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Abstract

We test Uncovered Interest Parity (UIP) using LIBOR interest rates for a wide range of maturities. In contrast to other markets, LIBOR markets have minimal frictions which could lead to rejecting UIP. Using panel unit root test suggested by Palm, Smeekes, and Urbain (2010) and cointegration techniques by Westerlund (2007), we find that UIP holds for short-term maturities, when market-specific heterogeneity is controlled for. Furthermore, the estimation results show that the speed of adjustment to the long-run equilibrium is proportional to the maturity of the underlying instrument.

JEL-Code: G120, G150, F310.

Keywords: UIP, LIBOR, panel cointegration.

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1. Introduction

Uncovered Interest Rate Parity (*henceforth* UIP) is one of the most researched topics in international economics. According to the UIP hypothesis, the difference in the return on identical assets from two different countries should be fully offset by the differential of the spot and the expected future exchange rate at the points in time when the interest-bearing assets are bought and redeemed. For the short-term horizon, UIP is rejected due to frictions, like irrational expectations (Mark and Wu, 1998; Frankel and Froot, 1989; Carlson and Osler, 1999), forecast errors (Lewis, 1989; 1995) and/or non-linearities (Sarno, Valente and Leon, 2006; Baillie and Kilic, 2006; Flood and Rose, 1996; Flood and Taylor, 1996 and Bansal and Dahlquist, 2000). Numerous studies examine the importance of these frictions.[1] However, to date no study addresses whether UIP holds if frictions are minimal. We examine this issue using London Interbank Offered Rates (LIBOR). LIBOR is a daily reference rate based on the interest rates paid on unsecured interbank deposits by international banks. As will be explained in some detail in section 2, the LIBOR market provides an environment with minimal economic frictions that may lead to rejection of UIP.

Our paper contributes to the literature in the following ways. First, to the best of our knowledge LIBOR has never been directly used for testing UIP although Juselius and MacDonald (2004), Harvey (2005) and Ichiue and Koyama (2007) have used LIBOR, but only as a proxy for Japanese domestic interest rates. Interestingly, LIBOR is a widely used benchmark for global financial transactions and provides a setup where several of the known frictions responsible for the failure of UIP are absent.

Second, this study tests UIP using fourteen different maturities, ranging from one week to 12-months. Previous studies on UIP mostly used only two or three maturities, such as 3-months, 6-months, or sometimes 12-months, generalizing the findings. The use of several maturities helps us to identify when UIP holds.

Third, we employ panel unit root and cointegration techniques. The UIP literature has extensively adopted unit root and cointegration techniques. However, the use of panel cointegration is relatively new to this area. A panel setup has several advantages. In the

[1] Reviews can be found in Froot and Thaler (1990), MacDonald and Taylor (1992), Flood and Taylor (1996), Isard (1996), Pasricha (2006), and Alper, Ardic, and Fendoglu (2009).

first place, it takes into account that financial markets are not isolated. For instance, a shock to the US debt market that increases US interest rates *vis-à-vis* Japanese interest rates will activate carry trade which, in turn, may affect the US Dollar/ Japanese Yen exchange rate. However, the US specific interest rate shock also affects other markets. Panel techniques exploit the multi-currency environment to isolate individual currency-specific effects. The within transformation, used to isolate the currency specific effect, may lower the correlation between the series, hence a panel set-up helps in mitigating the multicollinearity problem. Moreover, a panel approach yields efficiency gains and enhances the possibility of estimating the complex dynamics. Finally, the increased sample size is expected to improve the power of the tests.

Following most previous studies, we assume perfect foresight with respect to exchange rates. However, our findings deviate from the conclusions reached in most previous UIP studies. First, we conclude that UIP holds for almost all maturities between 7 and 12 months. Furthermore, the speed of adjustment of the exchange rate due to a shock in the interest rates is related to the maturity of the underlying assets, which is not in line with the efficient market hypothesis.

The remainder of the paper is structured as follow. Section 2 discusses the market structure of LIBOR. Section 3 reviews some previous studies, while section 4 delves into data and methodology issues. Section 5 presents our results. Finally, section 6 offers our conclusions.

2. Market homogeneity and LIBOR

London Inter-Bank Offered Rates (LIBOR) is a widely used benchmark for national and international transactions. Forbes Investopedia estimates that $360 trillion worth of international financial products are benchmarked with LIBOR. Additionally, one trillion dollars of sub-prime mortgages have rates adjustable to LIBOR.[2] LIBOR rates are used in LIBOR market Model (LMM) to produce the LIBOR forward rates.[3] These LIBOR forward rates are essential for pricing financial derivatives and determining a hedging

[2] http://www.investopedia.com/articles/economics/09/london-interbank-offered-rate.asp

[3] Using a stochastic process, LMM predicts the behavior of the LIBOR interest rates based on certain assumptions. Initially proposed by Brace et al. (1997), Miltersen et al. (1997) and Jamshidian (1997), LMM models are being continuously updated.

strategy for investors who hold them. In contrast to quantitative finance, in macroeconomics LIBOR largely remained an unexplored domain for researchers. Exceptions are Mariscal and Howells (2002), Kwan (2009), and Harmantzis and Nakahara (2007). Mariscal and Howells (2002) study the interest rate pass-through from the Bank of England's Policy rate to the GBP (British Pound)-LIBOR. Kwan (2009) examines the post-financial crisis behavior of USD (Dollar)-LIBOR. Harmantzis and Nakahara (2007) provide empirical evidence for a long-range dependence structure in LIBOR using 12 maturities of USD and CHF (Swiss Franc) LIBOR.

LIBOR rates are available in ten currencies: Euro, US Dollar (USD), British Pound (GBP), Japanese Yen (JPY), Swiss Franc (CHF), Canadian Dollar (CAD), and Australian Dollar (AUD), as well as the Danish Kroner (DKK), New Zealand Dollar (NZD), and Swedish Krona (SEK).[4]

The LIBOR markets have minimal frictions that may cause deviations from UIP.[5] Frictions may arise: when assets differ in risk perception (Branson and Henderson, 1985; Frankel 1983; 1984), due to transaction cost (Baldwin, 1990; Dumas, 1992), and due to the irrational noise traders present in the market (Carlson and Osler, 1999; Mark and Wu, 1998; Frankel and Froot, 1989; De Long, Shleifer, Summers and Waldmann, 1990). Specifically in debt markets, the importance of noise traders and the (expected change) in transaction cost determine the market-specific premium. Baldwin (1990) shows that even small transaction cost can induce a relatively broad range of deviations from UIP within which speculative activities will not occur.

Several studies control for frictions originating from the exchange rate side by assuming perfect foresight (Tang, 2010; Bekaert, Wei and Xing, 2007; Chinn and Meredith, 2004; Carvalho, Sachsida, Loureiro and Moreira, 2004). Dealing with other frictions is less straightforward. For example, interest rate differentials calculated for testing UIP are usually based on the assumptions that capital is perfectly mobile and

[4] The British Bankers Association (BBA) started reporting LIBOR for Danish Kroner and New Zealand Dollar from June 16, 2003 and for Swedish Krona from January 23, 2006.

[5] Since LIBOR is based on aggregation of non-binding quotes, as opposed to actual transactions, the possibility of strategic misrepresentation by certain bankers cannot be ruled out. This might explain why most researchers have not used this important information source. However, Michaud and Upper (2008) note that the BBA tries to reduce the incentives for such behavior (and to remove quotes that are untypical for other reasons) by eliminating the highest and lowest quartiles of the distribution and averaging the remaining quotes.

transaction cost are homogenous. Both assumptions are violated if markets are not homogenous. Perfect capital mobility and similar (expected change in future) transaction cost between markets are both unlikely. However, the London interbank market provides currency-specific interest rates that are immune from market-specific heterogeneity. Additionally, the multi-currency set up of LIBOR is ideal for using panel techniques, so that UIP can be estimated accounting for cross currency correlation and isolating the currency-specific effect.

3. Literature review

According to the UIP hypothesis, the differential of the return on two identical assets from different countries should be offset by the differential of the current and the future exchange rates, at the points in time when the interest-bearing asset are bought and redeemed. Denote $r_{i,t}$ and $r^{*}{}_{i,t}$ as a logarithmic gross return at any time *t* for maturity *i* on a domestic and foreign asset, respectively. Similarly, define s_t and s_{t+i} as the logarithmic spot exchange rate at time *t* and *t+i*, respectively. If F_{t+i} is the forward rate for maturity *i* then following Chinn (2007), Covered Interest Rate Parity (CIP) can be described as:

$$(F_{t+i} - s_t) = \alpha + \beta(r_{i,t} - r^{*}_{i,t}) + \varepsilon_{t+i} \quad (1)$$

If investors do not require compensation for uncertainty associated with trading currencies in the future, the expected future spot rate will be same as the forward rate and relationship (1) becomes:

$$[E(s_{t+i}) - s_t] = \alpha + \beta(r_{i,t} - r^{*}_{i,t}) + \varepsilon_{t+i} \quad (2)$$

also known as Uncovered Interest Rate Parity (UIP). $E(s_{t+i})$ is the expected future spot exchange rate after period *i*. In line with the previous literature we assume that individuals have perfect foresight, that means $E(s_{t+i}) = s_{t+i}$, and therefore equation (2) can be modified to:

$$[s_{t+i} - s_t] = \alpha + \beta(r_{i,t} - r^{*}_{i,t}) + \varepsilon_{t+i} \quad (3)$$

For simplicity, the exchange and interest rate differentials are denoted by y_{it} and x_{it}, respectively. Equation (3) then simplifies to

$$y_{it} = \alpha + \beta x_{it} + \varepsilon_{t+i} \quad (4)$$

Surveys by Froot and Thaler (1990), MacDonald and Taylor (1992), Isard (1996), McCallum (1994), and Engel (1996) report a negative beta for UIP at short horizon, contrary to the theoretical prediction of a positive unit coefficient. For instance, Froot and Thaler (1990) report an average beta coefficient of -0.88 for industrialized economies, while McCallum (1994) concludes that beta is typically around -3, while Engel (1996) argues that the representative beta coefficient falls between -3 and -4.

Recent studies have shown that a number of factors, including the functional form and the core characteristics of the underlying instruments defined by identity, maturity, and inherent risks, may influence the results. As the focus of this study is on the short-term horizon, generally defined to be a period less than a year and more than a few hours, this review is limited to studies using short-term instruments only. Appendix 1 offers a summary of several studies focusing on the scope and techniques used for analyzing this relationship.[6] In line with the earlier surveys mentioned, the Appendix shows that many studies fail to provide comprehensive evidence supporting UIP. Although some studies report mixed results, others reject UIP (cf. Mark and Wu (1998); Juselius and MacDonald (2004) and Campbell, Koedijk, Lothian and Mahieu (2007)).

Most studies use domestic interbank or money market rates to test UIP, except for Juselius and MacDonald (2004), Harvey (2005), and Ichiue and Koyama (2007) who employ LIBOR for one or two maturities. These studies have investigated UIP for the Japanese yen and agree that the information content of the JPY-LIBOR rate is superior to the Japanese short-term interest rate, since the money market in Japan was thin and heavily regulated until the late 1980s (Juselius and MacDonald, 2004).

In addition, almost all the studies referred to employ only two or three maturities to generalize their findings. Generally, the short end of the yield curve is more volatile compared to the longer end and the same is true for short-term rates. Therefore, the finding that UIP is rejected at a 3- or 6-month maturity should not be generalized to all maturities. We therefore investigate UIP using several maturities.

[6] More details of progress in this area can be found in recent surveys, such as Chinn and Meredith (2004, 2005), Pasricha (2006), and Alper et al. (2009).

4. Data and Methodology

4.1 Data

We use daily data on LIBOR from January 1, 2001 to December 31, 2008 from the British Bankers Associations' internet archive, which is publicly available.[7] LIBOR rates for seven currencies (US Dollar, British Pound, Euro, Japanese Yen, Swiss Franc, Australian Dollar, and Canadian Dollar) and for fourteen maturities, starting from one-week to twelve-months have been collected. Data on the exchange rate vis-à-vis the US Dollar come from the International Monetary Fund (IMF).[8]

A practical problem with the dataset is that it contains only daily values for the five trading days per week. Therefore, week length has been reduced to five days so that Monday comes immediately after Friday. For missing values, the last quoted value has been used as the current value. In case of an initial missing value, we used the first available value to fill the series backward.

As the movement in the exchange rate is calculated by differencing s_t from s_{t+i}, the use of overlapping data may cause autocorrelation in the error term as pointed out by Harri and Brorsen (2002). We have used unit root and cointegration tests that compute critical values using bootstrapping and hence our basic results will not be affected by this problem.

4.2 Methodology

As shown in Appendix 1, several authors have used unit root and cointegration techniques. Following Tang (2010) and Dreger (2010), we will use panel cointegration to examine UIP. A natural starting point is to test the stationarity of the data used. For this purpose, we employ Palm et al.'s (2010) Cross-sectional Dependence Robust Block Bootstrap (CDRBB) technique as it has advantages over first and second generation of panel unit root tests.

4.2.1 Panel Unit Root Tests

The first generation of panel unit root tests examines the stationarity of a series assuming

[7] http://www.bbalibor.com/rates/historical
[8] http://www.imf.org/external/np/fin/data/param_rms_mth.aspx

that the panel is cross sectionally independent.[9] This assumption is very restrictive for financial markets and for the LIBOR market especially as currency-specific interest rates influence each other. Baltagi et al. (2007) point out that tests which do not account for cross-sectional dependence can be subject to considerable size distortions and therefore tend to over-reject cointegration.

We follow Greene's (2000) recommendation to test cross-sectional independence by using the Breusch and Pagan LM test in panels with long time series. This test exploits contemporaneous correlations using seemingly unrelated regression (SUR). The resulting test statistic has a Chi-square distribution with [N*(N-1)/2] degrees of freedom, where N indicates the number of cross-sections. Table 1 gives the Chi-square statistics for the null hypothesis of independent cross-sections. The null hypothesis is rejected at the one percent level of significance for all maturities, indicating that the first generation of panel unit root tests is inappropriate for making inferences.

Table 1. Breusch-Pagan Lagrange's Multiplier Test of Independence

	Chi-Sq	p-values
1-week	6,692.4*	0.0000
2-week	7,733.4*	0.0000
1-month	8,735.0*	0.0000
2-month	10,475.9*	0.0000
3-month	10,918.0*	0.0000
4-month	10,873.6*	0.0000
5-month	11,029.5*	0.0000
6-month	10,998.1*	0.0000
7-month	11,130.2*	0.0000
8-month	10,084.9*	0.0000
9-month	9,958.0*	0.0000
10-month	9,595.4*	0.0000
11-month	9,497.2*	0.0000
12-month	9,653.7*	0.0000

Breusch and Pagan LM statistics with Null Hypothesis of Cross sections are independent. This test statistics has Chi-square distribution with N(N-1)/2 degrees of freedom. * and ** indicates respectively 1% and 5% level of significance.

Second generation of panel unit root tests relax the assumption of independent cross-sections. To capture the cross sectional dependence between the series, these tests

[9] Notable among the first generation of unit root tests are Levin et al. (2002) [commonly known as LLC], Breitung (2000), Im et al. (2003) [commonly known as IPS], Maddala and Wu (1999) [Commonly known as Fischer Test], Harris and Tzaralis (1999), Hadri (2000) and Sarno and Taylor (1998a, 1998b).

model the unobserved common factor across units.[10] Underlying this technique is the premise that variability among observed variables can be described by a potentially lower number of unobserved variables, called 'factors'. These common factors are assumed to account for the variation and co-variation across a range of observed phenomena.

However, the second-generation tests require panels with moderate or large number of cross-sections with long time series. In addition, these tests can only deal with common factor structures and contemporaneous dependence. Importantly, as we use a panel with six cross-sections only, also the application of a second-generation test would be inappropriate.

The CDRBB test[11] does not entail modeling the temporal and/or cross sectional dependence structures as it uses block bootstrapping. Moreover, the inferences from this test are valid under a wide range of possible data generating processes, which makes it an appropriate tool for dealing with the fixed number of cross-sections and large time series asymptotics. In a nutshell, the block bootstrap technique is the time series version of a standard bootstrap where the dependence structure of the time series is preserved by dividing data into blocks and then re-sampling the blocks. However, the block length selected can have a large effect on the performance of any designed block bootstrap test. The CDRBB test uses the wrap speed calibration method for selecting the optimal size of the block.

The CDRBB test provides 'pooled (τ_p)' and 'group-mean (τ_{gm})' test statistics, summarized by equations (5) and (6), respectively. N and T are the number of cross sections and time observations, respectively, and y_{it} can refer to exchange rate and interest rate differential series. The 'pooled' statistics presume that the members of the panel have the same autoregressive coefficient, which is quite restrictive. In other words, the statistics are obtained by pooling information without considering the individual member's characteristics. The 'group mean' test statistics, on the other hand, incorporates the members' specific individual autoregressive coefficients. Both statistics take as the null hypothesis that the series is non-stationary *vis-à-vis* the alternative hypothesis that

[10] Widely used second-generation unit root test includes, Bai and Ng (2004), Moon and Perron (2004), Pesaran (2007), and Choi (2005).
[11] Proposed by Palm, Smeekes, and Urbain (2010).

the series is stationary. Rejection of the null hypothesis when the series are in first differences and non-rejection of the null when the series are in levels indicates that the series concerned has a unit root.

$$\tau_p = T \frac{\sum_{i=1}^{N} \sum_{t=2}^{T} y_{i,t-1} \Delta y_{i,t}}{\sum_{i=1}^{N} \sum_{t=2}^{T} y_{i,t-1}^2} \tag{5}$$

$$\tau_{gm} = \frac{1}{N} \sum_{i=1}^{N} T \frac{\sum_{t=2}^{T} y_{i,t-1} \Delta y_{i,t}}{\sum_{t=2}^{T} y_{i,t-1}^2} \tag{6}$$

4.2.2 Panel Cointegration

Cointegration is essentially a method to detect the long-run relationship between integrated series. UIP requires a positive long-run relationship between interest and exchange rate differentials. Until recently, the literature has largely adopted residual based panel cointegration tests, like those proposed by Pedroni (1999; 2004), McCoskey and Kao (1998; 1999). However, we adopt the Westerlund (2007) error correction based procedure for testing cointegration for two reasons. First, it presupposes that regressors are weakly exogenous. In line with this presumption, the UIP hypothesis assumes that the causality runs contemporaneously from the interest rate to the exchange rate only. Second, this procedure provides robust critical values for the test statistics by applying bootstrapping which accounts for the cross sectional dependence.

$$\Delta y_{it} = \delta_i d_t + \alpha_i (y_{i,t-1} - \beta_i' x_{i,t-1}) + \sum_{j=1}^{p_i} \gamma_{1ij} \Delta y_{i,t-j} + \sum_{j=0}^{p_i} \gamma_{2ij} \Delta x_{i,t-j} + u_{it} \tag{7}$$

Westerlund (2007) suggests a panel cointegration test based on the error correction mechanism (ECM). As shown in Equation (7), d_i is the currency specific deterministic component, δ_i is the associated parameter, α_i is the speed of adjustment for the error correction term, β_i is the cointegrating vector while x_{it} and y_{it} are interest and exchange rate differentials, respectively. It is important to note that the cointegrating vector β_i is not separately identified here. The choice of the appropriate number of leads and lags, given by p_i, could transform u_{it} into white noise.

The null hypothesis of the cointegration test is $\alpha_i = 0$, which indicates no cointegration of the variables. Any value of α_i less than zero, leads to the rejection of the null. The statistics P_α and P_τ test the alternative hypothesis that the panel is cointegrated as a whole.[12] Asymptotically, these statistics have a limiting normal distribution and they are consistent. However, Westerlund (2007) points out that tests for P_α have higher power than those for P_τ in samples where T is substantially larger than N.

4.2.3 Estimates for Long-run Relationship

To specify the long-run relationship between cointegrated series, various estimation techniques have been proposed discarding ordinary least squares (OLS). Chen et al. (1999) have investigated the finite sample properties of OLS as well as the bias corrected OLS estimators and its t-statistics. They find that the bias corrected OLS estimator does not improve over the OLS estimator in general and alternatives, such as the Fully Modified OLS (FMOLS) estimator or the Dynamic OLS (DOLS) estimator, should therefore be considered for cointegrated panel regressions. Following the suggestion of Kao and Chiang (2001), we use both panel FMOLS and DOLS. OLS and the bias corrected OLS results are provided in Appendix 2 for comparison purposes.

The FM-OLS and DOLS estimators provide two forms of estimates. First, by restricting the slope parameter across individual members to be common ($\beta_i = \beta$), the estimates obtained are called homogenous panel estimates. Second, by allowing the slope parameters to differ across individual members the estimates obtained are called

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[12] To capture the individual specific heterogeneity, another set of statistics G_α and G_τ, test the alternative hypothesis that at least one member of the panel is cointegrated. It is also known as Group mean statistics. While the panel statistics are constructed by pooling information the group mean statistics are constructed using individual estimates of coefficients α_i's and its test statistics (t_{α_i}'s) such as $G_\alpha = N^{-1}\sum_i \alpha_i$ and

$$G_{\tau_\alpha} = N^{-1}\sum_i t_{\alpha_i,i}\ .$$

heterogeneous panel estimates. We only report the estimates of the homogenous panel as they are less affected by the small N bias.[13]

The FM-OLS estimator is constructed by correcting the OLS estimator for endogeneity and serial correlation. To remove the nuisance parameters, it employs a semi-parametric correction which results in asymptotically unbiased estimators with fully efficient mixture normal asymptotics such that the inferences from its limiting distribution can be drawn easily. The key to the FM-OLS estimation is the construction of long-run covariance matrix estimators which uses kernel estimates. Originally proposed by Phillips and Hansen (1990) for time series, the FM-OLS estimator has been modified for a panel context by Pedroni (2001), Philips and Moon (1999), and Kao and Chiang (2001).

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \tag{8}$$

$$x_{it} = x_{i,t-1} + \varepsilon_{it}$$

For a specification such as equations (8), where all regressors have a unit root and ε_{it} is white noise, the FM-OLS estimator can be given by:

$$\hat{\beta}_{FM} = \left[\sum_{i=1}^{N} \sum_{t=1}^{T} (x_{it} - \overline{x}_{it})(x_{it} - \overline{x}_{it}) \right]^{-1} \left[\sum_{i=1}^{N} \sum_{t=1}^{T} (x_{it} - \overline{x}_{it}) \hat{y}_{it}^{+} - T\hat{\Delta}_{\varepsilon u}^{+}) \right] \tag{9}$$

where $\hat{\Delta}_{\varepsilon u}^{+}$ is a serial correlation correction factor estimated using kernel estimate.

$$y_{it} = \alpha_i + \beta_i^{'} x_{it} + \sum_{j=-q}^{q} \varsigma_{ij} \Delta x_{it} + v_{it} \tag{10}$$

The dynamic OLS method removes the nuisance parameters by augmenting the lags and leads of the regressors. Using equation (10), the $\hat{\beta}_{DOLS}$ can be estimated directly; it is identically distributed and converges to the same limiting distribution as that of FM-OLS estimators. McCoskey and Kao (1998) formulate the single equation panel DOLS using the initial dynamic OLS method proposed by Saikkonen (1992) and Stock and

[13] The FM-OLS and DOLS estimators both assume that errors are independent across cross-sections which may not true in this case. In addition, the limiting distribution of both estimators follows the sequential limit theory where $T \to \infty$ followed by $N \to \infty$. This assumption is violated in our case, as the number of cross sections (N) is finite. However, estimation techniques for panel-cointegrated systems are still in an evolutionary phase and widely accepted answers to these problems have not yet been provided. Therefore, we apply the DOLS and FMOLS estimators suggested by Kao and Chiang (2001).

Watson (1993) for time series. The proposed estimators provide asymptotically efficient estimates of the cointegrating system. The notations have a similar meaning as in FM-OLS except for q which represents the number of leads and lags to be incorporated in (10).

5. Results and Analysis

For brevity's sake, Table 2 reports pooled statistics of the CDRBB test for the level of the series. The conclusions for group mean statistics are not very different from those based on pooled statistics and are therefore reported in Appendix 2 (see Table A1). Table 2 shows that the null hypothesis of non-stationary cannot be rejected for the exchange rate differential series for maturities from 7 to 12-months. The tests for the first difference of these maturities reject the null hypothesis (not reported), indicating that these series are I(1). Similarly, for the interest rate differentials, the tests do not (do) reject the null hypothesis for all (the first difference of) the interest differentials, indicating the series are I(1). Both exchange and interest rate differentials with maturities between 7 and 12 months are found integrated and therefore subjected to the cointegration test. The other series are ignored, as panel cointegration tests are useful only for integrated series.

Table 2. Pooled Statistics from Block Bootstrap Panel Unit Root Tests (at Level)

	Exchange Rate Differential Series			Interest Rate Differential Series		
	Coeff.	**5% CV**	**P-value**	**Coeff.**	**5% CV**	**P-value**
1-week	-514.9640	-18.5130	0.0000	-2.1430	-7.1530	0.7530
2-week	-268.9480	-16.1890	0.0000	-3.7460	-13.4880	0.8040
1-month	-125.3320	-13.5360	0.0000	-2.9060	-8.1240	0.6540
2-month	-58.3050	-14.2080	0.0000	-2.5120	-7.2110	0.6420
3-month	-35.9690	-15.7740	0.0000	-2.5880	-6.1380	0.5630
4-month	-25.9980	-16.6760	0.0010	-1.6670	-6.5250	0.8020
5-month	-19.1320	-16.2110	0.0150	-1.6350	-7.2410	0.8460
6-month	-16.7350	-15.8500	0.0350	-1.5290	-8.1020	0.8880
7-month	-15.3340	-16.7030	0.0830	-1.3470	-8.4220	0.9190
8-month	-14.4600	-17.3170	0.1380	-1.2320	-8.8660	0.9370
9-month	-13.8440	-17.6860	0.1870	-0.7240	-9.5970	0.9720
10-month	-12.7110	-17.2440	0.2490	-0.5790	-9.7320	0.9790
11-month	-12.1090	-17.9760	0.3420	-1.2700	-10.2690	0.9650
12-month	-11.6320	-17.5410	0.3270	-2.9970	-11.4850	0.9310

Estimated test statistics for equation (5) at level of exchange rate and interest rate differential series. 5% CV indicates robust critical values calculated at 5% level of significance. P-values indicate the corresponding probability values of the calculated test statistics.

Our results show the importance of considering a wide array of maturities. Had we considered, say, maturities of 3 and 6 months only, as most previous studies do, we would have ended up with the conclusion that both series are not integrated and therefore not-cointegrated; such an outcome would therefore have led us to reject UIP as cointegration is a necessary (but not sufficient) condition for UIP to hold.

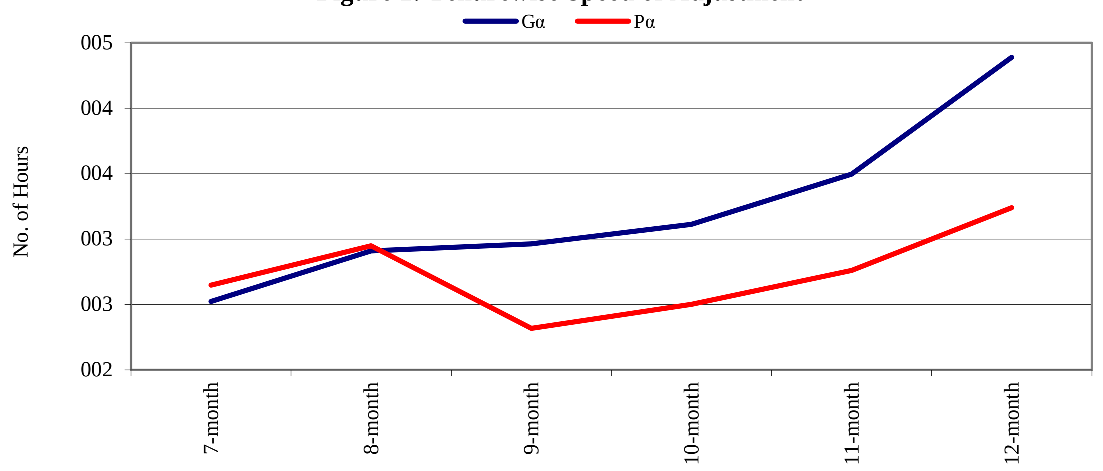
Table 3. Results of the Westerlund Cointegration Test for Homogenous Panel

	P_α			P_τ		
	Value	**Z-value**	**Rob. P-value**	**Value**	**Z-value**	**Rob. P-value**
7-month	-9.065	-6.801	0.000	-4.166	-2.498	0.030
8-month	-8.141	-6.019	0.010	-3.922	-2.289	0.040
9-month	-10.354	-7.892	0.000	-4.836	-3.072	0.020
10-month	-9.593	-7.248	0.000	-4.726	-2.977	0.0100
11-month	-8.697	-6.489	0.030	-4.521	-2.802	0.0500
12-month	-7.408	-5.399	0.030	-3.987	-2.345	0.0400

Estimates of ECM coefficient based on equation (7). The alternative hypothesis of these test statistics are the cointegration relationship exists when the panel taken as whole. 5 and 21 are the maximum number of leads and lags considered for estimation. Values give the estimated values of the coefficients and Z-values are their standardized values. Rob. P-values are the robust probability values calculated using the bootstrap technique. The corresponding values show the level of significance.

We apply the Westerlund (2007) cointegration test to the integrated series. The optimal number of leads and lags to be included in the error correction equation has been selected based on Akaike's Information Criterion (AIC). Moreover, critical values are calculated using bootstrapping. Table 3 shows the panel statistics only. The group-mean statistics are reported in Table A2 in Appendix 2. Robust p-values for both panel statistics P_α and P_τ show that the null hypothesis of no cointegration is significantly rejected at the five percent level of significance. So these tests confirm that there exists a long-run equilibrium relationship between exchange and interest rate differentials. In other words, any shock to a currency specific LIBOR rates vis-à-vis another currency specific rate effects the exchange rates between these currencies in the long run.

Figure 1: Tenurewise Speed of Adjustment



It is important to examine the speed of adjustment of the cointegrated series. Figure 1 shows the adjustment process of the exchange rate for different maturities.[14] The period of adjustment in the exchange rate is found to be increasing in the maturity of the underlying instruments. For the 7-month maturity the adjustment period is around 159 minutes while for the 12-month maturity it is 194 minutes. The group-mean statistics lead to similar conclusions. The relatively slow adjustment in 12-month compared to the 7-month maturity points towards possible arbitrage opportunities, albeit for a very short period. This finding seems in contrast with the efficient market hypothesis and does not support the finding of Bekaert et al. (2007). Using both short and long-term debt instruments, these authors reach the conclusion that the adjustment periods are related to

[14] For G_α slope coefficient see Table A2 in Appendix 2.

currencies and not to the maturities of the underlying instruments.

Table 4. Fully Modified OLS for Long-run Equilibrium Relationship

	Homogenous Panel Slope					
		H0: beta=0		H0: beta=1		
	beta coeff	T-ratio	P-value	T-ratio	P-value	Adj. R-sq
7-month	0.44560	1.91670	0.02760	-2.38490	0.00850	-0.02220
8- month	0.57160	2.40640	0.00810	-1.80320	0.03570	-0.02850
9- month	0.70690	2.88270	0.00200	-1.19510	0.11600	-0.03450
10- month	0.87680	3.42710	0.00030	-0.48180	0.31500	-0.03900
11- month	1.04500	3.93050	0.00000	0.16920	0.43280	-0.04010
12- month	1.19570	4.12590	0.00000	0.6754	0.2497	-0.04000

Long run estimates for homogenous panel based on equation (8). The estimate of long run variance has used KERNEL in COINT 2.0 with a Bartlett Window. Beta coefficient gives the slope of the interest rate differential series. Additionally, a null hypothesis of beta equals to one also tested to check if UIP holds on one to one basis. The corresponding p–values show the level of significance.

For the cointegrated system Tables 4 and 5 show estimates of the long-run relationship, using panel FM-OLS and DOLS estimators, respectively. In the FM-OLS estimates, the non-parametric technique (Bartlett Kernel) is used to estimate the long-run serial correlation factor. In the DOLS estimates, maximum leads of 5 days and maximum lags of 21 days have been used, similar to the cointegration test. The FM-OLS and DOLS estimates show that interest rates differentials are positively related with exchange rate differentials for all maturities considered (7 to 12 months). This finding is in contrast with the results of most previous studies which generally report negative beta coefficients for the short-run horizon.[15] In addition, the null hypothesis that beta equals one cannot be rejected for all maturities, except for a maturity of 7 months. This finding suggests that UIP holds for the short-run horizon if market specific heterogeneity is controlled for.

Although they are very different, the FM-OLS and DOLS methods provide almost the same estimate for the slope coefficients and their level of significance. Monte Carlo simulation results of Kao and Chiang (2001) show that FM-OLS estimates are more biased compared to DOLS in sample with small N. Furthermore, the negative adjusted R-square is in line with the existing literature on UIP which generally reports a low or even negative R-squared (Chinn, 2007).

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[15] Our OLS (see Table A3) and adjusted OLS results (see Table A4) in Appendix 2 also indicate that the slope coefficients are negative and fall in a range generally predicted by empirical research. These results are in line with the findings of earlier studies on UIP.

Table 5. Dynamic OLS for Long-run Equilibrium Relationship

	Homogenous Panel Slope					
	beta coeff	H0: beta=0		H0: beta=1		
		T-ratio	P-value	T-ratio	P-value	Adj. R-sq
7-month	0.49460	2.09880	0.01790	-2.14500	0.01600	-0.13460
8- month	0.63480	2.63580	0.00420	-1.51660	0.06470	-0.17060
9- month	0.80470	3.23640	0.00060	-0.78540	0.21610	-0.20190
10- month	0.97970	3.77630	0.00010	-0.07820	0.46880	-0.24440
11- month	1.13820	4.22080	0.00000	0.51240	0.30420	-0.29170
12- month	1.29500	4.40500	0.00000	1.00360	0.15780	-0.33170

Long run estimates for homogenous panel based on equation (10). 5 and 21 are the maximum number of leads and lags specified for estimation. Beta coefficient gives the slope of the interest rate differential series. The t- statistics and the relevant p-values also provided. The corresponding p–values show the level of significance.

Importantly, this paper shows that previous studies have ignored two key factors while studying UIP. First, different debt market behave differently and should not be considered as identical or homogenous. Second, cross currency dynamics in exchange and interest rates play an important role. Once these factors are accounted for, the UIP hypothesis is confirmed for the short run.

5. Conclusions

The UIP hypothesis as tested in this paper is a joint test of the rational expectations hypothesis and UIP. In line with several previous studies, we assume perfect exchange rate foresight. This paper has number of positive outcomes. Firstly, by controlling for market specific heterogeneity it shows that UIP holds in the short run. Secondly, our result support using a wide range of maturities as inferences based on one or two maturities may be misleading. Thirdly, the tenure wise adjustment behavior in the exchange rates do not support the efficient market hypothesis. We expect some serious debate on this issue, going forwards. Finally, this study shows that the information content of LIBOR is very rich and can be used for meaningful analysis subject to the choice of the proper technique. Until now, very few researchers have taken this information source seriously.

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Appendix 1. Literature Review

Author (s)	Period	Est. Type	Currency/Country Horizon	Interest Rate Variable	Methodology	Conclusion
De Haan, Pilat and Zelhorst .(1992)	1979 M10-1989 M6; Monthly	Time series	Dutch/German Exchange Rate	3-months Euro deposit rates and Amsterdam interbank rate	Unit Roots and Cointegration	Rejected
Baillie and Kilic (2006)	1978- 1998/2002; Monthly	Ind. Time Series	9 currencies	BIS; end month asked rates	Dynamic smooth transition regression	Mixed
Bansal and Dahlquist (2000).	1976 M1 to 1998 M5	Pooled	28 (Emerging and Developed	Spot Exchange Rate, Forward Rate, Interest Rate	Pooled OLS	Mixed
Bekaert, Wei and Xing (2007)	1972-1991; Monthly	Ind. Time Series	3 currencies, US, UK and Germany	Jorion and Mishkin (1991) dataset	VAR Analysis	Mixed
Bruggemann and Lutkepohl (2005)	1985 M1-2004 M12; Monthly	Ind. Time Series	Euro Vs USD	3-m Money Market Rates and 10-years Bonds	VECM	Supports UIP
Carvalho, Sachsida, Loureiro and Moreira (2004)	1990-2001; Monthly	Panel	4 currencies (Argentina, Brazil, Chile and Mexico)	Domestic Interest rates and official exchange rates	fixed and random effects	Mixed
Chaboud and Wright (2005)	1988-2002; high freq. data (5-min interval)	Time Series	JPY, Euro(DM), CHF, GBP against USD	Reuter Quotes at 5 min for ER and Overnight rate	OLS	Mixed*
Chinn and Meredith (2004)	1980-2000; Quarterly	Panel	G-7 countries	3-, 6- and 12- m exchange rate movement;	GMM	Mixed**
Flood and Rose (1996)	1981- 1994; daily	Pooled	Australia; Canada; France; Germany; Japan; Switzerland; & UK all against US	1- and 3- months Interest rate differential ; 1- and 3-months exchange rate movements	SUR technique	UIP holds
Campbell, Koedijk, Lothian and Mahieu (2007)	1970 M1- 2005 M12; Monthly	Individual Time Series	18 currencies against USD	Short term domestic treasury bills or money market rates	Standard and Rolling regression	Rejected
Candelon and Gil -Alana (2006)	1980 M1 - 2001 M12; Monthly	Ind. Time Series	6 Emerging economies	Short-term interest rates	Fractional Integration Technique	Mixed
Harvey (2005)	1989-1998; Quarterly	Ind. Time Series	USD- DM and USD- JPY	I-month LIBOR on USD, DM and JPY	Simple regression	Rejected
Ichiue and Koyama (2007)	1980-2007; Monthly	Pooled	JPY, GBP, CHF and DM against USD	IFS and LIBOR	Regime Switching	Mixed
Tang (2010)	1978Q1-2008Q4	Panel	Asean-5	IFS	Panel Unit root and cointegration	Mixed
Juselius and MacDonald (2004)	1975 M7- 1998 M1	Time series	USD-JPY	Long Bond rates and LIBOR	VAR Analysis	Rejected
Mark and Wu (1998)	1976 M1 to 1994 M1; Quarterly	Ind. Time Series	USD, GBP, DM, JPY	-	VECM	Rejected
Krishnakumar and Neto (2008)	1986 M1 - 2007 M2; Monthly	Time series	USD - CHF	3-month for short term and 1-year for long term interest rates	Threshold vector ECM	Supports UIP

* UIP accepted over very short windows of data that span the time of the discrete interest payment. However, adding even a few hours to the span window destroyed the positive UIP results.; ** Reject in the short run, more support in the long run

Appendix 2. Additional results

Table A1. Group Mean Statistics from Block Bootstrap Panel Unit Root Tests (at Level)

	Exchange Rate Differential Series			Interest Rate Differential Series		
	Coeff.	**5% CV**	**P-value**	**Coeff.**	**5% CV**	**P-value**
1-week	-498.9290	-21.5630	0.0000	-2.2290	-8.2120	0.8190
2-week	-258.8090	-18.6220	0.0000	-4.0840	-14.6340	0.8300
1-month	-120.5840	-15.4160	0.0000	-3.0270	-9.2160	0.7400
2-month	-56.5360	-16.1390	0.0000	-2.5460	-7.8570	0.7170
3-month	-34.6420	-17.8230	0.0000	-2.5880	-7.0560	0.6740
4-month	25.3290	-19.2990	0.0030	-1.6920	-7.4150	0.8580
5-month	-18.6040	-18.7100	0.0530	-1.6570	-8.4430	0.8970
6-month	-16.4860	-18.4700	0.1040	-1.5560	-9.2370	0.9320
7-month	-14.9890	-18.9170	0.1950	-1.3920	-9.6670	0.9490
8-month	-13.9600	-19.6570	0.3050	-1.2450	-10.2740	0.9640
9-month	-13.2610	-19.8830	0.3840	-0.6660	-11.2830	0.9860
10-month	-12.1840	-19.7420	0.4580	-0.5350	-11.4060	0.9900
11-month	-11.5560	-20.7260	0.5720	-1.1520	-11.9880	0.9860
12-month	-11.0560	-20.5360	0.5440	-2.8010	-13.3920	0.9720

Estimated test statistics for equation (6) at level of exchange rate and interest rate differential series. 5% CV indicates robust critical values calculated at 5% level of significance. P-values indicate the corresponding probability values of the calculated test statistics.

Table A2: Results of Westerlund Cointegration Test for Heterogeneous Panel

	G_α			G_{τ_α}		
	Value	**Z-value**	**Rob. P-value**	**Value**	**Z-value**	**Rob. P-value**
7-month	-9.515	-3.077	0.020	-1.737	-1.790	0.070
8-month	-8.250	-2.395	0.050	-1.583	-1.429	0.110
9-month	-8.098	-2.314	0.000	-1.643	-1.570	0.040
10-month	-7.714	-2.107	0.060	-1.646	-1.577	0.100
11-month	-6.863	-1.648	0.070	-1.548	-1.347	0.120
12-month	-5.467	-0.897	0.220	-1.287	-0.731	0.270

Estimates of ECM coefficient based on equation (7). The alternative hypothesis of these test statistics are at least one of the member of the panel is cointegrated. 5 and 21 are the maximum number of leads and lags considered for estimation. Values give the estimated values of the coefficients and Z-values are their standardized values. Rob. P-values are the robust probability values calculated using the bootstrap technique. *and ** indicates respectively 1% and 5% level of significance.

Table A3: OLS for Long-run Equilibrium Relationship

	Homogenous Panel Slope					
		H0: beta=0		H0: beta=1		
	beta coeff	**T-ratio**	**P-value**	**T-ratio**	**P-value**	**Adj. R-sq**
7-month	-0.66190	-12.00470	0.00000	-30.14260	0.00000	0.01220
8- month	-0.67300	-11.68190	0.00000	-29.04070	0.00000	0.01170
9- month	-0.65710	-10.92340	0.00000	-27.54600	0.00000	0.01030
10- month	-0.57640	-9.06740	0.00000	-24.79960	0.00000	0.00720
11- month	-0.44350	-6.59370	0.00000	-21.46170	0.00000	0.00380
12- month	-0.34980	-4.87210	0.00000	-18.79960	0.00000	0.00210

The estimates obtained using static OLS procedure where no correction applied to the long run covariance matrix. Beta coefficient gives the slope of the interest rate differential series. Additionally, a null hypothesis of beta equals to one also tested to check if UIP holds on one to one basis. The corresponding p–values show the probability values.

Table A4: Adjusted OLS for Long-run Equilibrium Relationship

	Homogenous Panel Slope					
		H0: beta=0		H0: beta=1		
	beta coeff	**T-ratio**	**P-value**	**T-ratio**	**P-value**	**Adj. R-sq**
7-month	-0.66540	-2.86360	0.00210	-7.16750	0.00000	0.01220
8- month	-0.67330	-2.83570	0.00230	-7.04750	0.00000	0.01170
9- month	-0.65230	-2.66130	0.00390	-6.74120	0.00000	0.01030
10- month	-0.56570	-2.21220	0.01350	-6.12320	0.00000	0.00720
11- month	-0.43470	-1.63580	0.05100	-5.39910	0.00000	0.00380
12- month	-0.34680	-1.19720	0.11560	-4.64960	0.00000	0.00210

The OLS estimates are obtained after applying bias correction due to long run correlation between the cointegrating equations and the stochastic regressors' innovations. Beta coefficient gives the slope of the interest rate differential series. Additionally, a null hypothesis of beta equals to one also tested to check if UIP holds on one to one basis. The corresponding p–values show the probability values.