-3.54*	-4.08*	-1.83	-2.16	-2.05	-2.47

*, ** and *** show the significant level of acceptance or rejection at 1%, 5% and 10% respectively of the null hypothesis that the series contains a unit root.

5.1.2 Panel unit root tests

The LLC and IPS tests are used to examine panel unit roots. For the real exchange rate, results are provided in Table 3, the LLC test shows that the panel has unit root at level for the three chosen lag-lengths with a constant and a constant and trend. However, after first difference, the series becomes stationary for lag 3 and 5 with both a constant and a constant and trend, but not at lag 5 with both a constant and a constant and trend. These results can be explained but the power of the test decreases by adding more lags.

The IPS test shows that for the real exchange rate the panel contains unit root (non-stationary) for the three levels of lags with a constant and a constant and trend and become stationary) after first difference.

Table 3: Panel unit root tests for Real exchange rate (q)

Lags	1		3		5	
Countries	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
Level						
Levin, Lin & Chu	-0.65	-1	-0.13	-0.32	0.69	0.56
Im, Pesaran and Shin	-1.10	-0.48	-0.92	-0.24	-0.32	0.31
Difference						
Levin, Lin & Chu	-13.19*	-13.67*	-6.28*	-5.86*	-0.43	0.84
Im, Pesaran and Shin	-13.63*	-12.78*	9.54*	-8.40*	-6.22*	-4.88*

*, ** and *** show rejection of the null hypothesis that the series contains a unit root respectively at significant levels of 1%, 5% and 10%.

For real interest rate differentials, results are provided in Table 4. The LLC and IPS tests show that for the three chosen lag-lengths with a constant and a constant and trend, the panel has unit root, and the series become stationary after first difference. Based on these results, the conclusion is that the panel unit root test indicate that real exchange rate series contains a unit root.

Table 4: Panel unit root tests for real interest rate differentials (r-r*)

Lags	1		3		5	
Countries	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
			Level			
Levin, Lin & Chu	0.47	-0.18	0.94	0.40	1.63	1.47
Im, Pesaran and Shin	1.09	0.54	1.48	-0.28	2.00	0.66
			Difference			
Levin, Lin & Chu	-15.14*	-17.02*	-4.89*	-4.80*	-2.33*	-1.88**
Im, Pesaran and Shin	-15.40*	-16.04*	-8.32*	-7.34	-7.29*	-6.65*

*, ** and *** show rejection of the null hypothesis that the series contains a unit root respectively at significant levels of 1%, 5% and 10%.

5.2 Cointegration Tests

5.2.1 Country-by-country cointegration analysis

The first condition for the Johansen test is that the series should be non-stationary andintegrated of the same order. Thus the Johansen test is performed for countries which are non-stationary at lag 1 and integrated of order one*I*(1). This means that the number of countries is reduced to 7countries. Results are provided in Table 5.

Countries excluded from the Johansen cointegration analysis because of the results of their real exchange rate series (see Table 1) are Mexico and UK, which is stationary at lag 1and Sweden which is not an*I*(1) process, and for real exchange rate unit root specific country unit root test are Israel, Mexico and Thailand,which are stationary at lag 1 with a constant. Critical values are provided by Mackinnon-Haug-Michelis (1999). The null hypothesis is no cointegration against the alternative hypothesis of cointegration.

Country-by-country cointegration results indicate that there is cointegration between real exchange rate and interest rate differentials, meaning that both series move together in the long-run, for three counties: Korea at a significance level of 5% for both tests Null(max) and Null (Trace) of order 1, Australia and South Africa. Results show that for Australia and South Africa there is cointegration at none at the level of significance of 10%. This can be considered a weak cointegration between both series. However, there is no cointegration between real exchange rate and real interest rate differentials for Canada, Iceland, New Zealand and Norway.

Table 5: Cointegration results for real exchange-real interest rate differentials

	Null(max)		Null (Trace)	
Countries	None	At most 1	R==0	r < 1
Australia	13.30	0.29	13.01***	0.29
Canada	10.59	6.53	14.26	3.84
Iceland	7.06	1.39	5.67	1.38
Israel	-	-	-	-
Korea	18.82*	3.80**	15.02**	3.80**
Mexico	-	-	-	-
New Zealand	8.35	1.50	6.85	1.50
Norway	8.58	2.49	6.09	2.50
South Africa	13.39	1.02	12.37***	1.02
Sweden	-	-	-	-
Thailand	-	-	-	-
United Kingdom	-	-	-	-

*, ** and *** show rejection of the null hypothesis that the series contains a unit root respectively at significant levels of 1%, 5% and 10%.

5.2.2 Panel cointegration test

The Pedroni test is a residual cointegration test used for panel cointegration analysis. The null hypothesis of the test is no cointegration against the alternative of cointegration. The test allows for homogeneity under the alternative hypothesis. The null hypothesis of no-cointegration is rejected if the t-statistics values are smaller than the critical values. The test is performed with no deterministic trend and a deterministic trend with-dimension and between-dimension. Results are provided in Table 6. Under the assumption of no deterministic trend, Panel pp-Statics and Panel ADF-Statistics show that real exchange rate and real interest rate differentials are cointegrated within-dimension at the significant level of 5% and 1% respectively. Only 2 tests out of 7 reject the null of no cointegration. Under the assumption of deterministic intercept and trend, none of the tests indicate that the series are cointegrated. This can be explained by the power of the tests which is affected when adding a deterministic intercept and trend. Thus, the conclusion is that the Pedroni panel cointegration test failed to reject the null hypothesis of no cointegration under the assumption of deterministic trend and deterministic intercept. This implies that real interest rate and real interest rate differentials are not cointegrated. Both series do not move to the same direction in the long run.

Table 6: Panel cointegration results (N=12)

	No deterministic trend		Deterministic intercept and trend	
	Statistics	Weighted statistics	Statistics	Weighted statistics
Common AR coefficients. (within-dimension)				
Panel v-Statistic	-1.52	1.28	-0.58	-0.94
Panel rho-Statistic	-0.63	0.26	0.54	0.58
Panel pp-Statistic	-0.62	-0.91	0.31	0.16
Panel ADF-Statistic	-1.75**	2.05**	-0.95	-0.15
Individual AR coefficients (between-dimension)				
Group rho-Statistic	0.43	-	1.48	-
Group pp-Statistic	-0.10	-	0.98	-
GroupADF-Statistic	- 1.39	-	-0.34	-

*, ** and *** show rejection of the null hypothesis that the series contains a unit root respectively at significant levels of 1%, 5% and 10%.

Table7: Panel cointegration results (N = 8)

	No deterministic trend		Deterministic intercept and trend	
	Statistics	Weighted statistics	Statistics	Weighted statistics
Common AR coefficients. (within-dimension)				
Panel v-Statistic	1.52**	1.28	-0.58	-0.83
Panel rho-Statistic	-0.63	-084	-0.54	0.57
Panel pp-Statistic	-0.62	-0.91	-0.31	0.15
Panel ADF-Statistic	-1.75**	-2.05**	-0.95	-1.03
Individual AR coefficients (between-dimension)				
Group rho-Statistic	0.42	-	1.48	-
Group pp-Statistic	-0.10	-	0.98	-
Group ADF-Statistic	-1.39	-	0.34	-

*, ** and *** show rejection of the null hypothesis that the series contains a unit root respectively at significant levels of 1%, 5% and 10%.

The results of the cointegration test when using a panel of the 8 countries for which contain unit roots (non-stationary) and *l*(1) are provided in Table 7. Under the assumption of no deterministic trend 3 outcomes out of 11 show cointegration between real exchange rate and real interest rate differentials. Under the assumption of deterministic trend, 0 outcomes out of

11 show that the both series are cointegrated. Thus, the conclusion is that the test failed to reject the null of no cointegration with no deterministic trend and with deterministic intercept and trend. The real exchange rate and real interest rate are not cointegrated. The two series do not move together in the long run.

6. Concluding Remarks

This paper examined the long-run relationship between real exchange rate and real interest rate differentials using cointegration methods for the period 1993-2018 using quarterly data for a panel of 12 countries that have adopted an inflation targeting framework. Tests for stationarity and cointegration were computed country-by-country and for the panel. The Johansen cointegration methodology indicated that 3 countries out of 7 were cointegrated at the usual level of significance. However, the panel unit root tests overall have rejected the hypothesis of cointegration, meaning that there is no long relationship between real exchange rate and real interest rate differentials, even though some outcomes within the test has indicated that there is cointegration. Our results are in line with the early work by Meese and Rogoff (1998) and Edison and Pauls (1993) who found no strong support for the relationship between real interest differentials and real exchange rates in the long run and in contrast with findings by authors such as MacDonald and Nagayasu (1999) and Hoffman and MacDonald (2009) in the panel cointegration analysis. Our results in the country-by country case is supported by the findings of Khairman and Chinchwadkar (2015). The study concludes that there is no clear evidence that the real interest rate – real exchange rate relationship in inflation targeting countries are different from other countries with well-developed financial markets.

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