The Forward Premium Puzzle And The Euro

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Abstract

This paper evaluates the forward premium puzzle using the Euro exchange rate. Unlike previous studies, our analysis utilizes time-varying parameter methods and is based on two approaches for evaluation of the puzzle; the traditional approach analyzing the sensitivity of interest rate differentials to the forward premium, and the other looking into deviations from the covered interest rate parity (CIRP) condition. Then we provide evidence that the forward premium puzzle indeed became more prominent around the time of the recent crisis periods such as the Lehman Shock and the Euro crisis. This is also shown to be consistent with a deterioration in the CIRP.

JEL classification: F31, F36, G01

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

1 Introduction

The forward premium puzzle can be regarded broadly as a violation of the Covered Interest Rate Parity (CIRP) condition which suggests an equi-proportional 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 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 the forward premium puzzle and the failure of the CIRP.

Among others, previous studies point to several 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. Indeed, recent studies (e.g., Coffey et al 2009) have pointed out that counterparty risk has become a driving force for CIRP deviations during the Lehman Shock. They have also argued that these deviations were lessoned when the Federal Reserves increased the US$ supply by means of a currency swap, and therefore the risk premium seem to be closely associated with liquid constraints. Second, the presence of transaction costs may prevent investors from trading even when there is a profit opportunity based on the CIRP criterion (Peel and Taylor 2002). This is another classic explanation of the violation of the CIRP and has been analyzed using the threshold model which allows to differentiate ranges in which prices may or may not make adjustments. The third 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).

Although there is a link with explanations of the CIRP deviations, more direct economic reasons exist for the forward premium puzzle. For example, recent studies have pointed out that the currency carry trade strategy is related to the puzzle (e.g., Menkhoff et al 2012). That is to say, when an interest rate is low and is perceived as likely to last for some time, investors borrow money in the low interest rate country

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

and purchase financial assets in a high interest rate country. Therefore, there is an increase in demand for foreign currency, and as a result a low interest rate country will experience currency depreciation. Furthermore, 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, by focusing on the risk premium and CIRP deviations, whether or not this puzzle has become more significant during recent periods. To our knowledge, although some economic explanations have been provided about the forward premium puzzle, few attempts have been made to clarify its relationship with CIRP derivations or investigate whether this puzzle during the crises is indeed statistically different from those in normal times. Using advanced statistical methods, we shall investigate these issues by including sample periods which contain information on the European debt crisis which kicked off in Greece in 2009.[3]

This paper consists of four more sections. In the next section, we explain further the concept of the forward premium puzzle and its empirical evidence, based on previous literature. Section 3 discusses the key data used in our paper; namely exchange rates and interest rates, and furthermore estimates the time-varying forward premium puzzle by employing a state space model. Section 4 analyzes whether the CIRP deviations have indeed increased in size during the recent crises and have become an explanation for the more significant forward premium puzzle, using the Markov-switching (MS) model with time-varying transition probabilities. This paper ends with a summary of our findings in Section 5.

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) has

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[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 our relatively low (monthly) frequency data are prone to be less sensitive to the timing of quotations.

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, 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 derivation of the Fama's 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 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 ($fp_t^j = f_t^j - s_t$) 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. The analysis of β_1 is probably the most orthodox method for the evaluation of the forward premium puzzle, and it is here called a direct approach.

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 serious 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 also 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:

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

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

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 $Cov(\widetilde{i}_t, Rp_t) < 0$. In other words, when Rp is an extra return required to invest at home, the covariance term is expected to be positive. Then, given a well-documented forward premium puzzle in previous studies, β_2 must be negative to have a downward bias.

As an indirect approach, the forward premium puzzle can also be analyzed by examining a deviation from the CIRP (Dev_t) and the risk premium.

$$\begin{aligned} Dev_t &\equiv i_t - i_t^* - fp_t \tag{4} \\ Dev_t &= f(Rp_t) \quad \text{where } f' < 0 \end{aligned}$$

When Europe is home and the US is a foreign country, this risk premium is thus an extra return necessary to compensate increased uncertainty when making investment in Europe. Thus in our setting (Eq. 4), a rise in Rp should lead to a decline in CIRP deviations. This relationship can be interpreted as the fact that an increase in the risk premium will weaken the relationship between fp and $i - i^*$, i.e., a decline in β_1, other things being constant, thereby providing evidence of the forward premium puzzle. On the other hand, an increase in Dev implies that β_1 will be greater than one, which is not in line with previous evidence of the forward premium puzzle. Thus, this residual-based approach to evaluate the forward premium puzzle is different from the conventional method based on Eq. 1, but we should still be able to obtain consistent results with the conventional one.

To our knowledge, there is no study providing clear evidence of the forward premium puzzle by examining the size of CIRP deviations. For example, increases in CIRP deviations in the summer of 2007 due to the sub-prime loan problem were

argued to be linked with credit and counterparty risk (Baba and Packer 2008, Coffey et al 2009, Levich 2011). Coffey et al (2009) and Griffoli and Panaldo (2011) suggest insufficient liquidity in the financial market as an explanation.[5] Furthermore, Peel and Taylor (2002) analyzed CIRP deviations during the 1920s using the threshold autoregressive (TAR) model in order to take account of transaction costs which prevent trading. But these studies have no direct relevance to the forward premium puzzle.

3 Forward Premium Puzzle under Investigation: A Direct Approach

This section empirically analyzes the forward premium puzzle based on a direct approach, i.e., Eq. 1. However, unlike previous studies, the state-space model is employed to calculate the time-varying parameter (β_1). In this way, we can highlight the degree to which the forward premium puzzle has varied over time. Prior to the estimation of this model, we shall explain our key data and conduct some preliminary analyses.

Our data are monthly and cover the sample period from 1999M1-2012M4 for the Euro/US\$ exchange rates (see Appendix). 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 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).

The forward premium and interest rate data are expressed in terms of annual

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[5]There are, however, many other explanations for the forward premium puzzle. For example, using the Fama-type statistical relationship, Eichenbaum and Evans (1995) argue that small sample problems and price rigidities can cause the forward premium puzzle. Furthermore, Bacchetta and van Wincoop (2010) point to infrequent portfolio adjustments as a reason for the puzzle.

[6]The quality of the LIBOR has been questioned recently (July 2012) as some banks allegedly indulged in illegal operations in order to manipulate this rate. However, the LIBOR is very comprehensive in terms of maturities.

rates and are summarized in tables. Table 1 shows the basic statistics of the forward premium and interest rate differentials for a variety of maturity lengths. In this table, the average value of these variables is reported to be negative, suggesting that the spot exchange rate was on average higher than the forward rate, and the US interest rate was higher than the European rate. Furthermore, the sizes of the forward premium and the interest rate differentials both increase along with maturity length, reflecting the higher likelihood of changes in these variables over longer time horizons. With respect to their variation in terms of the standard error (SE), interest rate differentials are more homogeneous than forward premiums whose variation declines more prominently along with maturity length. The high volatility of shorter maturities normally reflects their high trading volume.

Table 2 reports correlation coefficients obtained for the forward premium and interest rate differentials. It turns out that the correlation level between forward premiums and between interest rates with different maturities is very high–more than 90%. Furthermore, a high correlation between forward premiums and interest rate differentials is reported in the table.

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 of β_1 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 yielded a negative sign (Fama 1984, Froot and Frankel 1989). However, the unitary parameter restriction on β_1 is statistically rejected in all cases in the full sample, confirming the presence of the forward premium puzzle as reported in previous literature.

Having experienced financial crises, the full sample analysis may suffer from structural breaks. In this regard, we conduct two types of instability test; the Andrews-Quandt and Andrews-Ploberger tests, in order to examine the null hypothesis that β_1 is invariant over time. The statistics are based on OLS estimates but are adjusted for heteroschedasticity, and since these tests do not follow the conventional distribution, 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.[7] In addition, the table provides evidence of a structural break at the time of the Lehman Shock (2008M9). This break date is identified by the most extreme value of F statistic (i.e., the smallest p-value), and the presence of structural breaks

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

is consistent with a violation of the CIRP during the recent period (e.g., Levich 2011).

Using this information of a break date, we divide the full sample into two periods, and carry out sub-sample analysis. Our results show 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 recent observations. In contrast, while our data support the presence of the forward premium in most cases, there are two instances where a unitary restriction on β_1 is accepted by the statistical test from observations prior to the Lehman Shock. Thus our results also imply a relatively more severe forward premium puzzle during the recent crisis period.

Finally, in order to illustrate time-dependent bias, we estimate the time-varying parameter, β_1, as in Eq. 5 using the Kalman filter with a state space 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}).

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\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{5}
$$

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 (see Appendix for explanations about the Kalman filtering method). The unobserved time-varying components are assumed to follow a random walk process.

The estimates of β_{1t} which are of interest to us, are shown for all maturities in Fig. 1, raising two interesting points. First, consistent with the results in Table 3, it suggests that β_{1t} is indeed close to the theoretical value of unity in many periods and seems relatively stable prior to 2008. Second, this parameter stability does not last until the end of our sample period. The parameter size for all maturities dropped sharply after Lehman Shock. Although there is some recovery in the parameters afterwards, they dropped again in 2011 when the Greek debt crisis resumed and adversely affected other European countries such as Ireland, Italy and Spain. Thus, this figure shows that the recent rise in the forward premium puzzle is closely associated with the Lehman Shock and the European sovereign debt crisis. In the

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next section, we shall carry out a similar analysis but using an indirect approach.

4 CIRP Deviations and the Forward Premium Puzzle

Rather than investigating directly the size of β_1 in Eq. 1, this section seeks evidence of the puzzle by looking into deviations from the CIRP. In particular, as discussed, a significant negative departure from this condition becomes evidence of the increased importance of the risk premium since the risk premium (Rp) can be expressed as a linear function of CIPR deviations (see Eq. 4).

Furthermore, assuming that a proxy for financial market uncertainty (ρ) is positively associated with Rp:

$$Rp_t = f(\rho_t) \quad \text{where } f' > 0 \tag{6}$$

Then, Eq. 4 and 6 show that an increase in financial uncertainty will raise the risk premium and reduce CIRP deviations. This becomes equivalent to a decline in β_1 in Eq. 1 from the theoretical value of unity, other things being constant. One statistical advantage of this method is that there is no causality issue. Since some banks are known to offer interest rates which are derived from the forward premium, the endogeneity bias may be potentially problematic in Eq. 1. Interestingly, this approach has not been implemented in previous research analyzing the forward premium puzzle. Here by applying the Markov-switching (MS) model with time-varying transition probabilities to CIRP deviations, we shall analyze from a different perspective, whether indeed the forward premium puzzle becomes significant during crisis periods.

Before applying the MS model, we shall check the basic time-series properties of CIRP deviations. First, in order to understand the stationarity of the data, we carry out the most conventional unit root test (i.e., the Augmented Dickey-Fuller (ADF) test) as well as the Ziot-Andrews test which considers a possible regime shift in time-series data and where shift-dates are determined endogenously. Both tests examine the null of the unit root against the alternative of the stationarity, and a large negative statistic becomes evidence against the null. Here in addition to a different specification for the ADF test (i.e., with/without the time trend), two forms of the Ziot-Andrews test are examined: Models A and B. While Model A

includes a shift in the intercept, Model B considers a shift in the time trend.

The t statistics from the unit root tests (Table 4) suggest that CIRP deviations generally are stationary regardless of the maturity length. The null hypothesis of the unit root is rejected in most cases although somewhat weaker evidence is provided for longer maturities. Given that CIRP deviations are a linear function of Rp, our results imply a stationarity of risk premiums which is consistent with previous studies (Nagayasu 2011) utilizing other currency pairs.

Second, a further statistical test is conducted to provide evidence of nonlinearity in the CIRP in the context of the MS model with the constant transition probabilities. The LM test expressed in terms of a χ^2 statistic (Davies 1987) is applied to a two regime MS model with constant terms and raises strong evidence of nonlinearity in the system (Table 5) by rejecting the null hypothesis of parameter stability at the 1% significance level. This is consistent with our preliminary analysis using parameter stability tests (Table 3), and provides evidence overall in favor of a nonlinear model.

Next, in order to identify the timing and duration of crises, we employ the MS model with time-varying transition probabilities. There are a number of attractive features in this statistical method. First, being different from the traditional constant transition probability model,[8] our model allows for transition probabilities to be dependent upon exogenous economic variables. Furthermore, since these economic variables are chosen by researchers and contain information about the timing of structural breaks, it helps us interpret regimes. Second, while time-varying parameters can be calculated using the standard state space model like before, the MS model allows us to obtain regime- (rather than time-) specific estimates and conclusions. Third, the MS model can also prove useful since unobservable regime type will be identified endogenously by the data.

The time-varying transition probability model was introduced by Filardo (1994) and Diebold et al (1994) and is often used to model US business cycles. In Filardo (1994) for instance, the diffusion index, interest rates and stock prices are used to obtain the time-varying transition probabilities. Furthermore, Peria (2002) applied this model to studying speculative attacks during the crisis of the European Monetary System, where transition probabilities are designed to be influenced by the level of foreign exchange market pressure. A recent development in this model is the application of Bayesian statistics as an estimation method rather than the traditional maximum likelihood method. But this paper uses the traditional method

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[8]See Hamilton (1994) for detailed explanations of the constant transition probability model.

since we did not confront difficulties in finding an optimum point during estimation.

First, consider a constant transition probability (p_{ij}) model where a random variable s_t contains information about a regime type with integer values (i.e., $j = 1, 2, ..., N$). The Markov chains suggest that the probability of s_{t+1} depends only on its past value (i_t).

$$P\{s_{t+1} = j | s_t = i_t\} = p_{ij} \tag{7}$$

For N regimes, the transition matrix which contains all possible p_{ij} can be expressed as:

$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1N} \\ p_{21} & p_{22} & & \\ \vdots & & \ddots & \\ p_{N1} & & & P_{NN} \end{bmatrix} \tag{8}$$

where $\sum_{j=1}^{N} p_{ij} = 1$. This is a constant transition probability model which is widely used in many areas of economic research.

For the time-varying transition probabilities (p_{ijt}), Eq. 6 will be re-written as:

$$P\{s_{t+1} = j | s_t = i_t, |\Omega_{t+1}\} = p_{ijt+1} \tag{9}$$

where Ω_{t+1} is the information available at time $t+1$ and is a vector of exogenous variables which determine the transition probabilities and regime type. Similarly, Eq. 7 can be re-expressed as:

$$\mathbf{P}_t = \begin{bmatrix} p_{11t} & p_{12t} & \cdots & p_{1Nt} \\ p_{21t} & p_{22t} & & \\ \vdots & & \ddots & \\ p_{N1t} & & & P_{NNt} \end{bmatrix} \tag{10}$$

where

$$\begin{aligned} p_{1j,t} &= q_{1j,t} \\ p_{2j,t} &= (1 - q_{1j,t})q_{2j,t} \\ &\vdots \\ p_{Nj,t} &= (1 - q_{1j,t})(1 - q_{2j,t}) \cdots (1 - q_{N-2j,t})(1 - q_{N-1j,t}) \end{aligned} \tag{11}$$

where $q_{ij,t} = \Phi\left(\Omega_{ijt} b'_{ij}\right)$ and Φ is the cumulative normal distribution function for the estimated probabilities ranging from zero to one, which helps formulate a well-defined log-likelihood function (Filardo 1994).

We follow the previous research using the time-varying transition probability model and assume two regimes in the system ($s_t \in 1, 2$). This assumption is widely used in applied research partly because it is easier to interpret regimes (e.g., tranquil and turmoil periods) and also it helps reduce computational difficulties. As will become clear later, Regime 1 refers in this paper to a tranquil period and Regime 2 a crisis period.

In the two regime model, the probability of remaining in Regimes 1 and 2 can be expressed following Raymond and Rich (1997) as:

$$P\{s_t = 1|s_{t-1} = 1, \Omega_t\} = q_{11t} = \Phi\left(\rho_{t-1} b(1)\right) \tag{12}$$

$$P\{s_t = 2|s_{t-1} = 2, \Omega_t\} = p_{22t} = \Phi\left(\rho_{t-1} b(2)\right)$$

where Ω contains the lagged proxy for financial market uncertainty (ρ), which thus determines regime type endogenously in this paper. As a proxy for ρ, we consider a variable known as the financial market volatility (or crisis) index; namely, the EURO STOXX 50 Volatility Index (VSTOXXI). This index follows a similar compilation methodology to the Chicago Board Options Exchange Volatility Index (CBOEV), and its increases are viewed as representing higher uncertainty or volatility (in the following 30 days) in the prices of the benchmark index (EURO STOXX 50) which is closely linked with options values.[9] We use this index since it is closely associated with European financial market uncertainty and crises, and we expect that when this index increases, extra returns (i.e., the risk premium) are required for investment. One advantage of this index is that the data are discrete but give us more timely information about the level of financial chaos compared with, for example, credit ratings. This proxy is shown in Fig. 2, and indicates that high financial uncertainty exists at times of stock market downturns such as those 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 onwards).

In short, our two-regime MS model with time-varying transition probabilities applied to CIRP deviations (Dev) can be summarized as:

$$Dev_t = \alpha(s_t) + u_t, \quad u_t \sim N(0, \ \sigma^2(s_t)) \text{ where } s_t \in 1, 2 \tag{13}$$

[9] See the Chicago Board Options Exchange (2009) about compilation methodology.

where α presents an intercept and s suggests that this intercept will be estimated for Regimes 1 and 2. Furthermore, unlike Filardo (1994), our model considers regime-specific variance ($\sigma^2(s_t)$), and it is to be expected that volatility would be higher during the crisis period compared with normal circumstances due to the increased flow of new information in the former period. The estimation is carried out by maximizing the following log likelihood function:

$$\log f(Dev_2, Dev_3, ..., Dev_T | Dev_1; \boldsymbol{\Theta}) = \sum_{t=2}^{T} \log f(dev_t | I_{t-1}; \boldsymbol{\Theta}) \tag{14}$$

where Θ is a vector of parameters to be estimated and I_{t-1} contain all information on previous CIRP deviations (i.e., $Dev_{t-1}, ..., Dev_2, Dev_1$).

Table 6 summarizes the results from the MS model with time-vary transition probabilities and, provides clear evidence to support a multiple regime model. First, the variance terms in different regimes have a sizable difference. Notably, the variance in the crisis period (Regime 2) is higher than that at normal times (Regime 1), which confirms that Regime 2 contains observations during economic turmoil.

The constant terms (α) are also very different among regimes. Following standard presentation style in the literature, these parameters are presented as $\alpha(1)$ and $\alpha(1) + \alpha(2)$, and $\alpha(1)$ is significantly positive, regardless of the maturity length, in Regime 1. In contrast, $\alpha(1) + \alpha(2)$ turns out to be negative and often statistically significant. It follows that during economic turmoil (i.e., Regime 2), the deviation from the CIRP condition decreases (or a large negative number) on average, that indicates the increased level of the risk premium (Rp).[10] This is consistent with the expected relationship between our definition of financial turmoil (ρ) and the risk premium, and serves as an explanation of the forward premium puzzle (i.e., downward biased β_1 in Eq. 1).

Furthermore, the parameters in $\Phi(\cdot)$ are often negative, and either $b(1)$ or $b(2)$ is significant except for the one month maturity.[11] Their negative sign confirms that increases in financial uncertainty in Europe lead to decreases in CIRP deviations, again serving as an explanation of the forward premium puzzle.

The timing and duration of regimes are illustrated in Figures 3a and 3b using smoothed probabilities for Regimes 1 and 2 respectively. The smoothing technique

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[10]Since the parameter sign for $b(1)$ and $b(1) + b(2)$ is different and is statistically significant, we can conclude that $b(1)$ and $b(2)$ are statistically different without a further test.

[11]Instead of European financial market uncertainty, a proxy for the US counterpart could be used for the analysis.

essentially replaces the probability of a state at time t based on information at time t with information from an entire period (T).[12] According to Figure 3b, while there are some variations in the timing and duration of crises among maturity lengths particularly prior to 2008, there is quite clear consistency after the Lehman Shock. For a majority of time periods after 2008, smoothed probabilities have become more persistent than before and suggest that the economy is often in a crisis period.

The probabilities for each regime are also provided in Table 6, which suggests a higher probability for Regime 1 than Regime 2 (i.e., P_11 vs P_22). The average duration for Regime 1 is obtained as $1/(1 - P\_11)$, and that for Regime 2 as $1/(1 - P\_22)$. To be consistent with a higher probability of remaining in Regime 1, the average duration for Regime 1 is calculated often as over 2 time periods (or 2 months) and as less than 2 time periods for Regime 2. This relatively short average duration in both regimes implies high volatility in the risk premiums over time, and this similar length of regimes is due to a series of economic and financial crises after the sub-prime loan problem and Lehman Shock.

5   Conclusion

Using data including the recent crisis periods, this paper re-evaluates the forward premium puzzle for the Euro exchange rate which has close links with the Lehman Shock and the European sovereign-debt crisis. Unlike previous studies, we examine this puzzle from two perspectives; a traditional approach analyzing the sensitivity of interest rate differentials to the forward premium, and the other looking into the size and sign of CIRP deviations. Furthermore, in order to deal with the effects of a number of financial crises on the estimates, we applied the time-varying parameter model which helps us draw a time- or regime-specific conclusion.

Then, we provide evidence that the forward premium puzzle has become more significant during the Lehman Shock and thereafter. The parameter for interest rate differentials drops substantially to a level well below the theoretical value of unity. Similarly, there was a sizable decline (i.e., a negative increment) in CIRP deviations during the recent financial market turmoil, and the direction of changes in the CIRP is discussed as consistent with the forward premium puzzle. In other words, an increase in financial uncertainty in Europe will raise its risk premium, which will yield a downward bias on the parameter of the interest rate differential.

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[12]See Wang (2009) for details of the MS model estimation.

Thus, this study provides further evidence to Bansal and Dahlquist (2000) who distinguished the validity of the interest parity condition between developed and developing countries, and suggests that, even with the same pair of countries, the validity of the CIRP and the forward premium puzzle is very much dependent upon economic conditions.

Finally, our results also have some implications for a study on the integration of the world financial market. The CIRP condition has often been regarded as the most appropriate measure of market integration in the past (Frankel 1992). Yet our findings imply that one needs to exercise some caution about using the standard CIRP as a measure of international capital market integration. A rising risk premium, rather than change in administrative law, is the main driving force of the recent CIRP deviations since there was no major financial regulation imposed during this period in these countries.

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Appendix
Data Sources

- Forward exchange rates: Data for the maturity lengths 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 lengths of one, two, three, six, nine and twelve months are downloaded from DataStream.

- Financial market volatility index: the volatility index for Euroland, which measures expectations of volatility in a major stock price index (EURO STOXX 50) is 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,

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

Table 1. Basic statistics for the covered rate interest parity condition

	Obs	Mean	SE	Min	Max
fp^{1M}	160	-0.283	1.440	-2.935	1.963
fp^{2M}	160	-0.276	1.403	-2.825	1.956
fp^{3M}	160	-0.278	1.392	-2.874	1.946
fp^{6M}	160	-0.281	1.362	-2.780	1.899
fp^{9M}	160	-0.294	1.325	-2.763	1.873
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. Annualized rates.

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

	fp^{2M}	fp^{3M}	fp^{6M}	fp^{9M}	$fp1^{2M}$	$\widetilde{i}^{1M}$	$\widetilde{i}^{2M}$	$\widetilde{i}^{3M}$	$\widetilde{i}^{6M}$	$\widetilde{i}^{9M}$	$\widetilde{i}^{12M}$
fp^{1M}	0.997	0.994	0.982	0.968	0.956	0.971	0.969	0.964	0.954	0.944	0.933
fp^{2M}		0.999	0.992	0.981	0.971	0.974	0.976	0.972	0.965	0.957	0.948
fp^{3M}			0.996	0.987	0.978	0.973	0.976	0.974	0.969	0.963	0.955
fp^{6M}				0.998	0.992	0.968	0.974	0.974	0.976	0.974	0.969
fp^{9M}					0.998	0.958	0.966	0.968	0.975	0.976	0.975
$fp1^{2M}$						0.946	0.956	0.959	0.969	0.973	0.974
$\widetilde{i}^{1M}$							0.998	0.994	0.984	0.975	0.964
$\widetilde{i}^{2M}$								0.999	0.992	0.984	0.974
$\widetilde{i}^{3M}$									0.996	0.989	0.980
$\widetilde{i}^{6M}$										0.998	0.992
$\widetilde{i}^{9M}$											0.998

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	-0.128	-0.131	-0.152	-0.135	-0.130	-0.124
	(0.028)	(0.024)	(0.024)	(0.023)	(0.023)	(0.024)
$\widetilde{i}$	0.968	0.948	0.932	0.927	0.914	0.897
	(0.016)	(0.014)	(0.013)	(0.013)	(0.013)	(0.014)
H_0: $\widetilde{i} = 1$(t-value)	-2.000	-3.714	-5.231	-5.615	-6.615	-7.357
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	18.422	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	0.003	-0.004	-0.013	0.001	-0.008	-0.015
	(0.011)	(0.010)	(0.011)	(0.006)	(0.008)	(0.011)
$\widetilde{i}$	1.028	1.004	0.992	0.990	0.973	0.956
	(0.007)	(0.006)	(0.007)	(0.004)	(0.005)	(0.007)
H_0: $\widetilde{i} = 1$(t-value)	4.000	0.667	-1.143	-2.500	-5.400	-6.286
2008M9-2012M4						
Const	-0.219	-0.235	-0.308	-0.258	-0.185	-0.115
	(0.054)	(0.064)	(0.073)	(0.078)	(0.065)	(0.055)
$\widetilde{i}$	0.700	0.705	0.744	0.708	0.640	0.560
	(0.126)	(0.139)	(0.141)	(0.134)	(0.116)	(0.105)
H_0: $\widetilde{i} = 1$(t-value)	-2.381	-2.122	-1.816	-2.179	-3.103	-4.190

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

Table 4. Unit root tests applied for CIRP Deviations

Variables	ADF				Ziot-Andrews			
	Const		Const+Trend		Model A		Model B	
Dev^{M1}	-4.117	**	-5.008	**	-5.636	**	-5.434	**
Dev^{M2}	-3.352	*	-4.415	**	-5.214	*	-4.821	**
Dev^{M3}	-2.905	*	-4.744	**	-6.223	**	-5.480	**
Dev^{M6}	-3.460	*	-4.911	**	-6.156	**	-6.336	**
Dev^{M9}	-2.842	+	-3.912	*	-4.464		-4.566	*
Dev^{M12}	-2.672	+	-4.117	**	-4.777	+	-4.796	*

Note: The null hypothesis of nonstationarity is tested against the alternative of stationarity. Dev is CIRP deviations. The lag length is determined by the Akaike Information Criterion with the maximum of 12. The statistical significance is indicated by ** (1%), *(5%) and +(10%).

Table 5. The LR statistics for parameter stability

	Davis (1987)	
	LR	p-value
Dev^{M1}	187.35	0.000
Dev^{M2}	338.24	0.000
Dev^{M3}	413.74	0.000
Dev^{M6}	426.92	0.000
Dev^{M9}	387.77	0.000
Dev^{M12}	363.96	0.000

Note: Dev is CIRP deviations.

Table 6. Results from the MS model with time-varying transition probabilities

	$M1$	$M2$	$M3$	$M6$	$M9$	$M12$
$var(1)$	0.078	0.023	0.010	0.009	0.012	0.019
se	0.017	0.004	0.002	0.002	0.002	0.003
p	0.000	0.000	0.000	0.000	0.000	0.000
$var(2)$	1.705	1.597	1.401	1.560	1.681	1.658
se	0.193	0.217	0.226	0.401	0.462	0.421
p	0.000	0.000	0.000	0.000	0.000	0.000
$\alpha(1)$	0.418	0.466	0.534	0.492	0.459	0.456
se	0.038	0.019	0.012	0.011	0.013	0.017
p	0.000	0.000	0.000	0.000	0.000	0.000
$\alpha(1) + \alpha(2)$	-0.600	-0.599	-0.797	-0.805	-0.721	-0.652
se	0.331	0.325	0.285	0.299	0.303	0.312
p	0.072	0.067	0.006	0.008	0.018	0.039
$b(1)$	0.241	-1.173	-0.096	-0.134	-0.109	-1.163
se	0.245	0.505	0.143	0.137	0.158	0.497
p	0.326	0.022	0.503	0.330	0.491	0.021
$b(2)$	-1.469	-0.459	-1.104	-1.074	-1.014	-0.440
se	0.890	0.320	0.442	0.539	0.509	0.320
p	0.101	0.153	0.014	0.048	0.048	0.171
P_11	0.463	0.674	0.515	0.521	0.517	0.673
P_22	0.286	0.430	0.335	0.340	0.348	0.433
$Duration(1)$	1.862	3.067	2.062	2.088	2.331	3.058
$Duration(2)$	1.401	1.754	1.504	1.515	1.534	1.764

Note: Based on Eq. 12.

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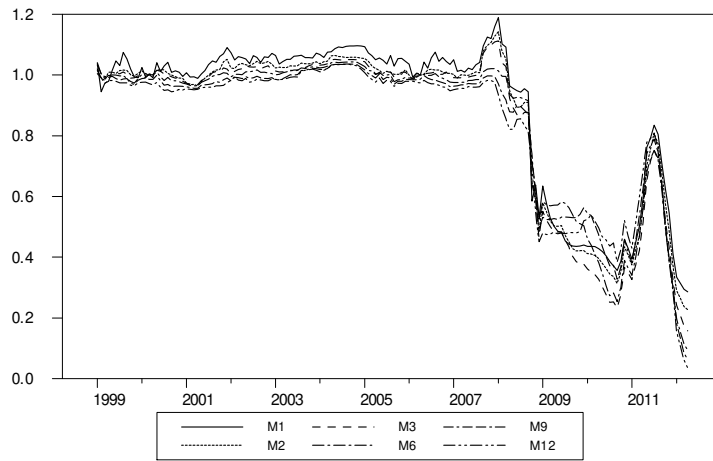
Note: M1 to M12 represent parameters (β_1) for a maturity of 1 to 12 months.

Figure 2. *Proxies for European financial market uncertainty*
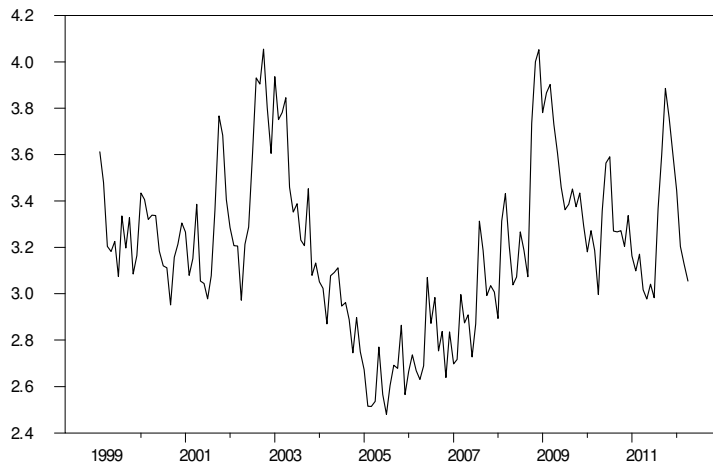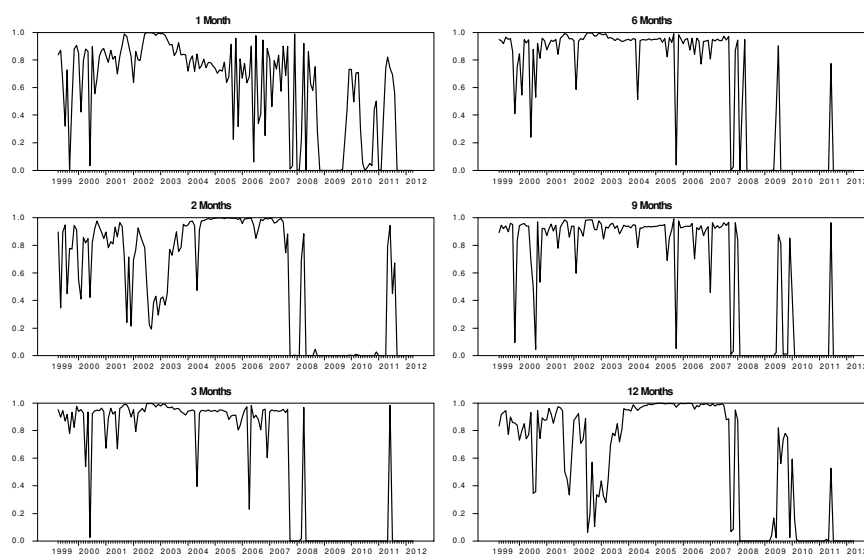
Figure 3a. Smoothed transition probabilities for Regime 1

Figure 3b. Smoothed transition probabilities for Regime 2