DOES RISK PREMIUM HAVE EXPLANATIVE POWER IN THE FORWARD PREMIUM PUZZLE?
A REVIEW OF UNCOVERED INTEREST PARITY AND ITS EMPIRICAL FAILURE.

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Abstract

One of the most studied topics in international macroeconomics and international finance is the empirical failure of uncovered interest parity condition which has come to be recognized as a stylized fact. In this paper I provide a brief review of interest parity theory and the so called *forward premium puzzle.* I have a closer look at the branch of literature that attempts to explain the puzzle with time-varying risk premia. Based on recent contributions to literature I investigate the validity of the risk premium approach and argue that time-varying risk premium explains part of the forward premium puzzle and, thus, should be taken into consideration in applications of uncovered interest parity.

The purpose of this work is not to contribute to existing literature but rather to provide a brief introduction to the topic and summarize the most convincing argumentation for the role of risk premium in the puzzle.

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Introduction

The theory of uncovered interest parity (UIP) provides a relationship between the interest rate on an asset denominated in one country's currency, the interest rate on a similar asset denominated in another country's currency, and the expected rate of change in the spot exchange rate between the two currencies. The assumption of uncovered interest parity is an important component of macroeconomic analysis of open economies. (Isard, 2006)

According to UIP theory, a high interest rate currency should depreciate against any lower interest rate currency such that the higher yields provided by the former are compensated in currency conversion. Otherwise there should be unreasonably high profits available on the market which contradicts with the assumption of market efficiency.

It has, however, become a widely recognized fact in international economics that the UIP condition does not hold empirically (e.g. Alexius, 2001; Ismailov & Rossi, 2018; Kumar, 2019). This failure is popularly referred to as *forward premium puzzle* and it has, indeed, become a stylized fact. The regression coefficients in UIP tests are not only inconsistent with the theory but also unstable over time. A whole branch of studies has arisen from this puzzle due to the importance of UIP in most international macroeconomic models as well as in the field of international finance.

Studies have attempted to reason the UIP failure with different arguments. Generally, the arguments can be divided in two main categories. The first category suggests that the systematic component of the UIP failure can be attributed to errors in market participants' expectations, in other words rejecting the assumption of rational expectations, due to which the expected values of exchange rates are biased. The second category of arguments sticks with the assumption of rational expectations and attributes a component of the puzzle to risk premium associated with currency exchange rates. The argument suggests that not all the market participants are risk neutral and that there are enough risk aversive participants to make the forward rate to deviate from the future spot rate. (Kumar, 2019)

Li et al (2011) say that "The time-varying risk premium is one of the most frequently cited reasons leading to the failure of UIP." Ismailov and Rossi (2018) argue that UIP holds when uncertainty is low and does not hold when uncertainty is high and, that large body of literature explains the UIP puzzle with time-varying risk premia, thus it is not really a puzzle. It sounds perhaps a little bold assumption that the exchange markets would systematically set the forward rates wrong, which makes the risk premium-related arguments seem more attractive.

In this paper I will have a look at the branch of literature that explains the UIP puzzle with risk premium associated with exchange rates. I will study the methods used and the conclusions made in the studies and provide a brief review of this branch of literature.

A notion for the reader: whenever mathematical formulation of exchange rates is used in this paper, the exchange rates denoted in lower case letters are logarithms, for example $x = ln(X)$.

1. Interest parity theory

To understand the UIP puzzle and the methods used to test the UIP condition, lets first have a look at the theory itself and its basic concepts. The historical origins of interest rate parity go back centuries (Levich, 2013). It was formalized in the early twentieth century by Keynes (1923) who paid attention to the rapid expansion of organized forward exchange trading after World War I, says Isard (2006). Forward exchange trading first gave birth to covered interest parity (CIP). It is obvious that forward exchange rates reflect expectations of future spot rates thus CIP was followed by UIP theory. UIP builds on CIP by assuming that market forces drive the forward exchange rate into equality with the expected future spot rate. (Isard, 2006) Therefore, lets have a look at the relationship between CIP and UIP theories to build understanding of the concept.

1.1 Covered interest parity

The basic concept of interest parity theory recognizes that at any time t investors have the choice of holding some asset denominated in domestic currency offering the domestic interest rate i^d between times t and t+k. The investors can optionally choose to invest in a similar asset denominated in another country's currency offering the foreign interest rate i^f for the same holding period. Lets assume that investors have 1 unit of domestic currency each. Investors can therefore accumulate a sum equivalent to $1 + i^d$ by investing in the asset denominated in domestic currency. They also have the option of converting into S_t units of foreign currency at the spot exchange rate and accumulate a sum equivalent to $S_t(1 + i^f)$ by investing in the foreign asset. If investors have an option to cover against uncertainty in future exchange rates in forward exchange market, they can then convert back to domestic currency after the holding period at the forward exchange rate $F_{t,t+k}$, which we can write as $\frac{1}{F_{t,t+k}}$ since the conversion rate is defined as foreign currency per unit of domestic currency in this example. Now we can write the market equilibrium, the condition of CIP:

$$1 + i^d = (1 + i^f)\frac{S_t}{F_{t,t+k}} \qquad (1)$$

The condition (1) postulates that interest rate differentials between the countries must be compensated by the factor associated with currency conversions such that the yields on domestic and foreign assets are equilibrated. If the CIP condition did not hold, there should be profitable arbitrage opportunities available in the market without exposing oneself to the risk associated with uncertainty in the future spot exchange rates.

1.2 Uncovered interest parity

Lets then consider the option of leaving the currency position uncovered. Investors can perform the operation described in the previous chapter without arranging the exchange rate at time t+k in forward. In this case they convert their foreign assets back to domestic account at future spot rate S_{t+k}. Investors now assess the future spot rate in terms of different probabilities, thus, the equilibrium now includes the expected value of future spot rate $E(S_{t+k})$ instead of the forward rate.

$$1 + i^d = (1 + i^f)E\left(\frac{S_t}{S_{t+k}}\right) \qquad (2)$$

The equation (2) is the UIP condition. It postulates that markets will equilibrate the return on the asset denominated in domestic currency with the uncovered foreign currency position.

Following Isard's (2006) reasoning, let's study the dynamics of the UIP condition by manipulating the equation (1) as follows. Let's first divide both sides by $1 + i^d$:

$$1 = \frac{1 + i^f}{1 + i^d} * \frac{S_t}{F_{t,t+k}}.$$

By taking a logarithm from both sides we get:

$$ln(1) = ln\left(\frac{1+i^f}{1+i^d}\right) + ln\left(\frac{S_t}{F_{t,t+k}}\right).$$

We can then manipulate the equation as follows:

$$-ln\left(\frac{S_t}{F_{t,t+k}}\right) = ln\left(\frac{1+i^f}{1+i^d}\right) - ln(1)$$

$$-\left(ln(S_t) - ln(F_{t,t+k})\right) = ln\left(\frac{1+i^f}{1+i^d}\right) - ln(1)$$

$$ln(F_{t,t+k}) - ln(S_t) = ln\left(\frac{1+i^f}{1+i^d}\right) - ln(1).$$

Now we can deduce:

$$ln(F_{t,t+k} - S_t) - ln(S_t) = ln\left(\frac{1+i^f}{1+i^d} - 1\right) - ln(1).$$

Since $ln(1)$ equals to zero we can drop it. Finally, let's remove the logarithmic form to get:

$$\frac{F_{t,t+k} - S_t}{S_t} = \frac{1+i^f}{1+i^d} - 1.$$

For values of $1 + i^d$ in the vicinity of 1, we can approximate:

$$i^f - i^d \approx \frac{F_{t,t+k} - S_t}{S_t}. \tag{3}$$

Furthermore, if we ignore Jensen's inequality[1], the UIP assumption can be approximated as:

$$i^f - i^d \approx E\left(\frac{S_{t+k} - S_t}{S_t}\right) = \frac{E_t(S_{t+k}) - S_t}{S_t}. \tag{4}$$

In equation (4) the interest rate differentials reflect information about market participants' expectations of future spot rates. We can see that the UIP assumption adds an element of dynamics to the CIP condition by hypothesizing a relationship between the observed values of variables at time t and the value of the spot exchange rate that market participants expect at time t to prevail at time t+1, hence the UIP assumption has been used in many multiperiod models of open economies says Isard (2006). In addition, he says, the UIP condition has been a central focal point in the policy debate over the effectiveness of official intervention in exchange markets according to Henderson and Sampson (1983). Besides the macroeconomic and policy implications the UIP condition is also one of the key relationships in international finance, hence the volume of discussion around the validity of the UIP assumption.

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[1] By Jensen's inequality $E_t\left(\frac{1}{S_{t+k}}\right) \neq \frac{1}{E_t(S_{t+k})}$. This would make us dependent on whether the exchange rate between some currencies *m* and *n* is defined as $\frac{n}{m}$ or $\frac{m}{n}$.

2. The empirical UIP failure

As earlier mentioned, the validity of UIP assumption has been disputed. Most of the empirical studies have reported findings that strongly suggest that the UIP condition does not hold.

UIP theory postulates that a high interest rate currency should depreciate against those with lower interest rates such that the higher yield is compensated in currency conversion. Alternatively, we can say that for UIP to hold, forward rate should be unbiased predictor of future spot rate. If we assume that the CIP condition holds, as it seems to be the case in empirical studies, interest rate differences are compensated in currency exchange when having covered position, just like described above. Therefore, future spot rate should equal to forward rate for UIP condition to hold. That is, the forward rate should be unbiased predictor of future spot rate. Currency appreciation or depreciation between time *t* and *t+k* should equal to the difference between $F_{t,t+k}$ and S_t.

However, there is large body of studies that have found regression coefficients suggesting exactly the opposite. A higher interest rate currency seems rather appreciate against those with lower interest rates or forward rate does not predict future spot rate at all (see for example Backus, Foresi, & Telmer, 1995; Fama, 1984; Kaminsky & Peruga, 1990; Li, Ghoshray, & Morley, 2012). Let's have a look at the empirical failure of UIP condition and the methodology used in the studies.

Anomalous estimates for coefficients in UIP regressions were first reported by Eugene Fama (1984), or he was at least one of the pioneers to really pay attention to this anomaly, thus his study is often referred to when talking about the forward premium puzzle. Regression equations similar to Fama's specifications have been used in many subsequent studies and similar findings have been reported with different data.

In his paper Fama (1984) tests a model for joint measurement of variation in the premium and expected future spot rate. In other words, he tests whether the differentials of forward rates for time *t+k* observed at *t* and spot rates at *t* $(F_{t,t+k} - S_t)$ contain information about differentials of spot rates $(S_{t+k} - S_t)$ ex post. Under the assumption of rational expectations these two differentials should correlate positively. That is, forward rates should be unbiased predictors of future spot rates for UIP to hold.

Fama (1984) starts theorizing that the forward rate $F_{t,t+k}$ can be split into expected future spot rate $E_t(S_{t+k})$ and time-varying premium P_t:

$$f_{t,t+k} = E(s_{t+k}) + p_t, \tag{5}$$

in which $f_{t,t+k} = ln(F_{t,t+k})$, $s_{t+k} = ln(S_{t+k})$ and $p_t = \ln(P_t)$.

From the equation (5) Fama (1984) then derives the difference between forward rate $\mathrm{f}_{\mathrm{t,t+k}}$ and spot rate $\mathrm{s_t}$ ($\mathrm{s_t} = \ln(S_t)$):

$$f_{t,t+k} - s_t = E(s_{t+k} - s_t) + p_t. \tag{6}$$

The equation (6) implies that the differential between variables observed at time *t* (the left-hand side) is split into expected currency depreciation (appreciation) and time-varying risk premium. Based on this equation Fama (1984) then defines the regressions of $f_{t,t+k} - s_{t+k}$ and $s_{t+k} - s_t$ (both observed at *t+k*) on $f_{t,t+k} - s_t$ (observed at *t*):

$$f_{t,t+k} - s_{t+k} = \alpha_1 + \beta_1(f_{t,t+k} - s_t) + u_{t+k}, \tag{7}$$

$$s_{t+k} - s_t = \alpha_2 + \beta_2(f_{t,t+k} - s_t) + u_{t+k}. \tag{8}$$

In the equations u_{t+k} is the random error.

Fama (1984) says that evidence of β_2 in (8) being reliably non-zero means that the forward rate observed at *t* has information about the spot rate to be observed at *t+k* and β_1 in (7) being reliably non-zero means that the premium component of $f_{t,t+k} - s_t$ has variation that reliably shows up in $f_{t,t+k} - s_{t+k}$.

Further, under the assumption of rational expectations (forward rates reliably predict future spot rates) and risk neutrality (no time-varying risk premium as in (6)), regression coefficients get theoretical values $[\alpha_1, \alpha_2 = 0;\ \beta_1, \beta_2 = 1]$. Now we have the UIP condition captured in a regression specification. For example, with null hypothesis $H_0\colon \alpha_2 = 0, \beta_2 = 1$ we could use the equation (8) to test if the UIP condition holds in data.

Scholars have then used similar specifications using spot rate differentials to test the validity of UIP assumption. These specifications are sometimes referred to as *the Fama regression*.

Let's define the UIP condition again only with the minimal difference to the equation (2), that the exchange rate S_t is now reciprocal $\frac{1}{S_t}$:

$$1 + i^d = \left(1 + i^f\right) E\left(\frac{S_{t+k}}{S_t}\right). \tag{9}$$

Taking natural logarithms of the equation (9) and applying rational expectations and risk neutrality assumptions we get to another typical regression specification used to test the UIP condition (see for example Li et al., 2012).

$$s_{t+k} - s_t = \alpha_3 + \beta_3\left(i^d - i^f\right) + u_{t+k}, \tag{10}$$

in which $s_{t+k} = \ln\left(S_{t+k}\right)$, $s_t = \ln\left(S_t\right)$ and u_{t+k} is the random error term. Logarithmic forms of exchange rates are used to deal with the Jensen's inequality problem, which was earlier tackled by using approximation in the vicinity of some particular point. In other words, using the logarithmic form we do not have to worry whether the currency conversion rate in the regression is defined as units of currency *m* per a unit of currency *n* or vice versa.

Under the null hypothesis that the UIP condition holds the regression coefficients in (10) again get theoretical values $\alpha_0 = 0$ and $\beta_0 = 1$.

In his paper Fama reported the β_2 in specification (8) getting, surprisingly, negative values which completely contradicts with the assumption of UIP. Fama tested spot rates and thirty-day forward rates on USD against nine major currencies. The value of β_2 coefficient ranged from -0.29 down to -1.58. (Fama, 1984)

Since then large number of studies have reported β coefficients significantly different from the theoretical values and often β is reported to be large and negative (e.g. Backus et al., 1995; Kaminsky & Peruga, 1990; Kumar & Trück, 2014). Froot & Thaler (1990) reported an average of -0.88 in over 75 studies. Zigraiova et al (2020) made an extensive meta analysis of forward premium studies and acquired average β of less than zero from 3,643 estimates in 91 published and peer reviewed studies. This empirical fact, the failure of UIP condition, constitutes the so called UIP puzzle (or forward premium puzzle).

As earlier mentioned, the UIP condition has important applications in international macroeconomics and international fincance. The equilibrium condition provided by UIP is, for example, a key equation in small open economy DSGE models. Because of its importance, the UIP condition has been used regardless of its empirical failure. For example, Adolfson et al (2008) explore the consequences of allowing negative correlation between the risk premium and the expected change in the nominal exchange rate (as described in the previous section, the β coefficient getting negative values) in a DSGE model because it cannot account for forward premium puzzle using standard UIP condition. Verdelhan (2010) says that many models in international macroeconomics and international finance do not produce time-varying risk premia and, as a result, in these models exchange rates and interest rates satisfy the UIP condition, even if it is completely rejected by the data. He says that these models assume that currencies with high interest rate depreciate, even if they appreciate on average.

Besides the problems that UIP failure poses on economic modelling, it is also a bothering grey spot simply for the idea of efficient markets. Negative slope coefficient in UIP regressions, that is, a higher interest rate currency appreciates against those with lower interest rates, implies that an investor who has a foreign position in higher interest rate currency does not only earn the spread between the domestic and foreign interest rates but also the return from foreign currency appreciation. Therefore, an investment strategy that exploits this anomaly can be profitable. This kind of investment strategy that exploits the UIP failure is called *carry trade* and it has, indeed, been successfully used.[2]

Against this background it is easy to see why there has been so much discussion around this topic and why all the effort in attempts to provide explanations for this puzzle. Let's see what kind of rationale studies have provided for this phenomenon.

2.1 Explanations for UIP failure

Scholars have speculated over a number of different explanations for the empirical UIP failure. These explanations can be roughly divided in two main categories. There are two possible fundamental reasons that can cause systematic deviations from UIP: time-varying risk premia and expectational errors.

The risk premium approach implies that some portion of market participants are risk aversive and when taking foreign positions, they want compensation for exposing themselves to the risk associated with exchange rate changes. It is then assumed that there are enough risk aversive market participants to make the forward rate to deviate from the spot rate. That is, we reject the assumption of risk neutral representative agent. If market participants were risk neutral, they would be indifferent between covered and uncovered positions since the returns should be equal on average. In fact, to be accurate, under the assumption of risk neutrality agents should slightly prefer the uncovered position due to transaction costs associated with covering the position in forward market, I speculate.

The reason for assuming the representative agent being risk aversive logically follows from the fact that CIP condition usually seems to hold but at the same time UIP does not seem to hold. That is, covered, risk-free foreign currency position does not provide extra yields compared to the domestic investment, but at the same time uncovered position seems to do so. As the expected returns for covered and uncovered positions should be the same, it must be that investors demand a premium for taking uncovered position.

The expectational errors approach postulates that markets systematically forecast changes in exchange rates wrong. As estimated β is usually negative, the prediction error should be to wrong direction if we assumed that expectational errors account for the whole deviation. Under the usual assumption of rational expectations errors are purely random. However, under certain conditions these errors might

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[2] Even though UIP failure can be exploited for profits, UIP is not an arbitrage condition (unlike CIP) since it includes an unknown element, the expected future spot rate. Even though carry trade exploiting UIP failure may be profitable in expectation, the probability distribution of $E(S_{t+k})$ exposes the investment strategy to uncertainty, which doesn't satisfy the definition of arbitrage, that is, risk-free profit.

be systematic over time say Campbell et al (2007). One of these is, they go on, so called “Peso problem”, which means that market participants anticipate changes in the underlying process generating the return distribution. Before investors learn about the true process, there may be a period during which expectational errors are systematic over time. The second is, they say, a monetary shock in form of a sudden shift in monetary regime.

There definitely is not consensus about the reason of UIP failure. Some studies claim that the puzzle can be attributed to expectational errors mostly (e.g. Bacchetta & van Wincoop, 2010; Campbell et al., 2007; Chakraborty & Haynes, 2005) while others say that time-varying risk premium has potential to solve a great deal of the forward premium puzzle or is at least significant in regressions, especially in emerging economies (e.g. Aysun & Lee, 2014; Kumar, 2019; Li et al., 2012).

The solution to the forward premium puzzle does not necessarily lie in just one of the two explanations. It is very possible (and perhaps likely) that these two factors exist simultaneously and together create the puzzle. Engel (1996) speculated over 20 years ago that future studies will very likely show that all these factors have a role in the puzzle. Now 24 years later it seems that he was right. Since then numerous studies have provided evidence of existence of each of these explanations. However, the risk premium approach has been somewhat more popular in literature.

2.2 The main explanations and the slope coefficient in OLS

Let’s study both of the two explanations from econometric perspective. How should they appear in standard OLS regression in theory? For example, Chakraborty and Haynes (2005) provide some reasoning to this question.

If time-varying risk premia and expectational errors are ignored, the slope coefficient β_2 in equation (8) is:

$$\beta_2 = \frac{Cov(s_{t+k} - s_t, f_t - s_t)}{Var(f_t - s_t)}. \tag{11}$$

By assuming that UIP holds, we can fix β_2 to 1.

In equation (5) we already defined forward rate including time-varying premium. Let’s rewrite it as:

$$E(s_{t+k}) = f_{t,t+k} - p_t, \tag{12}$$

Now the equation is adjusted to existence of risk premium. Instead, if the whole deviation from UIP is accounted to expectational error e_{t+k} we could write the future spot rate as:

$$s_{t+k} = E(s_{t+k}) + e_{t+k}. \tag{13}$$

Combining (12) and (13) we get:

$$s_{t+k} = f_{t,t+k} - p_t + e_{t+k}, \tag{14}$$

and by subtracting s_t from both sides we end up to familiar difference equation form, or Fama regression if you like:

$$s_{t+k} - s_t = (f_{t,t+k} - s_t) - p_t + e_{t+k}, \tag{15}$$

We can supplement the slope coefficient to account for covariation between time-varying risk premium and exchange rate differential and covariation between expectational error and exchange rate differential:

$$\beta_3 = 1 - \frac{Cov(p_t, f_t - s_t)}{Var(f_t - s_t)} + \frac{Cov(e_{t+k}, f_t - s_t)}{Var(f_t - s_t)}. \qquad (16)$$

β_2 is fixed to 1 in the equation (16). The two other terms capture the effect of time-varying risk premium and expectational error on the slope coefficient. If p_t was zero, that is, no time-varying risk premium exists, the second term would collapse to zero. Similarly, if there was no expectational error ($e_{t+k} = 0$), the last term would collapse to zero. Thus, if there were no time-varying risk premium and expectational error, the equation (16) would collapse to 1. The slope coefficient β would get the theoretical value that was earlier discussed. If the time-varying risk premium and the expectational error are excluded from the forward premium OLS regression and β_2 in (8) and (11) gets values inconsistent with the UIP theory (as it usually does), the second or the third term (or both) in (16) should cover the deviation from the theoretical value of β.

The failure of UIP condition can be theorized in quite simple and straightforward way as shown above. In a way we could say that the forward premium puzzle is solved in theoretical level assuming that time-varying risk premia and expectational errors really are to be blamed for the deviations. However, the real problem is how to capture the effect of time-varying risk premia and expectational errors in real data. It is challenging to control them in OLS. We cannot simply add control variables to fix the problem because we do not have such variables that could reliably capture these effects. Therefore, more econometric methods are required in order to show the existence of time-varying risk premia or expectational errors.

2.3 Arguments in favor of risk premium approach

The risk premium approach has been more popular in literature. There is reasonable arguments that may suggest time-varying risk premia being more important piece in the puzzle over expectational errors, or at least strongly speak for the existence of such phenomenon.

Firstly, forward premium has been shown to be persistent through time. For example, Maynard and Phillips (2001) studied the time series properties of forward premium and found out that forward premium is highly persistent, not just occasional phenomenon. As discussed above, the expectational errors, on the other hand, are related to anticipated changes or shocks in the return distribution generating process. Shocks appear randomly and distort investors' perceptions about the process. When investors learn about new properties of the process, the deviation from UIP gradually disappears. Peso problem might be more persistent where one occurs. However, it seems unlikely that this phenomenon could exist so widely through all periods, rather as an exceptional situation. Therefore, deviations from UIP due to expectational errors should be mostly transitory by nature rather than persistent through time.

Using new exchange rate uncertainty index Ismailov and Rossi (2018) show that deviations from UIP are stronger during periods of high uncertainty while UIP tends to hold better during periods of low uncertainty. This result sounds reasonable: investors want bigger risk premium when uncertainty is high, thus time-varying risk premium is consistent with Ismailov and Rossi's finding.

Also, time-varying risk premium seems to possess more explanative power in emerging economies than in developed economies (Kumar, 2019; Li et al., 2012). It seems quite logical that investors want more risk premium when holding more risky developing currencies, thus the UIP failure and the role of risk premium is more prominent in emerging countries.

Considering the convincing evidence in favour of risk premium arising from the literature, it seems that time-varying risk premia play important role in the forward premium puzzle, even though expectational errors are very likely to have explanative power as well.

Due to the scope of this work I will next focus on the role of risk premium in the forward premium puzzle. Taken the volume of research on the forward premium puzzle it is impossible to make full literature review within the boundaries of this work. I will leave out the expectational-errors-related branch of literature as well as other smaller streams of research.

I will next have a closer look at few of the most interesting recent contributions to the risk premium explanations. I will study two methods that have been used to capture the variation in forward premium ($f_{t,t+k} - s_t$) due to time-varying risk premium (p_t), in other words the covariation between forward premium and time-varying risk premium, and to control the uncertainty of environment in the relationship between interest rate and exchange rate differentials.

GARCH class models (generalized autoregressive conditional heteroskedasticity) have been used in several studies regarding the forward premium puzzle since they can recognize the heteroskedasticity of the error term. The time-varying risk premium manifests itself as such heteroskedasticity if it exists. Kumar (2019) and Li et al. (2012) found promising evidence of time-varying risk premium using component-GARCH-in-mean model.

Ismailov and Rossi (2018) shew that the OLS parameters in forward premium regressions are highly unstable over time. In other words, several structural breaks existed in their data, implying that some factor is changing the relationship between interest rate differentials and exchange rate differentials over time. They then supplemented traditional OLS regression with new kind of uncertainty measure and obtained parameter estimates more consistent with the theory.

2.4 Time-varying risk premium

So far we have been talking about time-varying risk premium without giving any attention to the reason why time-varying premium instead of risk premium that is constant over time. As we are specifically interested of anomalous values of the slope coefficient β in forward premium regressions, the reason may be obvious when looking at equation (8), for example. As we are examining OLS regression based on time series data, any time-constant effect is captured by α in regression specifications seen above, whereas time-varying risk premium is captured by the OLS residual and its correlation with the exchange rate changes biases the β estimate. If there is a risk premium that does not vary in time, it does not show up in the slope coefficient and thus, does not help us to explain the forward premium puzzle. Even though studies have also reported nonzero values of α, that is, deviations from the theoretical value ($\alpha = 0$) as discussed earlier, the focal point is the slope coefficient β. This is due to the fact that β is consistently reported to be negative, which, as discussed, is especially contradictory with the theory.

3. Measuring the time-varying risk premium using CGARCH-M model

As discussed, if we assume that part of the forward premium puzzle can be attributed to a time-varying risk premium, we face the question of how to capture its effect in data. How to quantify it once we have perhaps made reasonable qualitative arguments for existence of such effect?

Using newer time series techniques scholars have attempted to capture different components behind the volatility of forward premium and changes in the volatility. Promising results have been found using GARCH class models (e.g. Aysun & Lee, 2014; Kumar, 2019; Li et al., 2012; Poghosyan, Kočenda, & Zemčik, 2008). The main benefit of GARCH class time series models is that they can recognize heteroskedasticity of the error term, in other words the conditional variance of the time series. This heteroskedasticity implies that there may be some time-varying component causing fluctuations in volatility that has been excluded from regressions so far. Behind this heteroskedasticity may very well be the time-varying risk premium as already discussed.

Especially, using CGARCH-M model (Component-GARCH-in-mean) Kumar (2019) and Li et al (2012) show that time-varying risk premium is significant in most countries included in their studies. Many researchers find CGARCH a superior volatility model as it can decompose volatility in different components. Kumar (2019) found out that as high as 73% of the beta coefficients included in his study range between 0.5 and 1.5 for both advanced and emerging countries in presence of time-varying risk premium (that is, using CGARCH-M model) compared to only 34% when time-varying risk premium is excluded (OLS regression model). Li et al (2012) found out that the β coefficient is statistically much more significant when risk premium is included than what it is when using standard OLS regression. Therefore, lets study the basic idea of CGARCH-M model to understand how it may help us to measure risk premium in exchange rates and therefore solve the forward premium puzzle, at least partially.

Time-varying risk premium was included in forward rate in equation (5). As discussed in the previous chapter, we must take into consideration that the risk premium can be further divided into different components and we should somehow capture it in order to see what proportion of risk premium accounts to the constant α and what proportion to the slope coefficient β. Domowitz and Hakkio (1985) formulated this division of risk premium into constant and time-varying components as:

$$P_{t+k} = \alpha_4 + \theta\sigma_{t+k}, \tag{17}$$

in which α_4 is the constant risk premium and σ_{t+k} is the conditional component of the standard deviation of the error term in forward premium regression. Therefore, the time-varying risk premium is some proportion θ of the error term's standard deviation. Combining (10) and (17) we get:

$$s_{t+k} - s_t = \alpha_4 + \beta_4\left(i^d - i^f\right) + \theta\sigma_{t+k} + u_{t+k}. \tag{18}$$

Equation (18) depicts the conditional mean, that is, the predicted value for exchange rate change. The specification now includes the conditional standard deviation of the error term. The specification implies that if the volatility of the error term (σ_{t+k}) increases, the exchange rate change ($s_{t+k} - s_t$) increases, in other words the currency appreciates, and if the volatility of the error term decreases, the currency depreciates (or at least the exchange rate differential decreases). This is consistent with the assumption that investors holding the currency want the bigger risk premium the higher is the volatility of the exchange rate.

The conditional variance σ_{t+k} in (18) is formulated as follows:

$$\sigma_{t+k}^2 = \gamma_0 + \gamma_1 u_t^2 + \gamma_2\sigma_t^2. \tag{19}$$

The conditional variance at time *t+k* depicted in (19) is a function of conditional variance in preceding period *t* and the random error (or white noise) in the preceding period *t*.

Equations (18) and (19) together form the basis for CGARCH-M model that was used by Li et al (2012) and Kumar (2019). CGARCH-M model can decompose the volatility of time series in permanent and transitory components, since volatility varies through time, which is the main reason behind using the model, says Kumar (2019). The permanent component is assumed to be driven by macroeconomic fundamentals, while the transitory component reflects short-term market movement such as trading and other microstructure issues, he continues. In equation (19) the constant γ_0 represents the permanent component of volatility and reflects long-run macroeconomic fundaments, as described above. γ_1 and γ_2 represent the transitory component that varies through time and is driven by, for example, market sentiment. In equation (19) this transitory component is determined by previous value and previous volatility of the random error in (18).

Kumar (2019) and Li et al (2012) further supplement the CGARCH-M model defined by (18) and (19) with asymmetric effect in order to better capture the effects of unexpected shocks and uncertainty in economy such as 2008 financial crisis. Foerster (2014) says that uncertainty creates asymmetric effects in economy. Sudden rise in uncertainty causes changes in different economic variables. Once the uncertainty decreases, the rebound in economic activity may not cover the initial effect which suggests that spikes in uncertainty may produce persistent effects in economy. This may very well apply to changes in exchange rates that are caused by sudden shocks and spikes in uncertainty.

The CGARCH-M model supplemented with asymmetric effect as in studies by Kumar (2019) and Li et al (2012) is defined by a set of equations as follows:

$$s_{t+k} - s_t = \alpha_4 + \beta_4\left(i^d - i^f\right) + \theta\sigma_{t+k} + u_{t+k}$$

$$q_{t+k} = \gamma_1 + \gamma_2(q_t - \gamma_1) + \gamma_3(u_t^2 - \sigma_t^2)$$

$$\sigma_{t+k}^2 = q_{t+k} + \gamma_4(u_t^2 - q_t) + \gamma_5 D_t(u_t^2 - q_t) + \gamma_6(\sigma_t^2 - q_t) \tag{20}$$

We are already familiar with the first equation in (20) since it is formally the same as (18). The conditional variance is now decomposed further in more specific components defined by the latter two equations.

The second equation q_{t+k} is the permanent component of the conditional variance. It reflects the effect of long-run macroeconomic forces on the volatility. q_{t+k} converges towards the long-run time-invariable volatility level γ_1 with magnitude of γ_2. It means that γ_2 gets values from zero to one and, as $(q_t - \gamma_1)$ is the deviation from long-run volatility in period *t*, the smaller the value of γ_2 the quicker the system converges towards long run volatility driven by macroeconomic forces. The term $\gamma_3(u_t^2 - \sigma_t^2)$ tells how shocks affect the long-run volatility.

The third equation gives us the conditional variance in period *t+k*. It includes the permanent component q_{t+k} given by the second equation. D_t is a dummy variable for asymmetric effects of exchange rates. For an unexpected currency appreciation D_t equals one for $u_{t+k} < 0$, otherwise D_t equals zero. The model assumes that the effect of random error on the conditional variance is different when the random error is negative than what it is when the random error is positive, hence the condition $u_{t+k} < 0$ for D_t to get value of one. This is the modelling of asymmetric effects: unexpected currency depreciations (u_{t+k} is negative in the first equation) increase volatility through the term that includes the dummy variable conditional on the sign of the u_{t+k} but similar appreciations do not have that effect. As earlier theorized, unexpected shocks in economy may have persistent effects. This dummy variable approach attempts to catch that asymmetry. If γ_5 is negative, the effect is inverse.

$\gamma_6(\sigma_t^2 - q_t)$ and $\gamma_4(u_t^2 - q_t)$ are the short-run transitory components of the conditional variance. These components together are driven by market microstructure issues and reflect the current sentiment of market participants.

We have now defined the conditional variance of exchange rate difference. It consists of three components: the long-run macroeconomic component q_{t+k}, the short run volatility given by γ_4 and γ_6 and the asymmetric effect given by γ_5.

Finally, for the system to be stable, it must be that $\gamma_2 > \gamma_4 + \gamma_6$. This condition implies that the short-run volatility converges quicker than the long-run volatility. Otherwise the short-run component would dominate the process.

3.1 CGARCH-M estimation results

Perhaps the most important recent contribution to the study of risk premium's role in the UIP puzzle has been by Li et al (2012) and Kumar (2019) who both use the abovementioned CGARCH-M model. Most importantly the study by Li et al (2012) is the first time CGARCH model is used to measure the risk premium in UIP. They say that the financial and credit crises included in their sample period (Asian crisis 1997 and financial crisis 2008) have caused rapid changes in risk across the world. These rapid changes are exactly what CGARCH-M model adjusted with asymmetric effects can potentially measure and that is the reason for using the model. However, the sample period used by Li et al (2012) covers up to 2009, thus post-financial crisis period is not well included. Kumar (2019) continues the work by including more countries and longer time span.

Both of the studies share the same main result: risk premium is significant and it is important part of modeling exchange rates. Therefore, it should be taken into account in theoretical and empirical models. Also, both of the studies find out that the risk premium is more prominent in emerging economies than in developed economies. It makes sense if we think that investors demand bigger risk premium when it comes to more risky emerging currencies.

Li et al test currencies of five developed and five emerging countries against USD. First, they run conventional OLS regression for their data. OLS estimates for β range from -2.1875 to 1.0768. They report mostly negative and insignificant β estimates for developed countries which is similar to earlier empirical studies. Emerging countries get positive but mostly insignificant β estimates. (Li et al., 2012)

CGARCH-M estimation results in Li et al (2012) study suggest that the model performs better than OLS in terms of UIP even though the improvement is not especially big. The β coefficients are positive and significant for three of the five emerging countries and for two of the emerging countries β has increased and is close to the theoretical value of one. The β coefficients for the five included developed countries are all negative and significant except one that is insignificant. The risk premium coefficient, θ in (20), is insignificant in three out of ten countries. This may be, they say, due to poor measure of risk or misspecification of the model. That is, the conditional variance may not be a proper measure of risk or the univariate GARCH-M model is not an appropriate model to estimate the risk premium. The GARCH-M model, however, performs notably better than the conventional OLS regression in the study of Li et al (2012).

Kumar (2019) continues the attempt to address UIP failure to risk premium using the same CGARCH-M model as the earlier study by Li et al (2012). As said, the biggest improvement in Kumar's study is that he notably extends the scope of the study. Compared to ten countries studied by Li et al, Kumar includes 44 countries in his study, 22 of which are developed economies and 22 emerging economies by IMF's definition. Kumar also extends the time series to cover up to 2017 whereas the earlier study by Li et al included data up to 2009.

Kumar (2019) finds stronger evidence of existence of risk-premium in exchange rates than Li et al (2012). Kumar as well first runs conventional OLS regression to test UIP. β estimates for advanced countries from OLS regression range from -1.715 to 2.173 with mean of 0.544. Out of 22 advanced countries the β is significantly different from one only for six currencies at least at 5% significance level, which suggests that UIP holds quite well in developed economies. On the other hand, Kumar reports negative and significant β estimates for 18 out of 22 emerging countries. They range from

-3.629 to 3.384 with mean of -0.493. This result suggests that UIP failure is more prominent in emerging economies. As discussed above, Kumar suspects that explanation for this result may be that investors want compensation for holding more risky developing currencies and, as a result UIP condition gets broken if the risk premium is not taken into consideration.

Using CGARCH-M model Kumar (2019) then finds out that β coefficients in general move closer to one. Out of 22 developed countries only in two the β is negative and significantly different from one, whereas the null hypothesis was rejected for six out 22 advanced countries in OLS regression. β ranges from -0.618 to 1.431 with an average of 0.673 in developed countries. An encouraging finding by Kumar is that the coefficient for conditional variance (θ), that is, the time varying risk premium as earlier discussed, is significantly negative for exactly those six developed countries whose β was negative and significant in OLS regression. This finding strongly suggests that time-varying risk premium has explanative power in UIP deviations. The intercept α, implying existence of constant risk premium, is significant for four developed countries.

For half of the emerging economies Kumar (2019) observes significant intercept α, which is considerably more than among developed economies. The finding is consistent with the assumption that investors want bigger risk premium for holding more risky emerging currencies. The β coefficient is negative and significantly different from the theoretical value only for four emerging countries, which is a huge improvement from OLS model that gave negative and significant values for 18 out of 22 emerging countries. As with the developed countries, also for the emerging economies the time-varying risk premium coefficient θ gets negative and significant values with exactly the same countries that got values of β negative and significantly different from one in the OLS regression. The result strongly speaks for existence of time-varying risk premium. The β from CGARCH-M for emerging countries range from -1.289 to 1.583 with an average of 0.611.

Figures 1 and 2 show the frequency distributions of β coefficient from OLS and CGARCH-M models respectively in Kumar's (2019) study. The figures clearly show that that CGARCH-M model performs better in terms of UIP condition. The values of β are gathered closer to the theoretical value of one in the figure 2, while they are clearly more scattered around the scale in figure 1.

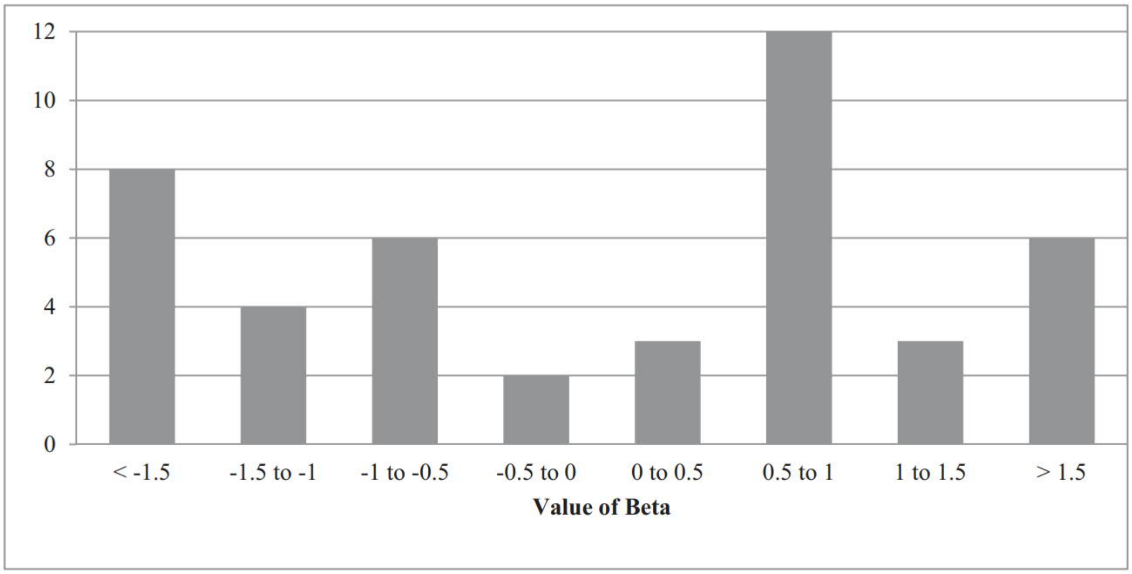

Figure 1*: Frequency distribution of beta coefficients from OLS regression (Kumar, 2019).*

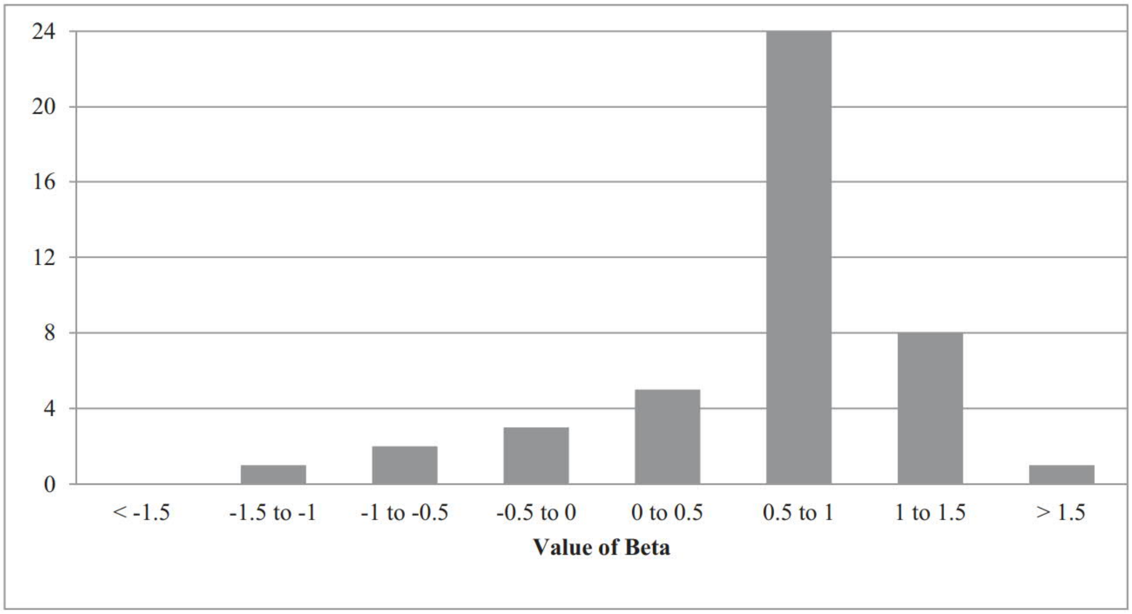

Figure 2*: Frequency distribution of beta coefficients from CGARCH-M model (Kumar, 2019).*

In his study Kumar (2019) shows strong evidence of existence of risk premium in exchange rates. Kumar concludes that his results suggest that considering risk premium in the UIP equation provides encouraging results in that the UIP puzzle disappears especially for emerging countries. He further concludes that risk should be evaluated in terms of permanent and transitory components as it is the key for the CGARCH-M model to measure the risk premium and thus to find slope coefficients more consistent with the UIP theory.

4. UIP condition in low and high uncertainty environments

As we saw in the previous chapter, the CGARCH-M approach by Li et al (2012) and Kumar (2019) provided results that strongly suggest that UIP failure and existence of risk premium are more prominent in emerging economies. As we reasoned, this finding makes sense as emerging economies are generally perceived riskier by investors, thus higher risk premium. Consistent with this reasoning is a study by Ismailov and Rossi (2018) who argue that deviations from UIP condition are more prominent in high uncertainty environments in contrast with lower uncertainty environments.

It doesn’t apply only to comparison between countries but also within a country as uncertainty of the environment varies through time. Shocks to macroeconomic fundamentals can create persistent effects in economy, as discussed earlier, thus we can see periods of lower and higher uncertainty following one another within a country.

Ismailov and Rossi (2018) say that “--uncovered interest rate parity is more likely to hold in low uncertainty environments, relative to high uncertainty ones, since arbitrage opportunity gains become more uncertain in a highly unpredictable environment, thus blurring the relationship between exchange rates and interest rate differentials.” In their paper Ismailov and Rossi introduce a new exchange rate uncertainty index that measures how unpredictable exchange rates are relative to their historical past. They then use the uncertainty index to study five industrialized countries and see whether the UIP condition holds better in low uncertainty environments.

Empirical evidence provided by Ismailov and Rossi (2018) is consistent with earlier findings in this literature review and provides more evidence for existence of risk premium and its explanative power in the UIP puzzle. Lets therefore study the paper by Ismailov and Rossi.

In their study Ismailov and Rossi (2018) focus on industrialized countries and include five currency pairs: the Swiss franc, the Canadian dollar, the British pound, the Japanese yen, and the Euro against the US dollar using data between 1993 and 2015.

4.1 Parameter instability – further evidence of time-varying risk premia

Ismailov and Rossi (2018) first drive traditional OLS regression postulated by equation (10) to test the UIP condition for the specified countries. As expected, they obtained α and β parameters inconsistent with the theory. They then use a set of tests to test for parameter stability, in other words to find out if there is structural breaks in the data. These tests include Quandt Likelihood Ratio test (QLR), Exponential-Wald (Exp-W) and Nyblom's test. Based on these tests Ismailov and Rossi report that parameter stability is overwhelmingly rejected without a doubt. They further investigate whether the parameter instability is stronger in the intercept α or the slope β. They find out that α is unstable in all five countries included in the study except the UK and β unstable in all the countries. The parameters should therefore be considered as $\alpha = \alpha_t$ and $\beta = \beta_t$.

Using the abovementioned tests Ismailov and Rossi (2018) further test the null hypothesis $H0\colon \alpha_t = 0, \beta_t = 1$, that is, they test if the empirical rejection of UIP condition is robust to parameter instabilities. They find out that UIP does not hold regardless the parameters are assumed to be stable or not.

The reported parameter instability is further evidence of time-variability in the relationship between interest rates and exchange rates. The result is consistent with earlier findings and reasoning of this review. The OLS estimator is biased and, additionally, its biasedness varies over time. As mentioned, some studies report that there seems to be periods during which the UIP tends to hold better. This time-variability is exactly the effect that Li et al (2012) and Kumar (2019) as well attempted to capture by measuring the conditional variance of the error term (heteroskedasticity) with CGARCH-M model, as discussed in chapter 3.

Ismailov and Rossi (2018) confirm the existence of two pieces of the UIP puzzle that have been found in empirical literature: UIP coefficients are different from their theoretical values and unstable over time. Ismailov and Rossi then attempt to provide an explanation for both of these pieces by arguing that uncertainty is one of the reasons behind these empirical findings.

4.2 Supplementing the UIP regression with an uncertainty measure

Rossi and Sekhposyan (2015) introduced a macroeconomic uncertainty index based on comparing the realized forecast error of a macroeconomic variable of interest with the historical forecast error distribution of the same variable. The uncertainty index is then used by Ismailov and Rossi (2018) in attempt to control the time-variability bias in UIP regressions.

Rossi and Sekhposyan (2015) define the forecast error for some scalar variable y_{t+k}:

$$e_{t+k} = y_{t+k} - E_t(y_{t+k}).$$

Forecast error's historical distribution (probability density function) is denoted as $p(e)$. The uncertainty index is based on cumulative density of forecast errors evaluated at the actual realized error:

$$U_{t+k} = \int_{-\infty}^{e_{t+k}} p(e),$$

thus, if the realized forecast error is found to be on the tails of its own historical distribution, it implies that uncertainty is high. The index gets values between zero and one by its formulation. Values at the left tail, that is values close to zero, imply a negative shock to the underlying variable, and values at the right tail, that is values close to one, imply a positive shock to the underlying variable.

The index U_{t+k} as itself is not very useful control measure in regressions as it does not express the uncertainty unambiguously: the value depends on whether the uncertainty is negative or positive by nature. Rossi and Sekhposyan (2015) therefore develop the index further.

$$U_{t+k}^{*} = \frac{1}{2} + \left| U_{t+k} - \frac{1}{2} \right|. \tag{21}$$

The uncertainty index as formulated in (21) gives values between 0.5 and 1. As value 0.5 from cumulative density function expresses the expected outcome, that is, forecast error being zero, values close to 0.5 from the uncertainty index U_{t+k}^{*} indicate low uncertainty and values close to 1 indicate high uncertainty, no matter whether the forecast error is negative or positive.

Ismailov and Rossi (2018) use the uncertainty index depicted in equation (21) to investigate if there is correlation between the uncertainty index and deviations from UIP condition. They plot a rolling estimate of parameters α_t and β_t for each country in their study and the uncertainty index. The plots indeed show some hints that the parameters could be closer to their theoretical values during periods of low uncertainty.

Ismailov and Rossi (2018) then further investigate the connection between uncertainty and deviations from UIP by estimating the following regression:

$$E(s_{t+k} - s_t) = \alpha_5(1 - D_t) + \beta_5(1 - D_t)(i_{t+k} - i_{t+k}^{*}) + \alpha_6 D_t + \beta_6 D_t(i_{t+k} - i_{t+k}^{*}), \tag{22}$$

in which D_t is a dummy variable equal to one if the uncertainty is exceptionally high. Ismailov and Rossi define high uncertainty as situations in which uncertainty U_{t+k}^{*} in the upper quartile of its distribution. In other words, they identify periods of high uncertainty with sub-samples including 25% highest values of uncertainty.

The equation (22) is an UIP regression conditional on whether the uncertainty is exceptionally high or not. α_5 and β_5 are parameters for periods of not exceptionally high uncertainty ($D_t = 0$) whereas α_6 and β_6 are parameters for periods during which uncertainty is exceptionally high ($D_t = 1$).

Results from the regression (22) show that empirical evidence in favour of UIP condition is considerably stronger during periods of low uncertainty. I gathered data of the reported α and β estimates with 95% confidence intervals during periods of low and high uncertainty in Ismailov and Rossi's (2018) study and illustrated the estimates with box plots (figures 3 and 4). Graphical illustration of the estimates reveals the dramatic difference between low and high uncertainty periods. During low uncertainty periods confidence intervals are much narrower and the estimates are closer to their theoretical values $\alpha = 0$ and $\beta = 1$. Ismailov and Rossi's (2018) finding that UIP is more likely to hold during low uncertainty periods is strong evidence for the assumption that risk premia have an important role in explaining the UIP puzzle.

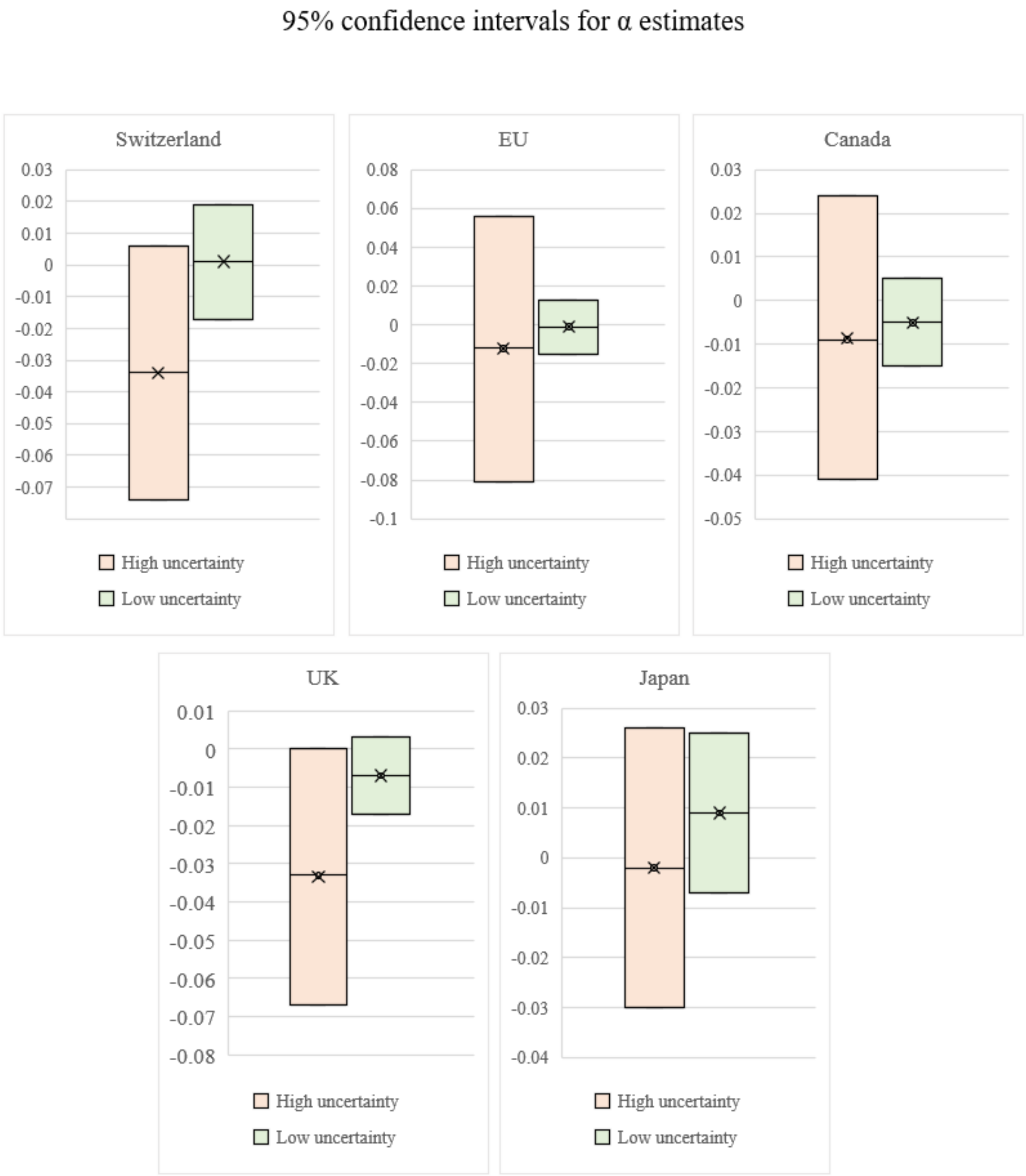

Figure 3*: Estimates of alpha parameter with 95% confidence intervals in the study by Ismailov and Rossi (2018). The estimates are based on the regression specification (22).*

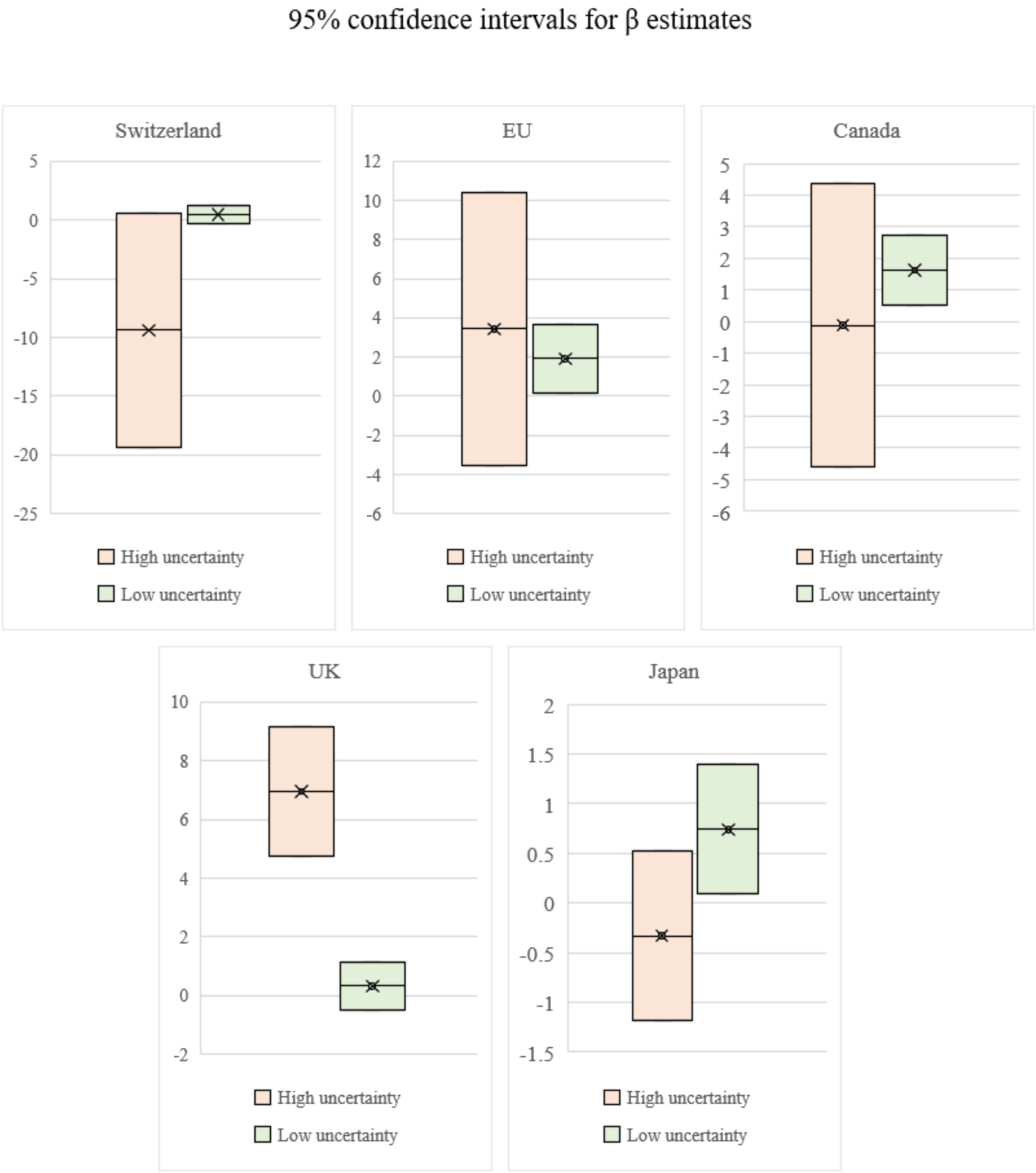

Figure 4: *Estimates of beta parameter with 95% confidence intervals in the study by Ismailov and Rossi (2018). The estimates are based on the regression specification (22).*

5. Conclusions

We have now taken a brief look into the interest parity theory and the empirical failure of UIP. We have speculated whether risk premia could help explain the anomalous values observed in empirical studies of UIP. Finally, by having a look at a few quite recent studies exploring the role of risk premia in the forward premium puzzle, we saw solid evidence suggesting that time-varying risk premium can explain substantial part of deviations from the theoretical values.

Li et al (2012) and Kumar (2019) used CGARCH-M model to deal with heteroskedastic errors and asymmetric effects and to measure time-varying risk premium. They both shew that the conditional variance in data, in other words the time-varying risk premium, is significant. They also found out that deviations from UIP are more prominent in developing countries which, as we reasoned, is consistent with the assumption of risk premium as investors perceive currencies of developing countries riskier than those of advanced countries. Kumar further shew that the slope coefficients obtained from CGARCH-M model are substantially closer to the theoretical value of unity when compared to those obtained from traditional OLS regression. Therefore, considering time-varying risk premium seems to help satisfy the UIP condition.

Ismailov and Rossi (2018) shew that the OLS regression that has traditionally been used to test the UIP is invalid because it assumes stable parameters while in reality the parameters are highly unstable. They found out that their data sample included several structural breaks suggesting that the connection between interest rates and exchange rates varies over time. Ismailov and Rossi suspected that this might be due to time-varying macroeconomic uncertainty, thus their results are naturally linked to time-varying risk premia. They then used a new macroeconomic uncertainty index to measure this variation. They found out that UIP condition is more likely to hold in low uncertainty environments in contrast to high uncertainty environments. This is more evidence in favour of time-varying risk premia as a key to the forward premium puzzle.

It makes very much sense to think that when uncertainty is low and the environment is highly predictable, the financial markets are more strongly driven towards the equilibrium because arbitrage opportunities are easier to exploit in predictable environment. Therefore, the UIP condition is more likely to hold during low uncertainty periods in contrast to high uncertainty periods. I suspect that more generally different theoretical frameworks tend to work better in highly predictable, low uncertainty environments, while unexpected shocks create confusion and potentially make different equilibrium conditions deviate from their theoretical values.

I am not suggesting that risk premia can explain the whole forward premium puzzle as expectational errors are likely to have explanative power as well. However, studies have provided such strong evidence of existence of time-varying risk premium that it cannot be ignored. There is still great deal of work to do in order to create such model that could satisfy the UIP condition in all environments. Regardless of open questions that still require further research, adjusting the current implications of UIP to account for time-varying risk premium could improve their performance.

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