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THE REAL INTEREST RATE DIFFERENTIAL: INTERNATIONAL EVIDENCE BASED ON NONLINEAR UNIT ROOT TESTS

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ABSTRACT

This paper aims at testing international parity conditions by using nonlinear unit root tests advocated by Kapetanios et al. (2003, KSS). Results from the KSS tests based on 17 countries (G7 and 10 Asian countries) overwhelmingly show that the adjustment of real interest rates towards the RIP follows a nonlinear process except for the Malaysian relationships with both the US and Japan. Overall, the empirical results are in favor of RIP using the US and Japan as the center countries but only if nonlinearities are accounted for in the data generating process. Our findings confirm that interest rate differentials, like the real exchange rates reported in recent literature, display a nonlinear mean reversion process.

Keywords: real interest parity, nonlinearities, unit root tests
JEL Classification: F32, F36

1. INTRODUCTION

In recent years, the extent to which the real interest rate is equalized across countries—the real interest rate parity (RIP)—has attracted much attention in the literature. The importance of this hypothesis is well documented in the literature. The monetary approach to balance of payments and the intertemporal model to current accounts are based on the work of Mundell-Fleming which emphasizes international capital mobility and the dynamics at the core of open-economy macroeconomics (Obstfeld, 2001). The RIP is also a key working assumption in various models of exchange rate determination, as in the model developed by Frenkel (1976) and Mussa (1976) which implies that the international parity holds in the long-run. Additionally, several authors have used the RIP criterion as a general indicator of macroeconomic convergence. From the policy perspective, increasing capital mobility has important implications for the effectiveness of macroeconomic policies. Specifically, in a world of perfect capital mobility, fiscal policy has no effect on output at all in a small open economy (Hallwood and MacDonald, 2000)[1]. This result should be of concern for the conduct of any stabilization policy. Yet, the extent of capital mobility even among the advanced economies is by no means a settled issue and therefore warrants further investigation.

The work by Wu and Chen (1998), Crowder (1995) and MacDonald and Taylor (1989), among others, found convincing evidence that is not in favor of RIP[2]. They found systematic deviation from parity although capital controls had been significantly relaxed or completely abolished in high-income countries. On the other hand, the empirical

[1] The argument derived from the Mundell-Fleming model is based on the fact that capital mobility gives rise to an exchange-rate induced crowding effect and thereby diminishes the effectiveness of fiscal policy.

[2] Unlike the earlier studies, these authors based their analysis on a series of unit root tests that are more powerful than the conventional ADF test. They pointed out that one reason for the failure of rejecting the nonstationarity may be due to the lack of power of the standard ADF or its variant.

evidence of Wu and Fountas (2000) and Wu and Chen (1998) for the EU, and Cavaglia (1992) for the OEDC are supportive of the RIP. Wu and Fountas (2000), for example, found that the RIP holds when structural break were allowed in the tests. Indeed, Obstfeld and Taylor (2002), using interest rates for UK, France and Germany from 1870-2000, have showed that the unit root test can be easily rejected in all sub-periods except during the recent float (1974-1986). From the perspective of the Pacific Rim Basin countries, Chinn and Frankel (1995) adopting a different methodology have concluded that, with few exceptions, the RIP holds for this group of countries.

An important feature of the above-mentioned articles is that they are all based on linear unit root and linear cointegration tests[3]. More recently, scholars have turned to nonlinear frameworks. Articles by Holmes and Maghrebi (2004, 2006) and McMillan (2004), for example, have found that the adjustment process towards an equilibrium (attractor point) follows a nonlinear process (e.g. the STAR process). Similarly, Enders and Siklos (2001) have found evidence of asymmetries in nominal interest rates. Meanwhile, McMillan (2004) in his assessment on the long-run relationship between long- and short-term interest rates, has argued for a quicker reversion to the equilibrium when the long-term rate exceeds the short-term UK interest rates. Findings from the papers cited above imply that the speed of the adjustment process is no longer constant. Thus, while the testing procedure for unit root (mean reversion) tests of the standard augmented Dickey-Fuller and the others assumes a linear adjustment process to the equilibrium, that is, the speed of return from a position of disequilibrium is the same

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[3] Some authors have explored the relationship by using panel unit root tests (Holmes, 2002; Wu and Chen, 1998). Panel unit root tests examine the null hypothesis of a unit root for all pooled real interest rate differentials, and rejecting the null does not guarantee that all the series are mean-reverting (Taylor and Sarno, (1998).

regardless of the magnitude of the deviation from the equilibrium, the nonlinear models allow for differing speeds of adjustment back to the equilibrium value[4]. As such, we can expect to find less favorable results on the international parity condition if nonlinearity in DGP is neglected. We also know from Kapetanios et al. (2003), Chortareas, et al. (2002), Taylor (2001) and Sarno (2001)[5] that if the true DGP is nonlinear, the use of a linear model (particularly with low frequency data) can seriously underestimate the speed of adjustment to the long-run equilibrium. In light of this new finding, this article extends the line of research using nonlinear stationarity tests to a set of 17 countries (G-7 and ten Asian countries), most of which have deregulated their financial and goods market.

The purpose of this paper is to determine whether the RIP holds for a group of 17 countries, including the high income countries like the US, Japan, Germany, France, Italy Canada and the UK (G7 countries). The lack of conclusive evidence on the RIP represents the motivation for this study. This article contributes to the existing literature by considering an alternative possibility, namely, that the RIP follows non-linear stationary processes. Specifically, a distinctive feature of this paper is that a new test that has been suggested in Kapetanios et al. (2003; KSS) is deployed to test for nonlinear unit roots. We were motivated by the work of Bahmani-Oskooee et al. (2007), Holmes and Maghrebi (2004, 2006), Chortareas et al. (2002), Taylor (2001), Sarno (2001), to name a few, that has reported strong evidence of non-linearities in the behavior of key macroeconomics variables (e.g. exchange rates, interest rates, and budget deficits, among

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[4] Nonlinearities can arise from transaction costs. Transaction cost can inhibit realignments towards purchasing power parity (PPP), uncovered interest parity (UIP) and RIP. Moreover, recent studies have argued that monetary authorities may react towards inflation and currency appreciation in an asymmetric fashion (see Holmes and Maghrebi, 2006).

[5] Kapetanios et al. (2003) provide an application of their test to real interest rates as well as exchange rates with the US dollar as the numeraire currency for 11 OECD countries. Their analysis based on quarterly frequency data over the 1957-2000 period is able to reject a unit root in many cases.

others)[6]. Recently, two papers by Chortareas et al. (2002) and Bahmani-Oskooee et al. (2007) that use the KSS test have confirmed the presence of nonlinearities in real exchange rates[7]. Further, Ender and Chumrusphonlert (2004) show that a threshold process is very supportive of PPP for most of the Asian countries. They show that asymmetric adjustments on nominal exchange rates play an important role in eliminating deviation from long-run PPP[8]. Similarly, using the STAR-based model, Holmes and Maghrebi (2004) find overwhelming evidence in favor of nonlinearities in the behavior of real interest rate differentials in the ASEAN countries. This later finding appears to suggest that the behavior of rids may be asymmetric because risk perception may vary with changes in the interest rates themselves (see e.g. Pakko, 2000).

The remainder of this paper is organized as follows. Section 2 explains the methodological issue and the data used in the analysis. In Section 3, we present the empirical findings. A summary is provided before conclusions are drawn in Section 4.

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[6] Some examples of recent work on nonlinear models include Sarantis (1999) who examined the dynamic behavior of the exchange rate for the G-10 countries. Holmes and Maghrebi (2004) examined the RIP for five Asian countries using the STAR-type models and Balke and Wohar (1998) on covered interest parity. Sarno (2001) applied nonlinear models to show evidence that the US public-debt behaves in a nonlinear fashion. The paper by Chortareas et al. (2002) using the KSS test has shown the presence of nonlinearities in real exchange rates.

[7] Focusing on real effective exchange rates (REERs) of 23 industrialized countries, Bahmani-Oskooee et al. (2007) found that the REERs in these countries tend to be stationary. Thus, suggesting that real devaluations will affect trade flows in a nonlinear fashion.

[8] The evidence that exchange rate converges to PPP in a nonlinear fashion due to the friction that may arise from transaction costs also suggests that the speed of adjustment of rid is not constant.

II. ECONOMETRIC METHODOLOGY AND THE DATA

The nonlinear unit root test developed by Kapetanios et al. (2003, KSS hereafter) is based on the following exponential smooth transition autoregressive (ESTAR) models:

$$\Delta y_t = \gamma y_{t-1}\left[1 - exp(-\theta y_{t-1}^2)\right] + \varpi_t \tag{1}$$

where y_t is the non-linear time series of interest (in our case, interest rate) and ω_t is an i.i.d error term with zero mean and constant variance. To show that a variable is a stationary process, KSS proposes the following tests to account for the testing of unit root in the presence of non-linearity[9]:

$$\Delta y_t = \delta y_{t-1}^3 + \text{error} \tag{2}$$

In addition, KSS also suggests the following auxiliary regression to correct for plausible serial correlation in the error term:

$$\Delta y_t = \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + \delta y_{t-1}^3 + \text{error}, \tag{3}$$

Notice that in Eq. 3, KSS has augmented the regression with lagged values of Δy_{t-j} which is similar to the standard Dickey-Fuller test. In both of the KSS tests, the null hypothesis to be tested is $H_0 : \delta = 0$ against the alternative $H_1 : \delta > 0$. As shown in Kapetanios et al. (2003), the asymptotic distribution for the *t*-test for H_0: $\delta=0$ in 3 is equivalent to (2). For more details on the theoretical aspects as well as the application of this test, see Kapetanios et al. (2003). The nonlinear approach is expected to provide alternative empirical evidence on the subject matter.

This study employs quarterly frequency data for 17 countries that include both high and middle income countries. Interest rate data were collected covering the period 1977:Q1 to 2002:Q1 from various issues of the International Monetary Fund's

[9] The test is obtained using the first-difference approximation of the ESTAR model.

International Financial Statistics. The sampling period included the introduction of a common European currency (Euro) in 1999 as well the financial crises of the1990s. The inflation rates were based on consumer price indices (CPI) and real interest rates were constructed using the *ex post* form of the Fisher equation[10]. We also constructed two sets of real interest rate differentials (RID_{it}) with the US and Japan each serving as the foreign country. That is, $RID_{it} = \boldsymbol{r_{it}} - \boldsymbol{r_t^*}$, where $\boldsymbol{r_{it}}$ is the real interest rate of country *i* and $\boldsymbol{r_t^*}$ is the real foreign interest rate. The data span as well as the use of short-term interest rates was dictated primarily by the availability of a reliable data set[11]. Further, we employ the short-term (3-month maturity) money market rates sourced from IFS, IMF. The nominal rates were: federal fund rates (US), call money rates (Japan, Germany, Italy, Canada, France, South Korea, Hong Kong, Philippines, and Thailand), lending rates (India) and 3-month interbank rates (UK, Taiwan, Singapore, Malaysia, Indonesia and Sri Lanka). The US and Japan were selected as the base country because of their respective size and influence on the rest of the world in international commerce, finance and macroeconomic coordination.

III. EMPIRICAL RESULTS

Given the mixed evidence in favor of RIP as reported in earlier studies, this paper turns to the nonlinear approach to test for stationarity (mean-reverting) interest rate differentials. For this purpose, we relied on the KSS tests for nonstationarity as discussed in the earlier section. We also applied the standard ADF test to the same set of data for comparison and

[10] Earlier authors found that the similar results using both *ex ante* and *ex post*. It may be shown that under the rational expectation hypothesis, *ex ante* and *ex post* interest rates are equal.

[11] Short-term rather than long-term interest rates are used to avoid any greater influence of risk premium and forecast error associated with the composition of rids. We also note that the availability of data was limited in some of the Asian countries.

the results of the linear ADF unit root tests are displayed in Table 1. It is noteworthy here that for the G-7 countries, only the UK-US and Japan-US pairs show evidence in favor of the parity condition based on the linear unit root tests at conventional significance levels. When Japan is used as the reference country, we find that three pairs (US-Japan, Canada-Japan and UK-Japan) are significant at the 10 percent level or better. We also observed that about 40-50 percent of the US and Japanese pairs reject the null hypothesis in favor of the alternative for the group of Asian countries. When, we apply the more powerful linear unit root tests developed by Elliot et al. (1996) and Ng and Perron (2001), however, the tests did not show any significant change in the empirical results.

All in all, these results suggest little evidence that RIP holds in the countries under investigation. The initial evidence so far might be expected because the acceptance of the null may be due to the low power of unit root tests. This problem, as highlighted in earlier studies, is further magnified by short time spans. As mentioned earlier, the ADF test is widely used in testing statinarity but it is not the most powerful test available. How robust is the evidence when the test's power is increased? We now turn to the nonlinear unit root tests developed by Kapetanios et al. (2003). Following the suggestions of KSS, lag length (p) is determined using the significance procedure as outlined in Ng and Perron (1995). Table 2 presents the results of the KSS tests for the US and Japanese pairs. As can be observed from Table 2, the null of a unit root was easily rejected against the nonlinear stationary alternative for all but two cases. It turns out that the Taiwan and Hong Kong interest rates failed to reject the null even at the 10% significance level by both the KSS(A) and KSS(B) tests. In these two cases, different types of nonlinearity may render the adjustments to equilibrium. In the case of Taiwan, both the linear ADF and PP tests showed reversion towards zero interest rate differentials with respect to the US and Japan and is consistent with the RIP hypothesis.

As mentioned above, the KSS(B) statistics correct for autocorrelation[12]. All in all, the KSS tests yield more favorable support for the RIP compared to the standard ADF unit root tests (Table 1). Given the importance of Japan in trade and investment (particularly in East Asia), it is appropriate to focus on Japan as the base country—real interest rate differentials with respect to Japan. When Japan is used as the anchor country, we arrive at the same conclusion as reported earlier. Thus, it appears that all these countries (except Hong Kong and Taiwan) are integrated with the major financial markets, namely, the US and Japan. In the context of the Asian region, the results from the US pairs and Japanese pairs perhaps indicate that the degree of financial regional integration is not different from the global one. Another interesting finding concerns the UK and the Canadian pairs where we found in favor of bilateral real interest convergence between these two countries and the US. However, this contrasts sharply with the results reported in Wu and Fountas (2000) as we observed that the confirmation of RIP is unaffected when using Japan as the base country for all the G-7 countries.

Hence, the above findings demonstrate the problem with using linear unit root tests as reported in earlier studies, that is, they tend to reject the stationary null in favor of the alternative hypothesis. Specifically, the classical linear unit root tests are not capable of rejecting the null hypothesis in the presence of nonlinearites in the adjustment process because they lack the power. Similar observations are made in Holmes and Maghrebi (2006) using nonlinear cointegration tests for the OECD countries. Additionally, this is

[12] Malaysia imposed a reform package based on capital controls and a fixed exchange rate in September 1999. To check for the robustness of our results due to capital controls, we dropped that data from the post-1999 period for Malaysia. Results (not reported) also failed to reject the null. Therefore, we cannot conclude that the presence of capital control was effective in restricting capital movements and interest rate arbitrage.

also in line with the emerging literature that suggests that the data DGP of some macroeconomic variables follows a nonlinear process.

IV. CONCLUSION

To conclude, we note that earlier studies that utilized linear unit root test for the RIP have had difficulties in verifying long-run convergence in real interest rates. This is because classical linear unit root tests are known to suffer from power deficiency when the data span is short. In this paper a new technique is employed, one that has been developed by Kapetanios et al. (2003), whereby the tests allow the RIP to follow a nonlinear stationary process. For all the 32 pairs of interest rates constructed from both G7 and Asian countries, we found that the hypothesis of real interest rate convergence cannot be rejected after allowing for nonlinearity in the real interest rate adjustments in all but two countries, Hong Kong and Taiwan. Hence, there is stronger evidence in favor of the RIP as real interest rate differentials display non-linear mean reversion when using both the US and Japan as the base countries. An implication of our finding is that the speed of adjustment towards the parity condition is likely to be positively related to the size of the shock, both in the G7 and the majority of the Asian countries. Additionally, we find no evidence to suggest that Asian counties have capital markets that are more closely integrated with Japan than the US.

The abolition of legal restrictions on cross-border capital movements and technological advances that have lowered information and communication costs considerably have all fostered the process of world-wide economic integration. It is therefore clear that the currency crises of the 1990s did not increase market segmentation in all the countries. More important, we also find that the introduction of the Euro has not affected the integration process of the EU with the global markets. Consequently, we may presume that the lack of evidence on the convergence of real interest rates reported in previous studies is due to the low testing power of classical unit root tests and the failure to account for non-linearity in the adjustment to the long-run equilibrium. In this respect, our study strengthens the emerging consensus that RIP converges to its long-run level but the convergence path follows a nonlinear process.

The interest rate differential is an important variable for investors in the foreign exchange market that engages in carry trade. In carry trade, investors borrow in a foreign country at lower interest rates than in their home country and invest their funds in the domestic market (usually in fixed-income securities). Authors like Ho et al. (2005) and Strauss and Wohar (2007), among others, relate rids with the potential for profit from carry trade. Currency trade is unlikely to occur when rids are low but likely to be prevalent when the difference between interest rates across countries increases as the potential for profits rises. Hence, the spread between foreign and domestic interest is important to investors as well. The implication of our findings here is that while such opportunities may exist in the short-run for investors, they tend to disappear in the long-run. Finally, in this study we assumed that the adjustments and alignments to the RIP can be characterized by a smooth transition. As pointed by Holmes and Maghrebi (2004), a very sharp transition from one interest rate to another is possible in some cases. Thus, it would be interesting to consider the possibility of other forms on nonlinearities to test the interest rate parity hypothesis. This leaves avenues for future research.

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Table 1: ADF Stationarity Test on Real Interest Differentials

	RID-US				RID-JAP			
	Lag	Constant	Lag	Trend	Lag	Constant	Lag	Trend
G-7								
US	-	-	-	-	2	-2.873 *	2	-2.870
Japan	2	-2.873 *	2	-2.870	-	-	-	-
Germany	7	-2.322	7	-2.307	8	-1.953	8	-2.366
France	7	-1.313	7	-1.255	4	-1.530	4	-2.120
Italy	2	-1.994	2	-1.958	8	-1.615	8	-1.537
Canada	12	-1.828	12	-1.807	1	-4.013 ***	1	-4.026 ***
UK	4	-3.543 ***	7	-4.182 ***	8	-3.288 **	8	-2.746
Asian-10								
HK	1	-2.465	1	-2.603	2	-2.328	2	-2.496
Korea	4	-2.822 *	4	-2.828	0	-2.785 *	2	-3.056
Taiwan	5	-4.112 ***	5	-4.148 ***	1	-3.898 ***	1	-3.839 **
Singapore	9	-2.801 *	9	-2.735	8	-2.219	5	-2.208
Indonesia	11	-2.573	9	-2.721	9	-2.573	9	-2.453
Malaysia	10	-2.643 *	3	-3.128	3	-2.534	3	-3.002
Philippines	9	-2.419	9	-3.078	9	-2.487	9	-3.274 *
Thailand	9	-2.528	8	-2.887	8	-2.607 *	8	-2.684
India	5	-3.109 **	5	-3.322 *	8	-2.833 *	4	-3.364 *
Sri Lanka	7	-1.487	7	-1.429	5	-2.024	5	-2.068

Notes: Asterisks *, ** and *** denote the significance level at 10%, 5% and 1% respectively. For the ADF test, the null hypotheses that the series contain unit root. The optimal lags are determined based on modified AIC within the maximum range of 12 lags.

Table 2: Detrending Tests of Unit Roots

	RID-US					RID-JAP				
	Ng-Perron			DF-GLS		Ng-Perron			DF-GLS	
	Lag	MZα	MZt	Lag	t-ratio	Lag	MZa	MZt	Lag	t-ratio
G-7										
US	-	-	-	-	-	2	-16.77 [a]	-2.85 [a]	2	-2.93 [a]
Japan	2	-16.77 [a]	-2.85 [a]	2	-2.93 [a]	-	-	-	-	-
Germany	2	-12.24	-2.44	2	-2.43	8	-10.10	-2.23	8	-2.31
France	7	-3.86	-1.25	7	-1.36	4	-6.63	-1.81	7	-2.53
Italy	1	-13.72	-2.58	1	-2.67	4	-14.33 [a]	-2.67 [a]	4	-2.59
Canada	4	-16.25 [a]	-2.84 [a]	4	-2.75 [a]	1	-27.62 [c]	-3.70 [c]	1	-4.00 [c]
UK	1	-6.82	-1.70	1	-1.70	6	-0.85	-0.48	6	-0.53
Asian-10										
HK	1	-2.97	-1.21	1	-1.22	1	-4.23	-1.41	1	-1.46
Korea	1	-20.89 [b]	-3.21 [b]	1	-3.42 [b]	1	-18.49 [b]	-3.04 [b]	1	-3.34 [b]
Taiwan	4	-6.87	-1.85	4	-1.81	4	-7.05	-1.85	4	-1.82
Singapore	5	-6.35	-1.76	5	-1.62	5	-3.50	-1.20	5	-1.28
Indonesia	10	-3.99	-1.33	10	-1.46	5	-11.48	-2.37	5	-2.40
Malaysia	1	-16.22 [a]	-2.84 [a]	1	-2.87 [a]	3	-6.74	-1.83	3	-1.77
Philippines	2	-33.30 [c]	-4.08 [c]	2	-3.78 [c]	2	-37.00 [c]	-4.30 [c]	2	-3.93 [c]
Thailand	1	-24.22 [c]	-3.48 [c]	1	-3.61 [c]	1	-25.09 [c]	-3.53 [c]	1	-3.66 [c]
India	4	-2.29	-1.06	4	-1.13	8	-1.02	-0.66	8	-0.79
Sri Lanka	7	-2.81	-0.97	9	-1.71	5	-5.89	-1.60	5	-1.80

Notes: Alphabets a, b and c denote the significance level at 10%, 5% and 1% respectively. In the DF-GLS test, Elliot-Rothenberg-Stock (1996) modified the ADF tests by detrending the data so that explanatory variables are taken out of the data prior to running the ADF regression. The MZα and MZt statistics advocated by Ng-Perron (2001) are also modified forms of the Phillips-Perron (1988) Zα and Zt statistics that based on the GLS detrended data. Optimal lags are determined based on modified AIC within the maximum range of 12 lags.

Table 3: Nonlinear Unit Root Test Result

Real Interest Rate	US-based			Japan-based		
	KSS(A)	Lag	KSS(B)	KSS(A)	Lag	KSS(B)
G-7 Countries						
US	-	-	-	-5.916***	1	-6.772***
Japan	-5.916***	1	-6.772***	-	-	-
Germany	-6.359***	9	-8.331***	-3.683***	3	-3.630***
France	-4.624***	1	-4.115***	-2.843*	1	-2.741*
Italy	-2.763*	1	-3.155**	-2.531	3	-3.330**
Canada	-6.029***	6	-5.025***	-6.130***	6	-4.910***
UK	-2.618	1	-2.856*	-2.894	2	-3.876***
10 Asian Countries						
HK	-2.151	2	-2.086	-2.256	5	-2.021
Korea	-2.833	1	-3.033**	-3.288**	1	-3.774***
Taiwan	-2.109	1	-1.975	-2.225	3	-1.819
Singapore	-4.821***	1	-5.860***	-4.695***	1	-4.920***
Indonesia	-3.148**	2	-3.863***	-3.116	2	-4.223***
Malaysia	-2.483	1	-2.804*	-3.449**	1	-4.137***
Philippines	-1.968	3	-2.487	-2.038	3	-2.599
Thailand	-3.400**	1	-3.467**	-3.220**	1	-3.634***
India	-4.493***	1	-4.529***	-5.929***	2	-5.908***
Sri Lanka	-3.837***	1	-3.570***	-3.756***	1	-3.389**

Notes: KSS(A) and KSS(B) denote KSS tests as specified in Equation (1) and (2) respectively. The 1, 5 and 10 percent asymptotic null critical values for both KSS tests are –3.48, –2.93 and –2.66, respectively. Asterisks *, ** and *** denote rejection of the unit roots at the 10%, 5% and 1% significance level, respectively.