The Forward Premium Puzzle And Risk Premiums

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Abstract

This paper re-evaluates the forward premium puzzle using the Euro/US dollar exchange rate. Unlike previous studies, a state-space model is used to measure the significance of this puzzle by estimating the time-specific parameter. Then we provide evidence that the forward premium puzzle became more prominent around the time of the Lehman Shock, and this additional effect of the puzzle is more clearly seen in longer maturity assets. Furthermore, while the risk premium does not tell the whole story about the time-varying puzzle, we show nevertheless that the puzzle can be lessened by this extra factor particularly at times of financial crises.

JEL classification: F31, F36, G01

Keywords: forward premium puzzle, risk premium, time-varying parameters, financial crises

1 Introduction

The forward premium (or discount) puzzle can be regarded broadly as a violation of the Covered Interest Rate Parity (CIRP) condition which suggests an equiproportional relationship between the forward premium and interest rate differentials. Despite the popularity of the CIRP in international finance however, there is mounting evidence against this theoretical prediction (e.g., Fama 1984). According to a survey of previous studies which focused largely on advanced countries (Froot and Thaler 1990), the CIRP relationship is often negative; the average size of this

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parameter reported in previous studies is -0.88. Due to the pervasive implications of this bias to open market economic theories,[1] a lot of research has been carried out in the past to seek explanations of a failure of the CIRP.

Among others, previous studies point to three sources of the violation of the CIRP. One reason is related to the risk premium, which relaxes the assumption of the CIRP about investors' risk neutrality and introduces their risk aversion behaviors in the model. The second reason is connected with the different timing of data quotations. Since research requires several economic indicators and is conducted in an international context, the data are likely recorded at different times. Actually when the consistently quoted data are used for analysis, more evidence is reported in favor of the CIRP (Taylor 1989). Finally, recent research, often referred to as the market microstructure model, emphasizes the role of private information in explaining exchange rate movements (e.g., Burnside et al, 2009). This departs from the standard CIRP model which is based on public information, and when order flow data are included in the model to capture private information, there is evidence of improvements in the interest parity relationship (e.g., Evans and Lyons 2002).[2]

Against this background, we analyze whether or not the forward premium puzzle has become more significant during recent periods which contain a number of financial crises. Furthermore, if this puzzle is found to be more significant, we attempt to explain the relationship between the puzzle and the risk premium.[3]

Previous research on the foreign exchange risk premium often relied on one of the following two methodologies. First, there is a branch of studies incorporating the risk premium using statistical models such as the Generalized Auto-Regressive Conditional Heteroschedasticity (GARCH) model. Notably, Engle et al (1987) model the premium using the GARCH-in-mean, but this type of model faces identification problems, when regarding conditional variance as the premium, because of lack of a theoretical foundation. Second, some researchers (e.g., Lusting and Verdelhan 2007, Kocenda and Poghosyan 2009) opt to employ the model like a Consumption Capital Asset Pricing Model (C-CAPM) to explain the premium, which contains more theoretical mechanisms for explaining the risk premium. However, it is well known in finance literature that consumption growth is not volatile enough to explain finan-

[1] For example, the CIRP is considered the most appropriate economic theory for measuring international financial mobility (Frankel 1992).

[2] Needless to say, evidence of the CIRP does not mean that there are no arbitrage opportunities. It only suggests that on average the CIRP is an appropriate economic concept.

[3] Our focus on the risk premium is partly due to our lack of access to order flow data and high frequency (tick) data which are more sensitive to the timing of quotations.

cial asset returns. Furthermore, the data availability of consumption is limited; even monthly data are not available for research. Thus in order to circumvent some deficiencies discussed above, unlike previous studies, we attempt to introduce a proxy for the risk premium to the standard CIRP.

2 Forward Premium Puzzle

The forward premium puzzle is one of the great unsolved research topics, first pointed out by Fama (1984), in international finance. Fama discussed this puzzle mainly in the context of the relationship between the forward premium and exchange rate changes, and most previous research (see Froot and Frankel 1989, Hall et al 2011) investigated Fama's specification partly because of easier access to data. However, we will conduct research in the framework of the forward premium and interest rates, i.e., the CIRP, which is more often cited in introductory textbooks and does not hinge upon investors' rationality. It is attractive to use this CIRP since the rational expectations assumption is normally required for the Fama specification but is not well supported by actual data (MacDonald and Torrance 1990).

The CIRP implies the equalization of returns from investment at home and abroad under the assumption of no risk premium. The difference in these investment strategies arises only from the currency denomination of financial assets. More specifically, let us consider the following the standard linear time-series CIRP relationship for different forward contract periods (j).

$$fp_t^j = \alpha + \beta_1 \widetilde{i}_t + e_t \tag{1}$$

The fp_t^j is the forward premium ($fp_{tj} = f_{tj} - s_t$) at time t, where the spot and jth-period forward exchange rates are expressed in natural logarithmic form as s and f respectively. The interest rate differential is shown as $\widetilde{i}$ (i.e., $\widetilde{i}_t = i_t^j - i_t^{j*}$), and the asterisk indicates a foreign variable. Greek letters are parameters to be estimated, and e is the residual. When the CIRP is an appropriate concept, a parameter restriction ($\beta_1 = 1$) must be supported by the data.

However, as referred to in the Introduction, the forward premium puzzle is often reported as being present in recent data among advanced countries (i.e., $\beta_1 < 1$); furthermore, this puzzle is more frequently observed in advanced countries than in developing countries (Bansal and Dahlquist 2000; Frankel and Poonawala, 2010).[4] Bansal and Dahlquist (2000), for example, argued that countries with high per capita income and low inflation—the characteristics of advanced countries—tend to suffer more seriously from this bias.

The forward premium puzzle can be expressed in terms of a misspecification bias. In this regard, let us relax the assumption about risk neutrality in the standard CIRP. Then Eq.1 is generalized by incorporating a proxy of the risk premium (Rp) and is re-expressed as:

$$fp_t^j = \alpha + \beta_1 \widetilde{i}_t + \beta_2 Rp_t + e_t \tag{2}$$

When Eq. 1 is estimated incorrectly instead of Eq. 2, there will be a bias in the estimate indicating the presence of a forward premium puzzle. Under regulatory conditions, this phenomenon can be expressed using the OLS estimates of Eq. 2 as:

$$plim\widehat{\beta}_1 = \beta_1 + \beta_2 \frac{Cov(\widetilde{i}_t, Rp_t)}{Var(\widetilde{i}_t)} \tag{3}$$

The omission of Rp brings about a bias which is represented by the second component of the RHS in this equation. This bias remains significant when $\beta_2 \neq 0$ and $Cov(\widetilde{i}_t, Rp_t) \neq 0$, and in such a case, the estimate will deviate from the true value, $\beta_1 = 1$. Furthermore, when the second component of the RHS is negative, the estimate of β_1 will be downwardly biased ($\widehat{\beta}_1 < \beta_1$). Thus a statistical condition of the forward premium puzzle is either $\beta_2 < 0$ and $Cov(\widetilde{i}_t, Rp_t) > 0$, or $\beta_2 > 0$ and $Cov(\widetilde{i}_t, Rp_t) < 0$. Given the presence of the forward premium puzzle often reported in previous studies, it would be expected that introduction of a risk premium would alleviate the puzzle.

There are studies providing indirect evidence of the forward premium puzzle during the recent period by examining the size of deviation from the CIRP, which can be obtained by subtracting interest rate differentials from the forward premium. For example, deviation from the CIRP became increasingly significant from the summer of 2007 by when the sub-prime loan problem had become more apparent, and it was argued that this deviation is linked with credit and counterparty risk (Coffey et al 2009, Levich 2011).

Furthermore, using the Fama-type statistical relationship, Eichenbaum and Evans (1995) argue that small sample problem and price rigidities can cause the forward

[4] See Engel (1996) for a comprehensive survey on the forward premium anomaly.

premium puzzle. Bacchetta and van Wincoop (2010) point to infrequent portfolio adjustments as a reason for the puzzle, and Griffoli and Panaldo (2011) suggest insufficient liquidity in the financial market as an explanation. In this regard, there may be several factors involved in explaining the forward premium puzzle, and thus our attempt to focus on the risk premium may not fully remedy the standard model.

3 Data and preliminary analysis

Our data are monthly and cover the sample period from 1998M11-2012M4 for the Euro/US$ exchange rates (see Appendix).[5] The beginning of the sample period is determined by the timing of the creation of the Euro, and this pair of currencies is chosen since they are most frequently traded by financial institutions in foreign exchange markets (Bank for International Settlements 2010). Furthermore the recent financial crises (i.e., the Lehman Shock and Greek sovereign debt crisis) are deeply rooted in these regions. The interest rates are the London Interbank Offered Rates (LIBOR), the most widely used reference rates for the short-term, and cover maturity lengths of 1, 2, 3, 6, 9 and 12 months (i.e., $j = 1, 2, 3, 6, 9, 12$).[6] While longer forward contracts are available, our main focus goes to relatively short-term rates (i.e., a less than one year maturity) since the majority of forward transactions are of less than one month maturity length (Bank for International Settlements 2010).

In addition, we use the level of financial turmoil as a proxy for the risk premium; the Chicago Board Options Exchange Volatility Index (CBOEV) for the US market and the EURO STOXX 50 Volatility Index (VSTOXXI) for the Euro area. These indices are closely associated with financial crises and follow a similar compilation methodology. Their increases are viewed as representing higher uncertainty or volatility (in the next 30 days) in prices of the benchmark (S&P500 and EURO STOXX 50) indices which are closely linked with option values.[7] We expect that when these variables increase, extra returns (i.e., the risk premium) are required for investment. One advantage of these data is that the data are discrete but give us more timely information about the level of financial chaos compared with, for

[5] All data are downloaded from DataStream.

[6] The quality of the LIBOR has been questioned recently (July 2012) as some banks allegedly indulged in illegal operations in order to control this rate.

[7] See the Chicago Board Options Exchange (2009) about compilation methodology. Our motivation for introducing these variables is similar to one using the GARCH-type model which estimates the conditional variance as a proxy for the time-varying risk premium.

example, credit ratings. This allows us to conduct research without prior knowledge of the exact timing of financial crises.

These proxies, which are used as a representative of the risk premium in each country, are shown in the figure and are summarized in the table. Fig.1 indicates that these proxies are highly and positively correlated with each other pointing to similar periods of financial market turmoil in these markets. Furthermore, high financial uncertainty exists at times of stock market downturns due to the burst IT bubble (2000-01), the September 11 attacks (2001), the aftermath of the Lehman Shock (2008), and the Greek sovereign debt problem (2011-12). Table 1 summarizes the basic statistics of the forward premium and interest rate differentials for a variety of maturity lengths. The average value of these variables is reported to be negative. Furthermore, their variation in terms of the standard error (SE) suggests that interest rate differentials are more volatile than forward premiums.

Table 2 reports correlation coefficients obtained for the interest rate differentials and a proxy for a risk premium (Rp). It turns out that the correlation level between interest rates with different maturities is very high–more than 90%–and furthermore, a positive correlation is obtained between interest rate differentials and Rp. It follows that the risk premium tends to increase at times when different types of monetary policy are implemented in these regions. The correlation level between interest rate differentials and Rp seems to increase along with rises in the maturity length. This may be an indication that longer term rates contain more information about the risk for each financial market as it is composed of more significant investors' expectations (like inflation). Finally, Rp in these regions is highly correlated with one another, suggesting a high level of financial market integration.

As a further preliminary analysis, Table 3 shows the OLS estimates of the CIRP using the Newey-West method in order to make an adjustment for autocorrelation. The estimates are reported to be positive, and thus the severity of the forward premium puzzle seems to be lessened compared with one using older observations which often report a negative sign (Fama 1984, Froot and Frankel 1989). Furthermore, the size of these parameters increases along with maturity length, and that of a 12 month maturity is about 10 times higher than that of a 1 month maturity and approaches a theoretical value of unity. Stronger evidence of the CIRP for longer maturity lengths is consistent with Chinn and Meredith (2004) who raised supportive evidence for the longer-term Uncovered Interest Rate Parity Condition due to the domination of economic fundamentals in exchange rate changes.

We conduct two types of instability test; the Andrews-Quandt and Andrews-

Ploberger tests, in order to analyze the parameter stabilities. The statistics are based on OLS estimates but are adjusted for heteroschedasticity, and in order to examine the null hypothesis that all parameters are invariant over time, p-values are obtained using the statistical method proposed by Hansen (1997). Table 3 reports results from these tests which are conducted for the trimmed sample period, and shows that this null is strongly rejected in all cases.[8]

Furthermore, the table provides evidence of a structural break at the time of the Lehman Shock (2008M9). The break date is identified by the most extreme value of F statistic (i.e., the smallest p-value) within the sample period, and the presence of structural breaks is consistent with a further violation of the CIRP during the recent period (e.g., Levich 2011). Furthermore, our sub-sample analysis shows that there is a substantial difference between β_1 from different regimes. The size of this parameter turns out to be much smaller for all maturities after the Lehman Shock, indicating a further deterioration of the CIRP condition in the recent observations.

4 Time-varying forward premium bias

In order to illustrate time-dependent bias, we estimate the time-varying parameter, β_1, as in Eq. 4 using Kalman filter with the random coefficients model. The Kalman filtering method is widely used in many research fields such as engineering, but today it is also used in finance too. This method assumes a linear dynamic system to obtain unobservable components (α_t and β_{1t}).

$$\begin{aligned} fp_t^j &= \alpha_t + \beta_{1t}\widetilde{i}_t + e_t \\ \beta_{1t} &= \beta_{1t-1} + \varepsilon_t \\ \alpha_t &= \alpha_{t-1} + z_t \end{aligned} \tag{4}$$

where $e_t \sim N(0, V_t)$ and $\varepsilon_t, z_t \sim N(0, W_t)$, and these residuals are internally and mutually independent errors (see Appendix for explanations about the Kalman filtering method).

The estimates of β_{1t} which are of our interest, are shown for all maturities in Fig. 2. First it shows that β_{1t} is higher for the long-maturity, and is indeed close to the

[8] The first and last 15% of observations are trimmed in order to carry out these tests.

theoretical value of unity for the 12 month-maturity asset. Second, the parameters are very stable prior to 2008; interestingly, the effect on the forward premium puzzle of the bursting of the IT bubble seems rather limited from this figure. In contrast, they decline substantially after the Lehman Shock. Furthermore, although there is some recovery in the parameters after the Lehman Shock, the parameters drop again in 2011 when the Greek debt crisis resumed to adversely affect other European countries such as Italy and Spain. A drop in these parameters is more significant for a longer maturity asset (Fig. 2).

We analyze if these time-varying parameters which measure the forward premium puzzle can be explained by our proxy of the risk premium. Taking into account the possible different order of integration of the data, the next equations (5a and 5b) are estimated by the OLS with the Newey-West method. As can be seen in Fig. 1 and 2, the puzzle becomes more significant at times of financial turmoil (i.e., risk premiums), and thus we expect a negative relationship between them (i.e., $\gamma_1, \gamma_2, \gamma_3, \gamma_4 < 0$) in Eq. 5a and 5b.

$$\Delta\beta_{1t} = \alpha_1 + \gamma_1 Rp_{euro,t} + \gamma_2 Rp_{USA,t} + e_t \quad (5a)$$

$$\beta_{1t} = \alpha_2 + \gamma_3 Rp_{euro,t} + \gamma_4 Rp_{USA,t} + u_t \quad (5b)$$

Overall, an increase in the risk premium (Rp) is found to reduce the parameter size (Table 4); in other words, a forward premium bias is more severe during periods of high uncertainty. What is more, the US risk premium is found to be more significantly associated with this parameter. Indeed, regardless of the specification of β_{1t}, the risk premium for the Euro turns out to be always statistically insignificant. This seems to be consistent with the findings of previous studies (Byrne and Nagayasu 2012) that the US market is very influential over other European economies. The significant influence of the US economy and economic policies can be observed in both advanced and developing countries (Bansal and Dahlquist 2000).

In order to understand the stationarity of the data, we carry out the most conventional unit root test (i.e., the Augmented Dickey-Fuller test) for β_{1t} and risk premiums. The t statistics reported in Table 5 suggest that the level of time-varying parameters (i.e., β_{1t}) seems to be nonstationary, but that of the proxy for risk premiums (Rp) is stationary since in the latter case their t statistics are high (in absolute terms) enough to reject the null hypothesis of the unit root against the alternative of stationarity. The stationarity of risk premiums is consistent with previous studies

(Nagayasu 2011) utilizing other currency pairs. Furthermore, we proceed to conduct the unit root test for changes in β_{1t}, and find evidence of stationarity. This conclusion remains unchanged when the composition of exogenous terms has altered. Thus given the stationarity of $\Delta\beta_{1t}$ and risk premiums, the results in the upper half of Table 4 seem statistically more appropriate. For this reason, we focus on the US risk premium in the subsequent study.

5 The modified CIRP relationship

More formally, we shall analyze from a different perspective, if the forward premium bias becomes more significant during moments of turbulence. In this regard, two modifications are made to the standard CIRP.

First, given that the CIRP suffers from a nonlinearity problem reported in Table 3, we shall re-examine the standard CIRP relationship using the Markov-Switching (MS) model which can be expressed as Eq. 6a and 6b. While time-varying parameters can be calculated using the random coefficient model like before, the MS model is attractive in order to obtain regime (rather than time)-specific estimates and conclusions. The MS model can also prove useful since the unobservable regime type can be identified endogenously by the data.

$$\text{Regime 0} \quad : \quad fp_t^j = \alpha^0 + \beta_1^0 \widetilde{i_t} + e_t \quad e_t \sim N(0, \sigma^2) \tag{6a}$$

$$\text{Regime 1} \quad : \quad fp_t^j = \alpha^1 + \beta_1^1 \widetilde{i_t} + e_t \quad e_t \sim N(0, \sigma 2) \tag{6b}$$

These are the two-regime MS models, and the superscripts on the parameters (i.e., 0 and 1) refer to the regimes.[9] The regime used will depend upon the unobservable variable (s_t) which follows a Markov chain, and the probability of shifting from one regime to another will be determined by the previous regime: $p_{i|n} = P[s_{t+1} = i|s_t = n]$, $\forall i,\, n \in \{1, 2\}$. The total of transition probabilities has to be equal to one; $\sum_0^1 p_{i|n} = 1$. Estimation of parameters and transition probabilities of unobservable states is carried out here using the filtering method developed by Kim (1994).[10]

[9] The number of regimes has been decided since they are supported by our unit root tests. Furthermore, our decision was made since the two-regime model is the most basic nonlinear model and there is no solid economic theory to suggest a greater number of regimes.

[10] The MS model is estimated by Ox.

Table 6 shows estimates from the two-regime MS model, and for presentation purposes, the smoothed transition probability is plotted in Fig 3. According to this figure, Regime 1 corresponds to the tranquil time, and Regime 0 to the crisis period because the probability in this regime increases at the time of the Lehman Shock and the recent Greek crisis. Thus the crisis period (i.e., Regime 0) is rather short compared with the length of the tranquil time.

Based on this regime classification, we observe evidence of a more severe forward premium bias during these crisis periods (Table 6). Exceptions among crises are the IT bubble and the September 11 attacks which seem to have had a very limited effect on the forward premium puzzle. Thus these early crises did not seem to have universal effects compared with the Lehman Shock and Greek debt crisis. Again, this appears to be consistent with Figure 2 where β_{1t} is relatively stable in our early sample period and with the conventional view that the Lehman Shock and the Greek debt crisis are more significant in size and are more global in nature involving other countries.

In order to justify use of a nonlinear approach, a statistical test is also conducted to provide evidence of nonlinearity in the CIRP. The LM test expressed in terms of a χ^2 statistic (Davies 1987) raises strong evidence of nonlinearity in the system (Table 6). The null hypothesis that the sensitivity is the same across regimes (Regimes 0 and 1) is rejected at the 1% significance level. This is consistent with our preliminary analysis using the parameter stability tests in Table 3.

The second modification to the standard CIRP is made by incorporating the US risk premium which was found to be closely associated with changes in β_{1t}. The results from this modified CIRP are reported in Table 7. Again a result similar to Table 4 is obtained for the parameters measuring the forward premium puzzle. In other words, the risk premium enters negatively in the equation to make up for the US interest rate. As can be seen in Eq. 3, this negative parameter is necessary to explain the forward premium puzzle (i.e., a negative bias) given the positive correlation between interest rate differentials and the risk premium (Table 2).

In addition, while we confirm the importance of the risk premium in almost all cases, Rp is found to play a more significant role in the short-term forward premium, which is again confirmation that the longer-term yield tends to contain more information about risk factors than the short-term rate. A significant role of the risk premium is in sharp contrast to the classic study (Froot and Frankel 1989) using the sample observations in the 1970s and 1980s. However, our finding is consistent with more recent studies, e.g., Coffey et al (2009) and Levich (2011) who claimed the significant role of counterparty risk in 2008.

Furthermore, improvements in the forward premium bias are more prominently observed during a crisis period when the risk premium increases. There are 5 instances out of 6 maturity cases where there is an (a marginal) improvement in parameters in Regime 0. In contrast, the size of the parameters drops, although very marginally, on 2 occasions during the tranquil periods. Thus, considering the magnitude of changes in these parameters for both Regimes 0 and 1, the net effect of Rp generally seems to be working toward improvements in this forward premium bias. However, given only modest improvements in the parameters and strong evidence of nonlinearity still remained in the modified CIRP (Table 7), we conclude that the risk premium does not seem to provide the whole story about the time-varying puzzle.

6 Conclusion

This paper re-evaluates the forward premium puzzle, using data including the recent crisis periods, for the pair of Euroland and the USA which have close links with the Lehman Shock and the Greek debt crisis. Unlike previous studies, we introduce a proxy of the risk premium, and the sensitivity of the puzzle to the risk premium is analyzed by estimating time-dependent measures of the puzzle.

Then, we provide evidence that the forward premium puzzle has become more significant during the Lehman Shock period, with further deviations from the CIRP. The parameter for interest rate differentials is well below the theoretical value of unity although it is still positive. Our further analysis suggests that the introduction of the risk premium seems to lessen the puzzle particularly during chaotic moments. Since there was no major financial regulation imposed during this period in these countries, our finding of a more severe forward premium puzzle during the very recent period implies some caution about using the standard CIRP as a measure of international capital market integration.

Finally, we would like to point out some directions for possible future research. First, whilst we acknowledge the importance of other factors other than the risk premium, it is very useful to find some other proxy for the risk premium which has more explanatory power over the forward premium. As reported, our modified CIRP model is still in the form of nonlinearity. This suggests that our proxy may not be adequate for explaining the forward premium puzzle, and the measurement error may be potentially significant. Second, while this study discussed a forward premium puzzle in the context of the CIRP (i.e., the forward premium and interest rate differentials), further analysis can be usefully carried out using the Fama-type model and the covered interest rate parity condition. In this way, one might usefully clarify the role of investors' expectations which may differ from time to time.

References

Bacchetta, P. & van Wincoop, E. (2010). Infrequent Portfolio Decisions: A Solution to the Forward Discount Puzzle. American Economic Review, 100(3), 870–904.

Bank for International Settlements (2010). Triennial central bank survey: Report on global foreign exchange market activity in 2010.

Bansal, R. & Dahlquist, M. (2000). The forward premium puzzle: different tales from developed and developing economies. Journal of International Economics 51, 115-144.

Burnside, C., Eichenbaum, M. & Rebelo, S. (2009) Understanding the forward premium puzzle: a microstructure approach. American Economic Journal: Macroeconomics 1(2), 127–54.

Byrne, J. P. & Nagayasu, J. (2012). Common factors of the exchange risk premium in emerging European markets. Bulletin of Economic Research, forthcoming.

Chicago Board Options Exchange (2009). The CBOE volatility index-VIX.

Chinn, M. D. & Meredith, G., 2004, Monetary policy and long-horizon uncovered interest parity. IMF Staff Papers 51, 409-430.

Coffey, N., Hrung, W. B. & Sarkar, A. (2009). Capital constraints, counterparty risk, and deviations from the covered interest rate parity. Federal Reserve Bank of New York Staff Report no. 393.

Davies, R. B. (1987). Hypothesis testing when a nuisance parameter is present only under the alternative. Biometrika 74, 33-43.

Eichenbaum, M. & Evans, C. L. (1995). Some empirical evidence on the effects of shocks to monetary policy on exchange rates. Quarterly Journal of Economics 110, 975-1009.

Engel, C. (1996). The forward discount anomaly and the risk premium: a survey of recent evidence. Journal of Empirical Finance 3, 123-192.

Engle, R. F., Lilien, D. M. & Robins, R. P. (1987). Estimating time varying risk premia in the term structure: the Arch-M model. Econometrica 55, 391-407.

Evans, M. D. D. & Lyons, R. K. (2002). Order flow and exchange rate dynamics. Journal of Political Economy 110, 170-180.

Fama, E. F. (1984). Forward and spot exchange rates. Journal of Monetary Economics 14, 319-338.

Frankel, J. A. (1992). Measuring international capital mobility: a review. American Economic Review 82, 197-202.

Frankel, J. & Poonawala, J. (2010). The forward market in emerging currencies: less biased than in major currencies. Journal of International Money and Finance 29, 585-598.

Froot, K. A. & Frankel, J. F. (1989). Forward discount bias: is it an exchange risk premium? Quarterly Journal of Economics 139-161.
Froot, K. A. & Thaler, R. H. (1990). Anomalies: foreign exchange. Journal of Economic Perspective 4(3), 179-192.
Griffoli, T. M. & Ronaldo, A. (2011). Limits to arbitrage during the crisis: funding liquidity constraints and covered interest parity, Working Paper.
Hansen, B. E. (1997). Approximate asymptotic p values for structural-change tests. Journal of Business & Economic Statistics 15(1), 60-67.
Hall, S. G., Swamy, P. A. V. B., Tavlas, G. S., & Kenjegaliev, A. (2011). The forward premium puzzle: a resolution, University of Leicester, Economics Department, Working Paper No. 11/23.
Kim, C-J. (1994). Dynamic linear models with Markov-Switching. Journal of Econometrics 60, 1-22.
Kocenda, E. & Poghosyan, T. (2009). Macroeconomic sources of foreign exchange risk in new EU members. Journal of Banking & Finance 33, 2164-2173.
Levich, R. M. (2011). Evidence on financial globalization and crises: interest rate parity, In the Encyclopedia of Financial Globalization, ed. Gerard Caprio, Elsevier Publishing Inc., forthcoming.
Lusting, H. & Verdelhan, A. (2007). The cross section of foreign currency risk premia and consumption growth risk. American Economic Review 97, 89-117.
MacDonald, R. & Torrance, T. S. (1990). Expectations formation and risk in four foreign exchange markets. Oxford Economic Papers, 42(3), 544-561.
Nagayasu, J. (2011). The common component in forward premiums: evidence from the Asia-Pacific region. Review of International Economics 19(4), 750-762.
Taylor, M. P. (1989). Covered interest arbitrage and market turbulence. Economic Journal 99, 376-391.

Appendix
Data Sources

- Forward exchange rates: Data for the maturity length of one, two, three, six, nine and twelve months are downloaded from DataStream.
- Spot exchange rates: Bilateral exchange rates vis-à-vis the USD are sourced from DataStream.
- Interest rates: LIBOR interest rates for the maturity length of one, two, three, six, nine and twelve months are downloaded from DataStream.
- Financial market volatility index: the volatility index (Chicago Board Options Exchange Volatility type index) for Euroland and the USA, which measures expectations of volatility in major stock price index (S&P500 and EURO STOXX 50) are downloaded from DataStream.

Kalman Filter
The Kalman filtering method is widely used in many research fields.
Let us write Eq. 4 using $b_t = (\alpha, \beta_t)'$ as

$$\begin{aligned} Y_t &= X_t b_t + v_t \\ b_t &= b_{t-1} + w_t \end{aligned}$$

where $v_t \sim N(0, V_t)$ and $w_t \sim N(0, W_t)$, and the initial condition is assumed to be $b_0|D_0 \sim N(m_0, C_0)$, where D_0 is the information set available at time 0. Then the posterior for b_{t-1} is $b_{t-1}|D_{t-1} \sim N(m_{t-1}, C_{t-1})$, and the prior for b_t is$b_t|D_{t-1} \sim N(m_{t-1}, R_t)$, where $R_t = C_{t-1} + W_t$. The one-step ahead forecast for Y is $Y_t|D_{t-1} \sim N(f_t, Q_t)$ where $f_t = X_t m_{t-1}$ and $Q_t = X_t^2 R_t + v_t$. In short,

$$\begin{pmatrix} b_t \\ Y_t \end{pmatrix} |D_{t-1} \Big) \sim N\left(\begin{pmatrix} m_{t-1} \\ f_t \end{pmatrix}, \begin{pmatrix} R_t & R_t X_t \\ X_t R_t & Q_t \end{pmatrix} \right)$$

Table 1. Basic statistics for the covered interest parity condition

	Obs	Mean	SE	Min	Max
fp^{1M}	160	-0.024	0.120	-0.245	0.164
fp^{2M}	160	-0.046	0.234	-0.471	0.326
fp^{3M}	160	-0.070	0.348	-0.718	0.487
fp^{6M}	160	-0.140	0.681	-1.390	0.949
fp^{9M}	160	-0.220	0.994	-2.072	1.405
fp^{12M}	160	-0.315	1.286	-2.782	1.794
$\widetilde{i}^{1M}$	160	-0.160	1.449	-2.968	2.152
$\widetilde{i}^{2M}$	160	-0.153	1.449	-2.794	2.113
$\widetilde{i}^{3M}$	160	-0.136	1.462	-2.949	2.188
$\widetilde{i}^{6M}$	160	-0.157	1.440	-2.844	2.121
$\widetilde{i}^{9M}$	160	-0.180	1.422	-2.792	2.226
$\widetilde{i}^{12M}$	160	-0.213	1.402	-2.849	2.266

Note: fp is the forward premium, $\widetilde{i}$ is the interest rate differential, and SE is the standard error.

Table 2. Correlations between forward premiums, interest rates and risk premiums

	fp^{2M}	fp^{3M}	fp^{6M}	fp^{9M}	fp^{12M}	$\widetilde{i}^{1M}$	$\widetilde{i}^{2M}$	$\widetilde{i}^{3M}$	$\widetilde{i}^{6M}$	$\widetilde{i}^{9M}$	$\widetilde{i}^{12M}$	Rp_{USA}	Rp_{Euro}
fp^{1M}	1.00	0.99	0.98	0.96	0.95	0.97	0.97	0.96	0.95	0.93	0.92	0.43	0.38
fp^{2M}		1.00	0.99	0.98	0.96	0.97	0.97	0.97	0.96	0.95	0.93	0.43	0.39
fp^{3M}			0.99	0.98	0.97	0.97	0.97	0.97	0.97	0.96	0.94	0.44	0.39
fp^{6M}				1.00	0.99	0.96	0.97	0.97	0.97	0.97	0.96	0.45	0.41
fp^{9M}					1.00	0.95	0.96	0.97	0.97	0.97	0.97	0.44	0.42
fp^{12M}						0.94	0.95	0.96	0.97	0.97	0.97	0.44	0.42
$\widetilde{i}^{1M}$							1.00	0.99	0.98	0.97	0.96	0.52	0.48
$\widetilde{i}^{2M}$								1.00	0.99	0.98	0.97	0.52	0.48
$\widetilde{i}^{3M}$									0.99	0.99	0.98	0.51	0.48
$\widetilde{i}^{6M}$										1.00	0.99	0.50	0.48
$\widetilde{i}^{9M}$											1.00	0.50	0.48
$\widetilde{i}^{12M}$												0.49	0.48
Rp_{USA}													0.93

Note: Rp is the risk premium. Also see Table 1 about the notation.

Table 3. Covered interest parity relationships

	M1	M2	M3	M6	M9	M12
Full Sample						
Const	*-0.011*	*-0.022*	*-0.038*	*-0.068*	*-0.097*	*-0.124*
	[0.002]	[0.004]	[0.006]	[0.011]	[0.017]	[0.024]
$\widetilde{i}$	*0.081*	*0.158*	*0.233*	*0.464*	*0.685*	*0.897*
	[0.001]	[0.002]	[0.003]	[0.006]	[0.010]	[0.014]
Instability test						
Andrews-Quandt	44.409	53.869	60.277	50.313	40.589	35.306
p-value	0.000	0.000	0.000	0.000	0.000	0.000
Andrews-Ploberger	19.509	24.550	27.405	22.778	18.423	16.402
p-value	0.000	0.000	0.000	0.000	0.000	0.000
Break date	2008M9	2008M9	2008M9	2008M9	2008M9	2008M9
1998M11-2008M8						
Const	0.000	-0.001	-0.003	0.001	-0.006	-0.015
	[0.001]	[0.002]	[0.003]	[0.003]	[0.006]	[0.011]
$\widetilde{i}$	*0.086*	*0.167*	*0.248*	*0.495*	*0.730*	*0.956*
	[0.001]	[0.001]	[0.002]	[0.002]	[0.004]	[0.007]
2008M9-2012M4						
Const	*-0.018*	*-0.039*	*-0.077*	*-0.129*	*-0.139*	*-0.115*
	[0.005]	[0.011]	[0.018]	[0.039]	[0.048]	[0.055]
$\widetilde{i}$	*0.058*	*0.118*	*0.186*	*0.354*	*0.480*	*0.560*
	[0.011]	[0.023]	[0.035]	[0.067]	[0.087]	[0.105]

Note: p-values for the instability test are based on Hansen (1997). The standard error is shown in brackets. Parameters which are significant at the 5% level or higher are in italics.

Table 4. The relationship between parameters ($\Delta\beta_1$) and financial uncertainty

$\Delta\beta_1$	M1	M2	M3	M6	M9	M12
Constant	*0.009*	*0.324*	*0.501*	*0.943*	*1.407*	*1.894*
	[0.004]	[0.012]	[0.020]	[0.037]	[0.049]	[0.063]
Rp_{Euro}	-0.001	-0.001	-0.006	-0.022	-0.023	0.002
	[0.002]	[0.017]	[0.026]	[0.044]	[0.061]	[0.080]
Rp_{USA}	-0.002	*-0.039*	*-0.058*	*-0.090*	*-0.149*	*-0.244*
	[0.002]	[0.016]	[0.025]	[0.044]	[0.061]	[0.079]
TREND	0.000	*-0.001*	*-0.001*	*-0.002*	*-0.003*	*-0.004*
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
β_1						
Constant	0.166	0.324	0.501	0.943	1.407	1.894
	[0.006]	[0.012]	[0.020]	[0.037]	[0.049]	[0.063]
Rp_{Euro}	-0.001	-0.001	-0.006	-0.022	-0.023	0.002
	[0.008]	[0.017]	[0.026]	[0.044]	[0.061]	[0.080]
Rp_{USA}	-0.020	-0.039	-0.058	-0.090	-0.149	-0.244
	[0.008]	[0.016]	[0.025]	[0.044]	[0.061]	[0.079]
TREND	0.000	-0.001	-0.001	-0.002	-0.003	-0.004
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Note: Estimation based on Eq. 5. The figures in brackets are standard errors. Parameters which are significant at the 5% level or higher are in italics.

Table 5. Augmented Dickey-Fuller unit root tests

Variables	Const	Const+Trend
${\beta_1}^{M1}$	0.060	-1.314
${\beta_1}^{M2}$	-0.281	-1.687
${\beta_1}^{M3}$	-0.161	-1.649
${\beta_1}^{M6}$	-0.273	-1.864
${\beta_1}^{M9}$	0.694	-1.035
${\beta_1}^{M12}$	-0.227	-1.890
Rp_{Euro}	-3.399	-3.392
Rp_{USA}	-3.201	-3.191
$\Delta{\beta_1}^{M1}$	-1821.630	-1791.820
$\Delta{\beta_1}^{M2}$	-8.457	-8.550
$\Delta{\beta_1}^{M3}$	-7.880	-8.001
$\Delta{\beta_1}^{M6}$	-12.617	-6.465
$\Delta{\beta_1}^{M9}$	-12.617	-12.795
$\Delta{\beta_1}^{M12}$	-12.613	-5.812

Note: The null hypothesis of nonstationary is tested against the alternative of nonstationarity. The lag length is determined by the Akaike Information Criterion with the maximum of 12. The critical values for the constant (Const) are -3.472 [1%], -2.880[5%] and -2.576[10%]. Those with the constant and trend are -4.020 [1%], -3.440 [5%] and -3.140 [10%].

Table 6. MS model for the covered interest rate parity condition

	Coef	SE	p-value	Coef	SE	p-value	Coef	SE	p-value
	1 month			2 month			3 month		
Const[0]	-0.044	0.010	0.000	-0.020	0.008	0.012	-0.035	0.012	0.006
Const[1]	-0.003	0.002	0.083	-0.003	0.003	0.199	-0.008	0.004	0.035
$\widetilde{i}[0]$	0.062	0.009	0.000	0.051	0.011	0.000	0.077	0.017	0.000
$\widetilde{i}[1]$	0.085	0.001	0.000	0.166	0.002	0.000	0.246	0.002	0.000
sigma	0.019	0.001	0.000	0.027	0.002	0.000	0.039	0.002	0.000
p[0|0]	0.900			0.934			0.937		
p[0|1]	0.019			0.025			0.025		
$\chi^2(4)$	88.176		0.000	132.200		0.000	149.160		0.000
	6 month			9 month			12 month		
Const[0]	-0.074	0.025	0.003	-0.205	0.043	0.000	-0.695	0.052	0.000
Const[1]	-0.012	0.006	0.026	-0.027	0.007	0.000	-0.050	0.011	0.000
$\widetilde{i}[0]$	0.142	0.031	0.000	0.265	0.048	0.000	0.638	0.045	0.000
$\widetilde{i}[1]$	0.488	0.003	0.000	0.720	0.005	0.000	0.938	0.008	0.000
sigma	0.060	0.004	0.000	0.085	0.005	0.000	0.131	0.007	0.000
p[0|0]	0.885		0.827				0.866		
p[0|1]	0.031		0.029				0.015		
$\chi^2(4)$	205.530		0.000	215.110		0.000	201.180		0.000

Note: The numbers in brackets refer to regimes. The nonlinearity test is shown as χ^2.

Table 7. MS model with risk premiums

	Coef	SE	p-value	Coef	SE	p-value	Coef	SE	p-value
	1 month			2 month			3 month		
Const[0]	-0.057	0.040	0.000	-0.009	0.026	0.744	-0.034	0.040	0.400
Const[1]	0.069	0.014	0.157	0.074	0.023	0.001	0.096	0.034	0.005
$\widetilde{i}[0]$	0.002	0.033	0.000	0.114	0.010	0.000	0.169	0.017	0.000
$\widetilde{i}[1]$	0.084	0.001	0.946	0.166	0.002	0.000	0.245	0.003	0.000
Rp_{USA}	-0.026	0.005	0.000	-0.028	0.008	0.000	-0.039	0.011	0.001
sigma	0.019	0.001	0.000	0.029	0.002	0.000	0.043	0.002	0.000
p[0|0]	0.000			0.844			0.850		
p[0|1]	0.008			0.016			0.016		
$\chi^2(4)$	82.531		0.000	100.40		0.000	105.69		0.000
	6 month			9 month			12 month		
Const[0]	-0.036	0.052	0.484	-0.121	0.075	0.109	-0.623	0.119	0.000
Const[1]	0.029	0.050	0.563	0.062	0.066	0.348	0.027	0.101	0.789
$\widetilde{i}[0]$	0.152	0.034	0.000	0.284	0.049	0.000	0.654	0.054	0.000
$\widetilde{i}[1]$	0.489	0.004	0.000	0.722	0.005	0.000	0.940	0.008	0.000
Rp_{USA}	-0.014	0.016	0.405	-0.030	0.022	0.177	-0.025	0.033	0.448
sigma	0.060	0.004	0.000	0.085	0.005	0.000	0.131	0.007	0.000
p[0|0]	0.888			0.828			0.866		
p[0|1]	0.030			0.029			0.015		
$\chi^2(4)$	189.2		0.000	201.07		0.000	189.23		0.000

Note: The numbers in brackets refer to regimes. The nonlinearity test is shown as χ^2.

Figure 1. Proxies for risk premiums

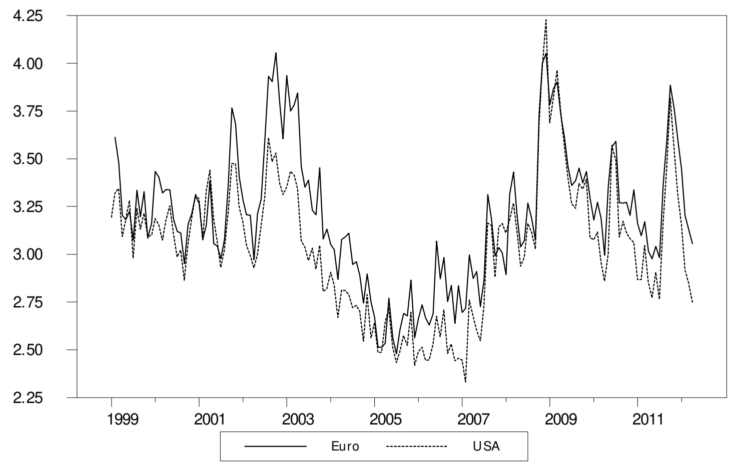
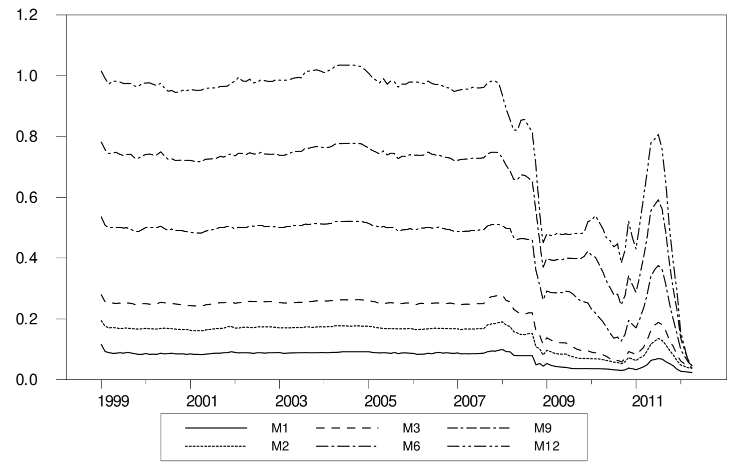
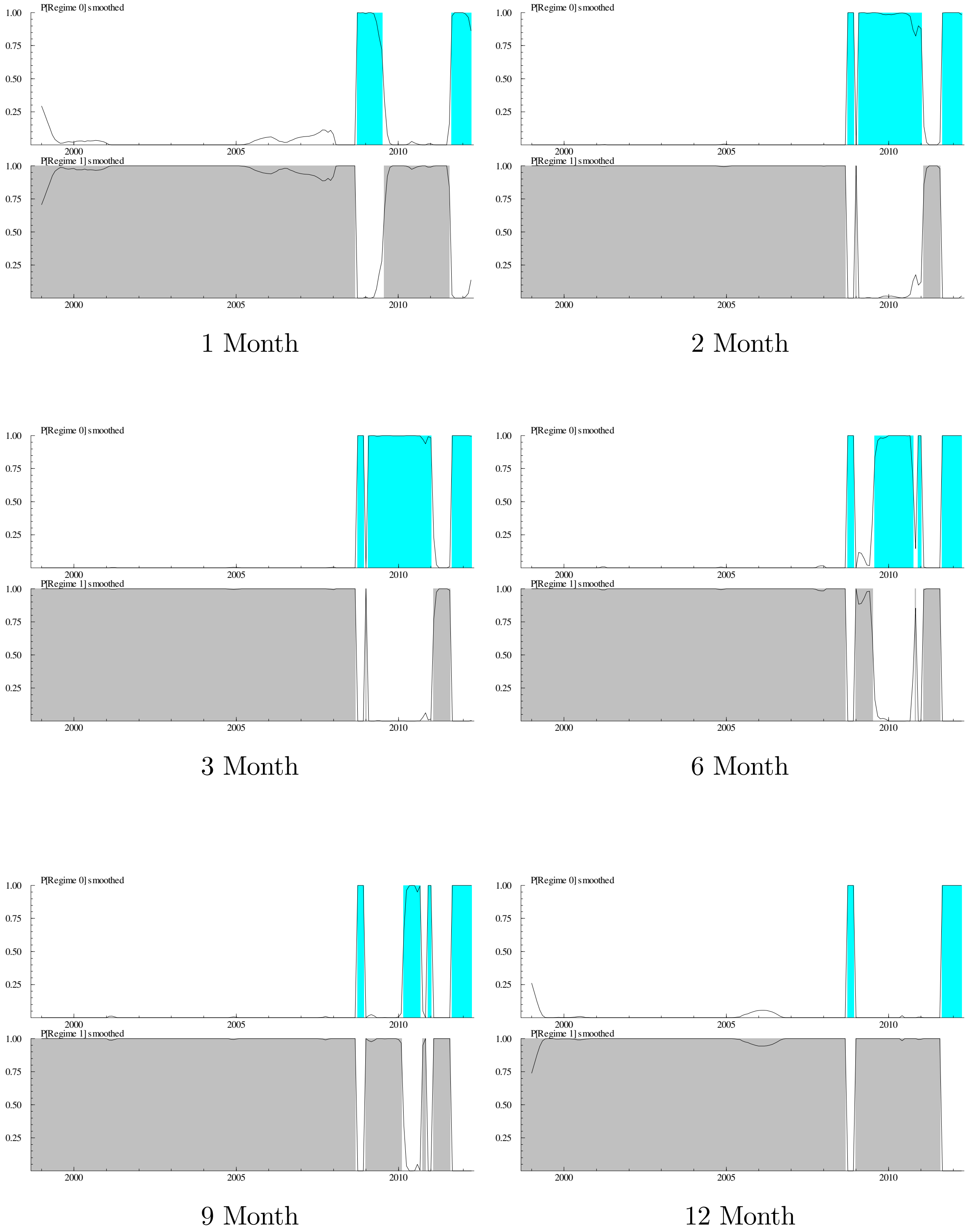


Figure 2. Time-varying β_1



Note: M1 to M12 represent parameters (β_1) for a maturity of 1 to 12 months.

Figure 3. Smoothed transition probabilities from the MS model



1 Month

2 Month

3 Month

6 Month

9 Month

12 Month