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The Threshold Nonstationary Panel Data Approach to Forward Premiums

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Abstract

This paper analyzes the stationarity of forward premiums in the foreign exchange markets. Considering a wide range of countries and contract periods and taking into account cross-sectional correlations and heterogeneities in nonstationary environments, we confirmed mixed evidence of stationary forward premiums. However, mounting evidence to support the stationarity is provided when regime shifts which likely reflect the effects of the Lehman Shock and changing monetary policies are considered. Thus these events seem to have increased the nonstationary element in the premiums, and our further analysis suggests the effect of these events can be captured by interest rates, leaving the covered interest parity condition as a valid long-run concept.

Keywords: Panel unit root tests, structural shifts, forward premiums, Lehman shock

JEL classification: F31, C12

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1 Introduction

Forward exchange rates have increasingly been used by investors in order to reduce market risks. Therefore, many researchers have analyzed the forward premium (fp_t) which can be expressed in natural logarithmic form as a difference between the jth-period maturity forward rate (f_t^j) and the spot rate (s_t) at time t (i.e., $fp_t = f_t^j - s_t$, known as a forward premium/discount and referred to as a forward premium hereafter). Among other factors, previous studies identified that the forward premium is caused by transaction costs (e.g., Engel 1996), market liquidity (Fukuta and Saito 2002), changes in macroeconomic conditions (Nagayasu 2011), and interest rate differentials according to the covered interest parity condition. The nonstationary forward premium indicates that these factors yield a persistent effect on the premiums. Given that changes in spot exchange rates were frequently reported to be stationary in previous studies, the nonstationary forward premium has been pointed out as a source of the forward rate puzzle (Barnhart et al 1999).[1]

While many theoretical models rely on the economic assumption of the stationary forward premium, previous empirical studies have provided quite mixed results.[2] For example, Baillie and Bollerslev (1994) used the fractionally integrated method to study forward premiums for Canadian, German and UK exchange rates against the US dollar. They showed that premiums for Germany and the UK follow a stationary process and those for Canada the nonstationary. But, the absolute value of fractionally differencing parameters for the first two countries was found to be close to 0.5—the threshold level differentiating a stationary and nonstationary process. Similarly, Liu and Maynard (2005) confirmed uncertainty regarding the stationarity of the premium using the currencies of Australia, Canada, France, Germany, Japan and UK against the US dollar. Furthermore, from a panel of premiums against the US dollar for Asia-Pacific countries, Nagayasu (2011) showed that the stationarity of premiums is sensitive to contract maturities; only short-term premiums are

[1] The study on forward premiums is related to the analysis of the unbiasedness of forward rates. The latter can be examined by testing whether forward rates are equal to future spot rates (i.e., $f_{jt} = s_{t+j}$). Thus, what is different from the forward premium study is that the future spot rate (at time $t + j$) is used rather the present spot rate (i.e., s_t). Recently Pippenger (2011) argued that the forward rate puzzle arises from a misspecification of the standard statistical model to test the theoretical model.

[2] Engel (1996) summarizes empirical studies related to forward premiums. An analysis of the forward rate unbiasedness hypothesis also raises mixed evidence. For example, Hai et al (1997) studied a long-run relationship between the forward and future spot exchange rates for advanced countries relative to the US dollar. Their cointegraton tests generally support a stationary relationship by imposing the theoretical parameter restriction. In contrast, Ho (2003) studied the unbiasedness of forward rates in the panel context using the nonstationary Seemingly Unrelated Regression (SUR) method and concluded that the unbiasedness hypothesis does not hold for advanced countries.

stationary.

Against this background, we shall analyze the stationarity of forward premiums, using the US dollar and Euro as numeraire currencies, in order to check if their behaviors are affected by historical events (e.g., Lehman Shock). Previous studies analyzed premiums relative to the US dollar, but they seldom asked any questions about the potential effect of a numeraire currency. Probably MacDonald and Moor (2001) is one exception which considered different numeraire currencies; the Deutschmark (DM) and US dollar. They reported that stability of the premium is sensitive to their choice and is obtained only when the dollar is used as a numeraire.[3]

More importantly, by taking account of possible shifts in forward premiums, we attempt to find reasons for their possible nonstationarity. Indeed, recent studies seem to point out the importance of shifts. For example, Jeon and Seo (2003) reported a breakdown of a cointegrated relationship between spot and forward exchange rates during the 1997 Asian crisis but an immediate recovery soon after this event. Similarly, Sakoulis, Zivot and Choi (2010) argued that the forward rate puzzle is attributable to the lack of consideration of shifts in their analysis of the forward rate unbiasedness hypothesis. In this connection, we employ panel unit root tests which have more statistical power than univariate tests and take account of premium-specific regime shifts. These techniques will be applied to our data set which comprises among many others one-week forward premiums which have not been intensively investigated before despite the fact that most forward contracts are short-term with a typical maturity length of less than one month (see next section).

2 The Description of the Exchange Rate Data

According to the survey conducted by the Bank for International Settlements (BIS 2010), the foreign exchange market has grown rapidly over the years, and gross turnover reached US$ 3,981 billion in 2010—a 20 percent increase since 2007. Out of this total turnover, US$ 475 billion was related to outright forwards when classified by instruments. In terms of the distribution of global foreign exchange market turnover, the US dollar has been a dominant currency (85 percent in 2010), followed by the Euro (39 percent), the Japanese yen (19 percent), and so on.[4] The turnover

[3] More generally, in international finance studies, it is well known that empirical results are sensitive to the choice of numeraire currency. For example, the purchasing power parity (PPP) theory tends to hold less when a numeraire is the currency of a large economy such as the US (e.g., Papell and Theodoridis 2001)

[4] The total of the share of currencies used in the foreign exchange rate market is 200% since each transaction involves two currencies.

for outright forwards can also be classified in terms of maturity length; 46 percent of outright forwards have a maturity of up to seven days in 2010, and 52 percent a maturity from 7 days to one year. Thus, the majority of outright forwards is characterized as short-term in nature and is denominated against the US dollar. This trend has not changed since 1998 when survey data became available.

Against this background, we gather monthly data on forward and spot exchange rates - with a maturity length of one week and one, two, three, six, nine and twelve months - from DataStream. These rates are denominated against the US dollar or Euro, which are the most important currencies for international trade, and cover the sample period from 1999M1 to 2011M3. The beginning of this period is determined by the timing of the introduction of the Euro. Due to the availability of forward exchange rates, we consider advanced countries; namely, Australia, Canada, Czech Republic, Denmark, New Zealand (NZ), the United Kingdom (UK), Japan, Norway, Singapore, Sweden, Taiwan, the United States (US) and the Eurozone.[5]

Table 1 summarizes the average of forward premiums which are calculated as $fp_t = f_t - s_t$ (as defined in Introduction). For premiums with the US dollar as a numeraire, about half - seven - countries have a positive one-week premium and the rest a negative premium. For those with the Euro as a numeraire, the number of negative premiums drops slightly to just 4 cases. Furthermore, the size of premiums tends to increase along with the maturity length. In particular, the average of one-year premiums relative to the Euro is about 60 times larger than that of the one-week premium. Thus, although we do not carry out a further detailed analysis, it follows that effects of, for example, market illiquidity, are more significant in the long-term premium.

Table 2 lists the standard deviation of forward premiums for each country and contract maturity. Generally speaking, the volatility is higher in long-term premiums. For example, a one-year premium relative to both the US dollar and Euro is about 38 times more volatile than a one-week premium. Therefore, higher volatility for the longer-maturity premium seems to be the case regardless of the country and/or numeraire currency.

In addition to these summary statistics, we have checked the cross-sectional dependence of our premiums. The Breusch-Pagan test is carried out to test the null hypothesis of the independence of forward premiums across countries. The test exploits residual correlations from the seemingly unrelated regression (SUR) estimators, and this statistic (Table 3) is distributed as χ^2. Corresponding p-values

[5]Forward rates relative to the UK pound are also available from DataStream; however, they are not available for all our countries or contract maturities during our sample periods.

suggest that this null is strongly rejected in all cases. This result likely reflects that a panel of premiums is based on the same numeraire currency (i.e., either the US dollar or Euro) and thus share common economic shocks. Furthermore, the cross-sectional dependence may arise from the mechanism of modern foreign exchange markets which are closely linked through Information Technology (IT), and whereby any relevant information will spread to other markets instantly. In short, these results suggest that it is important to consider contemporaneous correlations when analyzing the behaviors of the premiums.

Finally, the persistence of data (say, y) on spot and forward exchange rates will be examined by estimating the size of a fractionally differencing parameter, d, which contains information about the order of integration of data. This parameter is often expressed in the process of the Auto-Regressive Fractionally Integrated Moving Average, ARFIMA (p, d, q), in the time-series literature. With zero mean, this is expressed in a parametric form as:

$$\Phi(L) = (1 - L)^d y_t = \Phi(L)\varepsilon_t \tag{1}$$

where L is the lag operator, $\Phi(L) = 1 - \phi_1 L - ... - \phi_p L^p$, and $\Theta(L) = 1 + v_1 L + ... + v_q L^q$. Furthermore, the residual follows the while noise process (i.e., $\varepsilon_t \sim IID(0, \sigma_\varepsilon^2)$). When $d = 0$, an ARFIMA model becomes the standard ARMA model, and the unit root process of exchange rates can be shown when $d = 1$. Granger and Joyeux (1980) showed that the premium is stationary when $|d| < 0.5$ and is nonstationary for $|d| > 0.5$. Since it is difficult to draw a clear conclusion about data stationarity from the conventional unit root tests due to their inability to distinguish between statistical hypotheses in the case of the near unit root, it is useful to estimate the size of d, which does not need to be binary as in the case of the conventional unit root tests.

We estimate it using a semi-parametric approach (Phillips 1999a and 1999b) which is a modified version of Geweke and Porter-Hudak, GPH, (1983). Phillips pointed out statistical deficiencies in the GPH method yielding an inconsistent estimate when $d > 1$. Since exchange rates (in levels) were often reported to be nonstationary in previous studies, Phillips' modification is very useful here. Table 4 shows that spot and forward exchange rates are often nonstationary since $|d| > 0.5$. Exchange rates which are more or less fixed against a numeraire currency tend to have a relatively low value for $|d|$. Examples are the HK dollar which is fixed vis-a-vis the US dollar and the Czech Koruna relative to the Euro. Czech has not joined the Euro zone but has been preparing to do so for some time.

Furthermore, shorter forward rates tend to have a similar value of d to that of spot rates. While a similar size of d between spot and forward exchange rates does not guarantee the presence of cointegration, the significant discrepancy between them indicates nonstationary forward premiums. Thus, our data indicate that longer-term premiums are more likely to be nonstationary.

3 Empirical Results

As part of efforts to seek explanations for the nonstationarity of some forward premiums, we shall attempt to find historical events using an advanced statistical method. A stationarity test was originally developed in order to check the time-series properties of univariate data (Dickey and Fuller 1979). Since then, much progress has been made in a number of directions, and Levin and Lin (1992) is one such example which proposed a panel unit root test. Since researchers often face limited observations, it is said that statistical power will be enhanced by incorporating cross-sectional information. Here the stationarity of forward premiums will be examined using the Lagrangian Multiplier (LM) based panel unit root test (Im et al 2005) which is an extension of the LM unit root test for univariate data and allows us to estimate endogenously the timing of structural breaks, which may differ among premiums.

More specifically, Im et al (2005) have proposed a panel unit root test with a level shift in order to examine the null hypothesis that all series are unit roots against the alternative that at least one of them is stationary. Since breaks are considered under both null and alternative hypotheses, this is not a test to evaluate the presence of breaks. However, obtaining evidence of both 1) nonstationary premiums without consideration of level shifts and 2) stationary premiums with shifts becomes a sign that such breaks and events are significant. In that case, we shall utilize this information in order to identify historical events relevant to the nonstationarity of the premiums.

For N premiums ($i = 1, \ldots, N$) and time ($t = 1, \ldots, T$), the LM panel data approach with a level shift for each premium (fp_{it}) can be summarized as follows.

$$
\begin{aligned}
fp_{it} &= z_{it} + x_{it} \\
z_{it} &= \gamma_{1i} + \gamma_{2i} t + \delta_i D_{it} \\
x_{it} &= \phi_i x_{it-1} + \varepsilon_{it}
\end{aligned} \tag{2}
$$

where $D_{it} = 0$ when $t \leq T_{Bi}$ and $D_{it} = 1$ when $t \geq T_{Bi} + 1$. The residual ε_{it} follows a normal distribution with zero mean and variance σ_i^2, and the timing of breaks are expressed as T_B. Thus this model allows a level shift which can be different among premiums. The null hypothesis of the unit root against the alternative of some stationary variables will be tested by $\phi_i = 1$. In this case, equation (2) suggests that x_{it} and thus fp_{it} follows the unit root process given that ε_{it} is stationary. Alternatively, this null can be tested by $\beta_i = 0$ where $\beta_i = -(1-\phi_i)$ in the following equation which can be obtained from equation (2):

$$\Delta fp_{it} = \beta_i fp_{it-1} - \beta_i \gamma_{1i} + [1-(\beta_i+1)(t-1)]\gamma_{2i} + (\Delta D_{it} - \beta_i D_{it-1})\delta_i + \varepsilon_{it} \quad (3)$$

where Δ is a difference term. The parameters will be estimated by the maximum likelihood method based on the following log likelihood function.

$$\ln L = \sum_{i=1}^{N} (-0.5T \ln 2\pi\sigma_i^2 - 0.5\sigma_i^{-2}\mathrm{SSE}_i) \quad (4)$$

where $\mathrm{SSE}_i = \sum_{t=1}^{T} \{\Delta fp_{it} - \beta_i fp_{it-1} + \beta_i \gamma_{1i} - [1-(\beta_i+1)(t-1)]\gamma_{2i} - (\Delta D_{it} - \beta_i D_{it-1})\delta_i\}^2$. The location of a shift will be determined for each premium and will be estimated on the basis of equation (4).

The LM panel unit root statistic can be calculated like the approach of Im et al (2003). The basic specification can be expressed as:

$$\begin{array}{c} \Delta fp_{it} = \gamma_{2i} + \delta_i \Delta D_{it} + \beta_i S_{it-1} + \sum_{j=1}^{p_i} \rho_{ij} \Delta S_{it-j} + \varepsilon_{it} \\ S_{it-1} = fp_{it-1} - \gamma_{2i}(t-1) - \delta_i D_{it-1} \end{array} \quad (5)$$

In order to evaluate the null $\beta_i = 0$, the cross-sectional average of t statistic $(\bar{t}_{LM,NT}(p))$ will be calculated as:

$$\bar{t}_{LM,NT}(p) = \frac{1}{N} \sum_{i=1}^{N} t_{LM,iT}(p_i) \quad (6)$$

where $t_{LM,iT}(p_i)$ is obtained from each premium equation. The panel LM statistic, which is asymptotically distributed normally with zero mean and unit variance, can be constructed while making adjustments to the mean and variance:

$$\Gamma_{LM}(p) = \frac{\sqrt{N}\left\{\bar{t}_{LM,NT}(p) - \frac{1}{N}\sum_{i=1}^{N}[\iota_{LM,T}(p_i)]\right\}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} V[\iota_{LM,T}(p_i)]}} \sim N(0,1)$$

where $E[.]$ and $V[.]$ are the expected value of the mean and variance respectively which are obtained by stochastic simulations (Im et al 2005). This statistical distribution will not be affected by the presence or location of the level shift since ΔD_{it} (rather than its level) is used here.

For operational purposes, the cross-sectional average of the premiums is removed from original data consistent with the theoretical assumption of the test. This data transformation is necessary since we have obtained evidence of significant cross-sectional correlations in our data (Table 3). In addition, following the suggestion of Im et al (2005), to adjust autocorrelation in equation (5) the lag length is determined by the general-specific approach for each premium with a maximum of three lags, and the grid search method is applied to the trimmed sample period (from $0.1 * T$ to $0.9 * T$) in order to find the location of optimal breakpoints.

Table 5 summarizes the results from this test and suggests that level shifts are indeed important for understanding the behaviors of the forward premiums: regardless of the maturity length, strong evidence of at least one stationary premium is obtained when level shifts are considered. First, LM statistics are calculated based on the abovementioned approach without a level shift dummy (D). Table 5 shows that there is evidence of stationary premiums only for a one-week maturity. For the rest, we failed to reject the null hypothesis. The stationarity of the shorter premiums is consistent with the implication from Table 4 and Nagayasu (2011) which assumed no structural break in the premiums. However, when level shifts are considered, we are able to obtain evidence in favor of stationary premiums for all maturity lengths, and this evidence is not affected by the number of shifts in the test. Given the different conclusions, from these analyses, with and without D, we regard these shifts as a significant factor influencing the behaviors of forward premiums.

Since the alternative hypothesis of the panel LM test is that some premiums are stationary, this test does not give us any information about which series are stationary. Therefore, in order to identify them, we carry out the univariate LM test (Lee and Strazicich 2003, 2004) which assumes one or two breaks for each series (Tables 6 and 7 respectively).[6] The results from our univariate analysis are consistent with those from the panel LM test with regime shifts. There is evidence of stationarity for a majority of premiums using the conventional statistical level.

For illustrative purposes, the break-dates identified by the panel test with one shift are classified by year (Figure 1).[7] The identified break-date differs considerably among premiums, but the shift took place most often in the year 2008 regardless of the numeraire, which coincides with the Lehman Shock. A combination of the occurrence of shifts in years 2008 and 2009 to include both the immediate effects and the aftershocks of the Lehman Brothers bankruptcy suggests that about 30 percent of premiums relative to the US dollar identified these break-dates. This proportion increases slightly for the premiums relative to the Euro.

The timing of shifts may reflect changes in US monetary policy. In response to a

[6] This study considers one and two shifts since Lee and Strazicich (2003, 2004) developed an LM test with a maximum of two level shifts.

[7] The panel test with 2 shifts also shows a similar distribution of potential breaks.

higher than expected increase in inflation caused by a hike in energy and commodity prices worldwide, the US short-term interest rate (the federal fund rate) started to increase from June 2004, raising worries about future uncertainty among investors. Furthermore, in order to facilitate financial stability and US economic recovery, aggressive accommodative monetary policies were implemented leading the federal fund rate to less than one percent in October 2008. Note that Sakoulis, Zivot and Choi (2010) also interpreted shifts as monetary shocks in their study on the forward rate unbiasedness hypothesis.

In order to obtain some statistical evidence of links between the timing of shifts in forward premiums and these two historical events, we conduct a stability test for data on the federal fund rate, the world commodity price (S&P GSCI commodity total return) and the US house price index (Case-Shiller home price index, 10-city composite), all from DataStream. Two tests (Andrews-Quandt and Andrews-Ploberger) are employed to analyze the null hypothesis of no shift in the data. Table 8 shows clear evidence of shifts in the data, and the timing of the shift is found to be 2008 for the commodity price and the federal fund rate although the former is statistically insignificant. A shift-date of 2006, when the sub-prime loan problem became apparent in the US, is identified by house price data. Therefore, this statistical evidence supports our view that the two shifts are related to monetary policies and the effects of the Lehman Shock, but furthermore unlike the Asian crisis (Jeon and Seo 2003), these events generated a permanent effect on the forward premiums.

However, in contrast to previous studies, our results are not found to be very sensitive to the numeraire currency. MacDonald and Moor (2001) found cointegration for the premium against the US dollar but not for the DM premium. They interpreted the lack of cointegration for the DM premiums as evidence of the lack of credibility of the ERM target zone. In this connection, our results suggest the strength of the Euro relative to the DM.

In order to establish a more solid relationship between forward premiums and interest rates which seem to capture the effect of the Lehman Shock and changes in monetary policies, we analyze the covered interest parity (CIP) condition. These events are likely captured by interest rates from our previous analysis, and given the fact that they contain a structural break, evidence in favor of this condition (i.e., the presence of cointegration) suggests the presence of co-breaking where structural breaks occur in each data (i.e., forward premiums and interest rates) at a similar time but their effects vanish in a linear combination of these variables.

Using the panel cointegration test (Westerlund 2007) and the bootstrap method,

Table 9 shows strong evidence in favor of the CIP; the null hypothesis of no cointegration is rejected in all cases by P_α test statistics. This test examines an adjustment coefficient of the error correction terms in the panel data context, and thus like a time-series analysis the large negative test statistic becomes evidence against the null. Since the alternative hypothesis of P_α is that all pairs of the CIP relationship are cointegrated, one could conclude from our results that the nonstationary element of the forward premiums and that of the interest rates are cointegrated. This confirms that a structural break in the forward premiums can be explained by interest rates and follows that the risk premiums (i.e., the residual of the CIP) are stationary and thus do not have a permanent impact on the CIP relationship.

Finally, for presentation purposes, the parameters of the CIP are also presented in Table 9. These parameters are estimated by the Dynamic OLS method (Kao and Chiang 2000) and are correctly signed and statistically significant, thereby providing further evidence of a long-run CIP. This result is also consistent with previous studies (e.g., Taylor 1987).

4 Conclusion

Using advanced nonstationary panel data estimation methods, we have examined the stationarity of forward premiums for advanced countries. Such methods introduce many types of heterogeneities and cross-sectional correlations in the tests. Furthermore, unlike previous studies, forward premiums with a wide variety of maturity length are analyzed in order to seek a conclusion more relevant to actual practices in forward markets.

In short, like previous research, we have confronted difficulties in drawing a clear conclusion; however, generally speaking, one could conclude that forward premiums are stationary when structural breaks are appropriately taken care of. In this regard, unusual historical events seem to increase the level of nonstationarity in the premiums. Therefore, when an analysis is conducted for a reasonable span of data, one often finds nonstationary forward premiums in previous studies. Thus, our findings complement the analysis of the forward rate unbiasedness theory by Sakoulis, Zivot and Choi (2010), and imply that the increased nonstationarity of forward premiums resulting from such historical events is part of the explanation of the forward rate puzzle. However, these impacts on the forward premiums are discussed as more permanent than the Asian crisis.

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Table 1. Description of Forward Premiums (Mean)

	1w	1m	2m	3m	6m	9m	1y
				US$			
Australia	4.20E-04	1.87E-03	3.66E-03	5.45E-03	1.09E-02	1.62E-02	2.15E-02
Canada	2.23E-05	4.82E-05	7.47E-05	9.90E-05	1.86E-04	3.13E-04	4.60E-04
Czech	2.71E-05	7.01E-05	1.23E-04	1.57E-04	2.40E-04	2.24E-04	1.61E-04
Denmark	-5.54E-06	-9.22E-05	-1.74E-04	-2.46E-04	-5.28E-04	-9.04E-04	-1.44E-03
Euro	-5.18E-05	-2.82E-04	-5.50E-04	-8.29E-04	-1.67E-03	-2.62E-03	-3.71E-03
NZ	5.24E-04	2.35E-03	4.58E-03	6.80E-03	1.35E-02	2.01E-02	2.66E-02
UK	2.02E-04	8.58E-04	1.67E-03	2.47E-03	4.85E-03	7.10E-03	9.25E-03
HK	-8.20E-05	-3.50E-04	-6.57E-04	-9.19E-04	-1.48E-03	-1.76E-03	-1.85E-03
Japan	-5.65E-04	-2.53E-03	-4.98E-03	-7.45E-03	-1.49E-02	-2.26E-02	-3.05E-02
Norway	2.57E-04	1.10E-03	2.14E-03	3.16E-03	6.00E-03	8.64E-03	1.11E-02
Singapore	-2.66E-04	-1.18E-03	-2.34E-03	-3.53E-03	-7.03E-03	-1.04E-02	-1.39E-02
Sweden	-4.63E-05	-2.27E-04	-4.49E-04	-6.73E-04	-1.25E-03	-1.61E-03	-1.86E-03
Taiwan	-3.45E-04	-1.30E-03	-2.54E-03	-3.81E-03	-7.64E-03	-1.11E-02	-1.44E-02
Average	**6.98E-06**	**2.58E-05**	**4.29E-05**	**5.22E-05**	**9.06E-05**	**1.22E-04**	**1.09E-04**
				Euro			
Australia	4.79E-04	2.16E-03	4.22E-03	6.29E-03	1.25E-02	1.89E-02	2.52E-02
Canada	7.98E-05	3.36E-04	6.31E-04	9.34E-04	1.86E-03	2.94E-03	4.17E-03
Czech	8.90E-05	3.63E-04	6.83E-04	9.96E-04	1.92E-03	2.85E-03	3.88E-03
Denmark	5.62E-05	2.00E-04	3.86E-04	5.92E-04	1.15E-03	1.72E-03	2.28E-03
NZ	5.84E-04	2.64E-03	5.14E-03	7.64E-03	1.52E-02	2.27E-02	3.03E-02
UK	2.43E-04	1.13E-03	2.21E-03	3.29E-03	6.51E-03	9.71E-03	1.30E-02
HK	-2.11E-05	-5.81E-05	-9.76E-05	-8.11E-05	2.02E-04	8.68E-04	1.87E-03
Japan	-5.02E-04	-2.24E-03	-4.42E-03	-6.61E-03	-1.33E-02	-2.00E-02	-2.68E-02
Norway	3.19E-04	1.40E-03	2.70E-03	4.00E-03	7.68E-03	1.13E-02	1.48E-02
Singapore	-2.08E-04	-8.88E-04	-1.78E-03	-2.69E-03	-5.36E-03	-7.81E-03	-1.02E-02
Sweden	1.50E-05	6.49E-05	1.11E-04	1.65E-04	4.34E-04	1.02E-03	1.86E-03
Taiwan	-2.83E-04	-1.01E-03	-1.97E-03	-2.98E-03	-5.96E-03	-8.47E-03	-1.07E-02
Average	**6.94E-05**	**3.37E-04**	**6.43E-04**	**9.51E-04**	**1.89E-03**	**2.95E-03**	**4.10E-03**

Note: Full sample (1999M1-2011M3). The US/Euro rate is not shown here since it is a reciprocal of the Euro/US rate. The contract maturities are one week (1w), one month (1m), two months (2m), three months (3m), six months (6m), nine month (9m) and one year (1y).

Table 2. Description of Forward Premiums (Standard Deviation)

	1w	1m	2m	3m	6m	9m	1y
				US$			
Australia	3.35E-04	1.49E-03	2.88E-03	4.29E-03	8.60E-03	1.28E-02	1.69E-02
Canada	1.73E-04	7.47E-04	1.47E-03	2.20E-03	4.38E-03	6.48E-03	8.56E-03
Czech	3.27E-04	1.46E-03	2.80E-03	4.18E-03	8.01E-03	1.15E-02	1.47E-02
Denmark	3.02E-04	1.28E-03	2.42E-03	3.56E-03	6.83E-03	9.86E-03	1.27E-02
Euro	2.82E-04	1.24E-03	2.41E-03	3.58E-03	6.99E-03	1.02E-02	1.31E-02
NZ	3.45E-04	1.54E-03	2.95E-03	4.33E-03	8.38E-03	1.21E-02	1.57E-02
UK	2.35E-04	1.06E-03	2.05E-03	3.06E-03	6.04E-03	8.85E-03	1.14E-02
HK	4.93E-04	4.93E-04	9.49E-04	1.40E-03	2.95E-03	4.61E-03	6.40E-03
Japan	3.93E-04	1.72E-03	3.36E-03	5.01E-03	9.84E-03	1.45E-02	1.88E-02
Norway	4.16E-04	1.84E-03	3.58E-03	5.30E-03	1.03E-02	1.49E-02	1.91E-02
Singapore	2.63E-04	1.12E-03	2.11E-03	3.09E-03	5.86E-03	8.40E-03	1.09E-02
Sweden	3.55E-04	1.57E-03	3.05E-03	4.53E-03	8.79E-03	1.28E-02	1.64E-02
Taiwan	1.03E-03	2.84E-03	4.47E-03	6.19E-03	1.04E-02	1.35E-02	1.71E-02
Average	**3.81E-04**	**1.42E-03**	**2.65E-03**	**3.90E-03**	**7.49E-03**	**1.08E-02**	**1.40E-02**
				Euro			
Australia	2.01E-04	8.84E-04	1.69E-03	2.52E-03	5.08E-03	7.59E-03	9.99E-03
Canada	1.68E-04	7.32E-04	1.45E-03	2.17E-03	4.37E-03	6.46E-03	8.42E-03
Czech	2.64E-04	1.16E-03	2.26E-03	3.36E-03	6.53E-03	9.67E-03	1.27E-02
Denmark	6.97E-05	2.75E-04	4.60E-04	6.93E-04	1.21E-03	1.68E-03	2.12E-03
NZ	2.45E-04	1.06E-03	1.99E-03	2.90E-03	5.46E-03	7.75E-03	9.79E-03
UK	1.85E-04	8.02E-04	1.56E-03	2.31E-03	4.55E-03	6.71E-03	8.74E-03
HK	3.06E-04	1.33E-03	2.61E-03	3.90E-03	7.85E-03	1.18E-02	1.56E-02
Japan	2.43E-04	1.05E-03	2.06E-03	3.05E-03	5.96E-03	8.75E-03	1.13E-02
Norway	2.74E-04	1.21E-03	2.31E-03	3.38E-03	6.40E-03	9.11E-03	1.15E-02
Singapore	2.38E-04	9.79E-04	1.87E-03	2.74E-03	5.24E-03	7.53E-03	9.73E-03
Sweden	1.18E-04	5.11E-04	9.79E-04	1.45E-03	2.87E-03	4.26E-03	5.55E-03
Taiwan	1.06E-03	3.07E-03	5.02E-03	7.07E-03	1.23E-02	1.66E-02	2.13E-02
Average	**2.81E-04**	**1.10E-03**	**2.05E-03**	**3.01E-03**	**5.75E-03**	**8.32E-03**	**1.08E-02**

Note: Full sample (1999M1-2011M3). The US/Euro rate is not shown here since it is the same as the Euro/US rate.

Table 3. Breusch-Pagan Test of Independence

	1w	1m	2m	3m	6m	9m	1y
				US$			
χ^2 (78)	2319.042	3166.637	3410.989	3394.386	2674.150	2279.116	2196.319
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
				Euro			
χ^2 (78)	1318.854	1259.225	1289.248	1196.459	1165.527	974.371	931.446
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Full sample. This test examines the null of cross-sectional independency of the data and is based on the seemingly unrelated regression estimators. The statistics are distributed as χ^2 with the degree of freedom equal to $N*(N-1)/2$ where N is the number of premiums.

Table 4. Estimates of Fractionally Differenced Parameters (*d*)

	Spot rate	Forward rate						
US$		1 w	1m	2m	3m	6m	9m	1y
Australia	0.348	0.352	0.365	0.381	0.397	0.445	0.483	0.515
Canada	0.894	0.896	0.902	0.910	0.916	0.937	0.955	0.969
Czech	0.647	0.646	0.645	0.644	0.644	0.649	0.659	0.669
Denmark	0.876	0.877	0.880	0.886	0.891	0.909	0.927	0.945
Euro	0.869	0.870	0.875	0.880	0.886	0.905	0.923	0.940
NZ	0.897	0.897	0.896	0.897	0.898	0.897	0.892	0.886
UK	0.899	0.900	0.904	0.908	0.913	0.926	0.936	0.944
HK	0.649	0.637	0.586	0.547	0.529	0.543	0.588	0.617
Japan	1.112	1.112	1.110	1.109	1.109	1.112	1.117	1.124
Norway	0.650	0.653	0.664	0.679	0.694	0.739	0.779	0.814
Singapore	1.012	1.013	1.022	1.031	1.042	1.067	1.075	1.073
Sweden	0.706	0.708	0.715	0.724	0.734	0.761	0.783	0.801
Taiwan	0.727	0.723	0.704	0.684	0.664	0.612	0.568	0.526
Average	**0.791**	**0.791**	**0.790**	**0.791**	**0.794**	**0.808**	**0.822**	**0.832**
Euro								
Australia	0.983	0.983	0.984	0.984	0.984	0.991	1.003	1.021
Canada	1.008	1.007	1.003	1.001	0.998	1.001	1.001	1.003
Czech	-0.055	-0.028	0.059	0.144	0.207	0.328	0.401	0.456
Denmark	0.830	0.811	0.821	0.883	0.897	0.937	0.957	1.045
NZ	0.879	0.878	0.875	0.872	0.869	0.856	0.842	0.834
UK	0.958	0.957	0.956	0.954	0.952	0.950	0.951	0.954
HK	0.846	0.848	0.852	0.858	0.865	0.888	0.911	0.933
Japan	1.000	0.999	0.999	0.997	0.996	0.999	1.006	1.013
Norway	0.964	0.962	0.956	0.953	0.950	0.957	0.972	0.992
Singapore	1.194	1.194	1.195	1.197	1.199	1.081	1.216	1.226
Sweden	1.073	1.073	1.074	1.075	1.075	1.206	1.084	1.083
Taiwan	1.432	1.436	1.428	1.418	1.406	1.411	1.428	1.427
Average	**0.922**	**0.922**	**0.929**	**0.940**	**0.945**	**0.962**	**0.977**	**0.994**

Notes: Full sample. The parameters are estimated by Phillips' approach (1999a and 1999b). The US/Euro rate is not shown here since it is the same as the Euro/US rate.

Table 5. LM Panel and Individual Unit Root Tests With/Without Level Shifts

	1w	1m	2m	3m	6m	9m	1y
			US$				
No shift	**-3.464**	-1.024	-0.871	-0.620	-1.005	-1.102	-0.896
One shift	**-14.967**	**-8.856**	**-7.132**	**-7.293**	**-6.603**	**-7.191**	**-7.602**
Two shifts	**-29.171**	**-11.485**	**-13.845**	**-13.058**	**-12.575**	**-11.814**	**-12.079**
			Euro				
No shift	**-3.892**	-0.652	-0.534	-0.630	-1.341	-1.128	-0.934
One shift	**-14.141**	**-7.496**	**-6.659**	**-6.741**	**-6.793**	**-6.923**	**-7.406**
Two shifts	**-23.948**	**-16.555**	**-12.872**	**-12.527**	**-12.057**	**-11.549**	**-12.044**

Notes: The test is based on Im et al (2005) and the statistics follow the standard normal distribution.

Table 6. Unit Root Tests for Each Premium (With One Shift)

	1w	1m	2m	3m	6m	9m	1y
				US$			
Australia	**-5.052**	-2.979	*-3.231*	*-3.457*	**-3.914**	**-4.239**	**-4.468**
Canada	**-6.373**	-3.118	-3.029	-2.964	*-3.34*	*-3.53*	*-3.515*
Czech	-2.467	-2.082	-2.639	-2.630	-2.195	-2.456	-2.553
Denmark	**-3.854**	**-4.131**	-3.125	-3.087	-2.73	-2.705	-2.638
Euro	**-6.196**	**-4.406**	*-3.489*	-3.15	-2.794	-3.088	-2.905
NZ	**-4.468**	*-3.327*	*-3.522*	**-3.777**	**-3.88**	**-3.773**	**-3.906**
UK	**-5.045**	-3.084	-2.518	-2.618	-2.255	-2.484	-2.763
HK	-2.828	-2.431	-2.328	-2.727	-2.510	-2.689	-2.845
Japan	*-3.288*	-2.316	-2.257	-2.261	-2.376	-2.282	-2.383
Norway	-2.066	-2.320	-1.653	-2.237	-2.182	-2.386	-2.476
Singapore	-2.881	-3.026	-2.765	-2.836	-3.071	-3.125	*-3.344*
Sweden	-3.156	-3.005	-2.965	-3.038	-2.685	-2.861	-2.884
Taiwan	**-9.564**	**-8.122**	**-7.057**	**-6.599**	**-5.528**	**-5.056**	**-4.844**
				Euro			
Australia	**-5.149**	-3.049	*-3.401*	*-3.363*	**-4.011**	**-4.376**	**-4.686**
Canada	**-7.167**	*-3.283*	*-3.350*	-3.301	*-3.560*	**-3.776**	**-3.779**
Czech	**-4.361**	-2.006	-2.755	-2.695	-2.194	-2.359	-2.559
Denmark	*-3.410*	**-3.775**	-3.004	-2.802	-2.506	-2.608	-2.561
NZ	**-4.208**	*-3.405*	*-3.501*	**-3.715**	**-3.881**	**-3.774**	**-3.914**
UK	**-5.214**	-3.148	-2.718	-2.801	-2.869	-2.625	-2.703
HK	-3.025	-2.572	-2.454	-2.387	-2.586	-2.723	-2.889
Japan	-3.092	-2.143	-2.090	-2.063	-2.220	-2.215	-2.199
Norway	-1.970	-2.160	-1.735	-2.260	-2.196	-2.332	-2.417
Singapore	-3.082	-2.891	-2.796	-2.913	-3.117	-3.163	*-3.389*
Sweden	-2.891	-2.843	-2.832	-2.923	-2.890	-2.700	-2.733
Taiwan	**-9.562**	**-8.141**	**-7.123**	**-6.667**	**-5.616**	**-5.166**	**-4.949**

Notes: Tests are based on Lee and Strazicich (2004). The critical values for the 5 and 10% significance levels are -3.566 and -3.211. Boldfaced figures are statistics significant at the 5% level or higher, and italic figures are at the 10% significance level.

Table 7. Unit Root Tests for Each Premium (With Two Shifts)

	1w	1m	2m	3m	6m	9m	1y
				US$			
Australia	**-8.140**	-3.501	**-3.941**	**-3.855**	**-4.449**	**-4.709**	**-5.012**
Canada	**-7.296**	*-3.352*	*-3.722*	*-3.60*	**-3.884**	**-3.974**	**-3.849**
Czech	**-4.395**	-3.044	*-3.780*	*-3.720*	*-3.564*	*-3.758*	*-3.629*
Denmark	**-8.622**	-2.946	**-4.642**	**-4.123**	**-4.054**	*-3.645*	*-3.523*
Euro	**-11.022**	-2.742	**-4.673**	**-4.033**	**-4.039**	*-3.556*	-3.35
NZ	**-5.620**	**-4.236**	**-4.690**	**-5.038**	**-4.928**	**-4.647**	**-4.722**
UK	**-8.860**	-3.224	**-4.742**	**-4.728**	**-4.258**	*-3.784*	*-3.838*
HK	**-3.877**	**-5.542**	*-3.805*	-3.491	*-3.655*	*-3.525*	*-3.606*
Japan	**-5.902**	-2.778	-3.502	*-3.547*	-3.496	-3.422	**-4.054**
Norway	-2.679	-2.796	-2.472	-2.581	-2.686	-3.014	-3.223
Singapore	**-6.809**	**-4.355**	*-3.767*	*-3.695*	*-3.725*	*-3.700*	**-3.854**
Sweden	**-4.034**	-3.059	*-3.573*	*-3.607*	-3.359	-3.259	-3.213
Taiwan	**-10.098**	**-8.290**	**-7.535**	**-7.072**	**-5.961**	**-5.446**	**-5.104**
				Euro			
Australia	**-8.673**	**-3.968**	**-3.969**	**-3.949**	**-4.487**	**-4.761**	**-5.122**
Canada	**-7.919**	**-4.877**	**-3.847**	*-3.784*	**-4.019**	**-4.111**	**-4.035**
Czech	**-4.491**	*-3.678*	-3.404	*-3.504*	-3.280	-3.464	*-3.538*
Denmark	**-6.255**	**-5.302**	**-4.230**	*-3.708*	*-3.621*	*-3.381*	-3.266
NZ	**-5.388**	**-4.826**	**-4.843**	**-5.010**	**-4.933**	**-4.692**	**-4.774**
UK	**-6.468**	**-4.908**	**-4.761**	**-4.732**	**-4.124**	**-3.906**	**-3.978**
HK	**-4.137**	**-4.706**	**-3.982**	*-3.612*	*-3.790*	*-3.653*	*-3.725*
Japan	**-5.192**	-3.403	-3.214	-3.391	-3.223	-3.221	*-3.733*
Norway	-2.548	-3.072	-2.309	-2.601	-2.766	-2.912	-3.102
Singapore	**-7.454**	**-5.896**	**-4.194**	**-4.227**	**-4.147**	**-3.990**	**-4.008**
Sweden	*-3.743*	*-3.563*	*-3.508*	*-3.598*	-3.476	-3.190	-3.288
Taiwan	**-10.139**	**-8.494**	**-7.509**	**-7.043**	**-5.959**	**-5.466**	**-5.257**
US	**-3.858**	**-3.904**	-2.994	-2.770	-3.111	-3.103	-3.077

Notes: Tests are based on Lee and Strazicich (2004). The critical values for the 5 and 10% significance levels are -3.842 and -3.504.

Table 8. Shift-Dates of World Key Economic Data

Data	Andrews-Quandt	Andrews-Ploberger	Estimated Shift Date
Housing price	173.836 [0.000]	83.105 [0.000]	2006M5
Commodity price	5.678 [0.166]	0.887 [0.246]	2008M6
Federal fund rate	101.760 [0.000]	47.851 [0.000]	2008M8

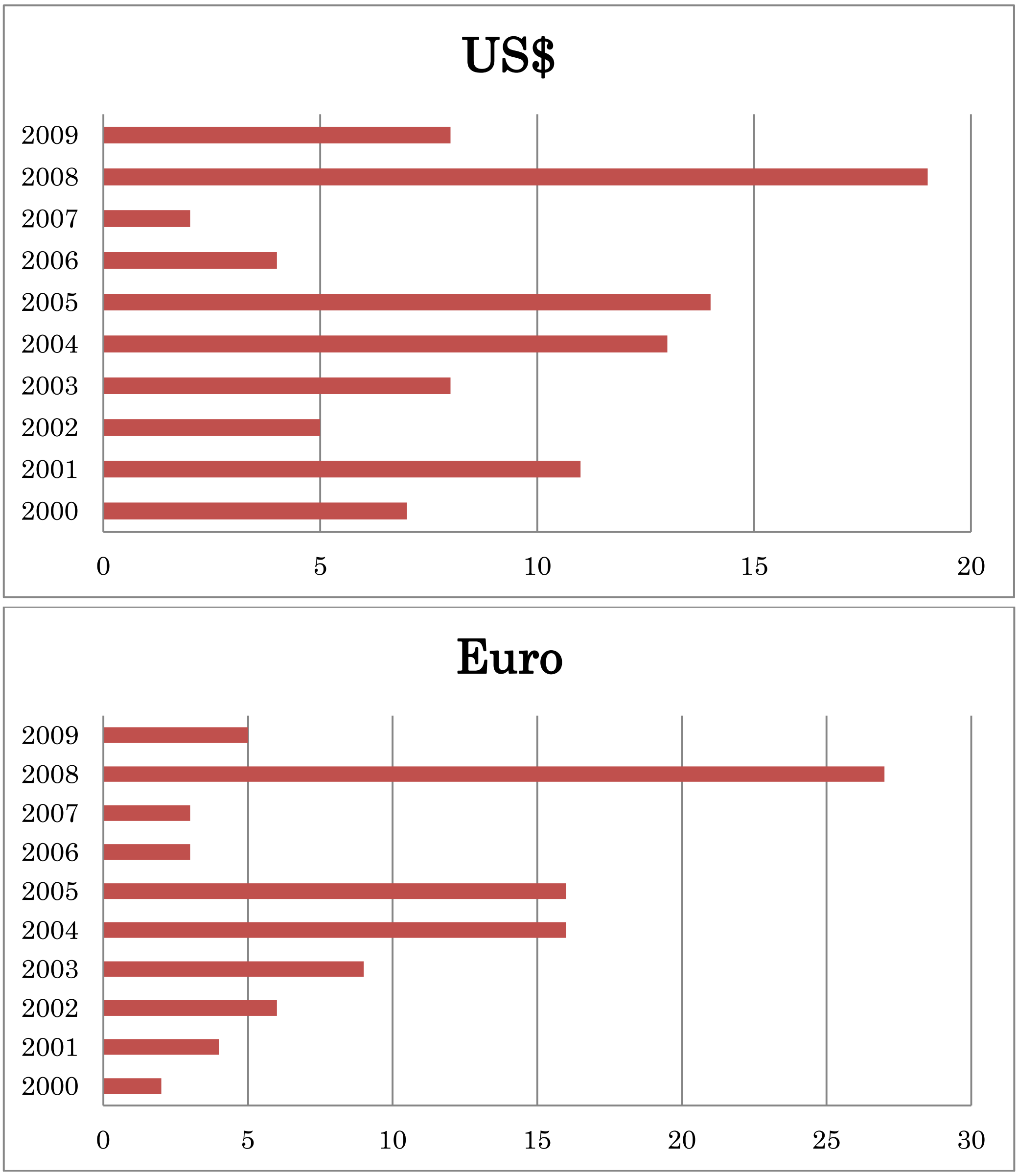
Note: Full sample. P-values are reported in brackets and are obtained via the bootstrap method with 10,000 replications.

Table 9. The Covered Interest Parity Condition

		1w	1m	2m	3m	6m	9m	1y
DOLS estimates					US$			
Int		0.021	0.087	0.171	0.255	0.504	0.745	0.980
	P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Int_us		-0.022	-0.081	-0.158	-0.235	-0.462	-0.683	-0.894
	P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panel cointegration test								
P_α		-26.274	-21.656	-14.714	-13.035	-8.928	-6.809	-6.025
	P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOLS estimates					Euro			
Int		0.020	0.087	0.170	0.254	0.501	0.740	0.974
	P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Int_euro		-0.018	-0.081	-0.158	-0.235	-0.461	-0.677	-0.886
	P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panel cointegration test								
P_α		-17.046	-11.302	-9.282	-7.986	-5.900	-4.597	-3.710
	P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Tests are based on Westerlund (2007) and p-values on the bootstrap method (10,000 replications). The Dynamic OLS (Kao and Chiang, 2000) with 6 lags and leads is used to estimate parameters for interest rates. “Int” contains interest rates of home countries, and “Int_us” and “Int_euro” contains interests of the US and the Euro area respectively.

Figure 1. Frequency of Shift Dates



Notes: Based on one shift in each premium.