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Long-run UIP Holds even in the Short Run

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Long-run UIP Holds even in the Short Run*

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Abstract

The failure of uncovered interest rate parity to explain short-term interest rate movements is well-documented. We show that *short-term* changes in *long-term* interest rates do help explain short-term exchange-rate movements. The relationship gets stronger over our sample period, as the liquidity of the exchange rate market increased. We also show that controlling for time-varying exchange-rate risk also helps improve the fit of the relationship.

Keywords: Currencies, long-term interest rates, uncovered interest parity.

JEL Classification Codes: F31, F37, G15.

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1 Introduction

Uncovered interest parity (UIP) is one of the oldest theories in economics (Fisher (1896)). It provides an attractive explanation for the behavior of exchange rates – exchange rates adjust to equalize returns on loans across countries. This means that high interest-rate currencies will depreciate relative to low interest-rate currencies. Unfortunately, empirical research has not been kind to this hypothesis. Not only do exchange rates not adjust in the direct predicted by the theory, but in some samples (Chinn and Quayyum (2012)) interest-rate currencies appreciate. (See Hodrick (1987), Froot and Thaler (1990) and Engel (1996) for surveys of the existing literature.)

One positive finding is at long horizons. Chinn and Guy (2004) finds that over long time horizons, exchange rates move in the direction predicted by UIP. If the 5-year interest rate is higher in one currency than in the other, then over the course of the next 5 years the exchange rate will depreciate. Left unexplained is exactly when in the 5 years the adjustment occurs.

By looking at an alternative measure – monthly changes in long-term interest rates – we find a contemporaneous short-term relationship between changes in interest rates and exchange rates, and that this relationship goes in the same direction as would be expected from UIP.

2 Theoretical Considerations

In this section, we offer a simple argument for why changes in long-term rates should be reflected in short-term changes in exchange rates.

Assume an idealized economy with no uncertainty. Then future interest rates are known today. Let i_τ^d be the interest rate used to discount a single coupon in the domestic currency at time τ, and i_τ be the same for the foreign currency. In this setting, uncovered interest parity is the assumption that

$$i_\tau^d = S_{\tau+1}/S_\tau i_\tau.$$

Suppose that we have a perpetuity that pays 1 in the domestic currency,

$$P_d^t = \sum_{\tau=t}^{\infty} \prod_{\tau'=1}^{\tau} \frac{1}{1+i_d^{\tau'}}.$$

The single-period change in the price of perpetuity is

$$\frac{P_d^{t+1}}{P_d^t} = \frac{1}{1+i_d^t}.$$

The present value of a foreign currency perpetuity, in terms of the domestic currency, is

$$S_t P_t = \sum_{\tau=t}^{\infty} S_\tau \prod_{\tau'=1}^{\tau} \frac{1}{1+i_d^{\tau'}},$$

The single period change in the price of the perpetuity is

$$\frac{P^{t+1}}{P^t} = \frac{S_{t+1}}{S_t} \frac{1}{1+i^t}. \tag{1}$$

The ratio of these two price changes is the change in exchange rates, S_{t+1}/S_t. If we take the logarithm of both sides, we get a simple linear relationship, with coefficient one.

So in this simple economy, UIP leads to a simple relationship between the change in exchange rates and the return on a perpetuity.

Realistically, in the presence of uncertainty this relationship will no longer hold exactly. Unlike for short-term interest rates, the value of the future perpetuity is uncertain, so unless the risk is purely idiosyncratic, a risk-averse investor will demand a premium. In some of our specifications, we control for this risk premium by using a currency volatility index.

3 Specifications

3.1 Standard Specification

$s_{t+1} - s_t$ is change of the log spot exchange rate, where s is quoted as the amount of domestic currency necessary to buy one unit of the foreign currency and $i_t - i_t^*$ is the interest differential between the domestic and the foreign interest rate. This means if the interest differential between the domestic and the foreign currency is negative (i.e. the foreign interest rate is higher than the domestic interest rate), $s_{t+1} - s_t$ is also negative and the foreign currency will depreciate by $i_t - i_t^*$. The standard regression to test UIP measures whether the interest return between t and $t+1$ is offset by the exchange rate loss (or vice versa) with the following regression:

$$s_{t+1} - s_t = \alpha + \beta_{Level}(i_t - i_t^*) + e_{t+1}, \tag{2}$$

where e_{t+1} is the disturbance term, which is independent from the interest differential and the exchange rate. The UIP hypothesis is a test of $\alpha = 0$ and $\beta = 1$.

Estimates for β in equation (2) have proven to be very unstable and depend on the analyzed period, the investment horizon and the currency pairs. Nevertheless, in most studies $\beta = 1$ can be rejected, while $\beta = 0$ cannot be rejected and the estimate for β is often negative. For example, the average beta across 75 papers surveyed by Froot and

Thaler (1990) is -0.88. The bulk of the literature analyzed the time period from the seventies, using short term interest rates from 1 month up to 1 year, and with main focus on dollar exchange rates. While one might argue such a time horizon was too short for papers published in the eighties, this argument does not hold anymore today with nearly 40 years of data since the abandonment of the Bretton-Woods fixed exchange rate system in 1973. Even recent papers almost never report positive values for beta.

Chinn (2006) analyzes the G7 currencies against USD from 1980-2000 using interest rates between 3 month and 10 years. While the beta is negative for the panel estimates with interest rates up to 12 months, it is positive for the 3, 5 and 10-year interest rates with values of 0.03, 0.67 and 0.68. Chinn concludes than UIP seems to hold better at long horizons that with short ones. He argues that measured interest rates and exchange rates are imperfect measurements of the equilibrium values, but the errors-in-variable problem is relatively smaller for long-term variables. Nonetheless he admits that for long-term rates the analyzed horizon is rather short, as he holds long-term interest rates always to maturity.

Bekaert and Xing (2007)) analyze the failure of the interest rate parity and the term structure simultaneously with a vector autoregression. They find that UIP depends on the currency pair (holds for USD-DEM while fails for USD-GBP and DEM-GBP), while the term structure expectation theory fails for all currency pairs. However, they do not see any difference in the time horizon for UIP.

4 Modified Uncovered Interest Rate Parity

As we argued in the previous section, the difference in log price changes in domestic-currency and foreign-currency perpetuities should equal the log change in exchange rates. Of course, the perpetuities are not actually traded, so we proxy the bond price implied by the 10-year swap rate. Let r_t be the log price change implied by changes in the domestic swap rate, and r_t^* be the same for the foreign swap rate. We refer to these quantities as the *swap return*.

This leads to the following specification for short-term interest rates in terms of swap returns,

$$s_{t+1} - s_t = \alpha + \beta_{Return} \left(r_{t+1} - r_{t+1}^* \right) + e_{t+1} \quad (3)$$

As we do not have overlapping data with this regression, we do not need to make the Hodrick-Hansen correction for overlapping data (compare to Chinn and Guy (2004)), which allows us the present clear statistical results.

We also consider the consequences of risk aversion for exchange rate risk, in a similar way as it has been done by Chinn and Guy (2004), Bekaert and Xing (2007)) and Clarida, Davis, and Pedersen (2009),. We consider two specifications to control for the riskiness of future exchange rates. The first specification considers the impact of risk aversion alone on exchange rates,

$$S_{t+1} - S_t = \alpha + \beta_{Volatility}\left((\sigma_{t+1} - \sigma_t) * sign(i_t - i_t^*)\right) + e_{t+1} \tag{4}$$

The term $sign(i_t - i_t^*)$ differentiates whether $(i_t - i_t^*)$ is positive or negative, since $\beta_{Volatility}$ is expected to have the opposite sign for negative $(i_t - i_t^*)$.

We combine the two specifications to consider the following joint specification:

$$\begin{aligned} s_{t+1} - s_t = \alpha + \beta_{Return}\left(r_{t+1} - r_{t+1}^*\right) \\ +\beta_{Volatility}\left((\sigma_{t+1} - \sigma_t) * sign(i_t - i_t^*)\right) + e_{t+1} \end{aligned} \tag{5}$$

A test of the modified UIP regression is $\alpha = 0$, $\beta_{Return} > 0$ and $\beta_{Volatility} > 0$. If investors are risk averse then the response to changes in long-term interest rates will be incomplete, and β_{Return} will be less than 1. We can assume that β_{Return} is smaller than 1, because it would be 0 if there is no trade, as exchange rate would not move in that case.

5 Empirical Results

5.1 Data

We use Bloomberg and Datastream as our sources of data, with the exception of the Swiss 10-year government yield, which we obtained directly from the Swiss national bank. The currency universe consists of the US dollar (USD), Canadian dollar (CAD), Japanese yen (JPY), Swiss franc (CHF), British pound (GBP), Australian dollar (AUD) and Euro (EUR). Before January 1st 1999, we use the German mark (DEM) instead of EUR.

We replicate the existing short-run results by using either the official 1 month LIBOR rates or the 12 month interbank rate by Datastream. (The 12 months interbank rate available for a longer horizon.) Spot exchange rate data against the USD is taken from Bloomberg. Cross-exchange rates are computed from the USD exchange rates.

For long-term interest rate returns, we consider both 5 and 10 year swap rates and government yields from Datastream. The advantage of the swap rates is that they are actively traded and have consistent terms and conditions, as they are all based on LIBOR rates and have the same framework under the ISDA (International Swaps and Derivatives Association). Swaps also have a constant maturity – every day, there are tradeable prices available for the 10-year swap beginning that day. This is an advantage over government yields, which do not have uniform terms and conditions. On the other hand, government yields typically have a longer horizon.

Perpetual interest rates would be the best proxy for long-term interest returns, but they do not exist for many currencies. There are also swap rates available with longer maturity of 20, 30, 40 and 50 years, but again not for all currencies and they have only been available for a short time. Furthermore, long-term swap rates are not as liquid as the 10-year ones. In a study of Avellaneda about the interest rate swap market (Avellaneda and Cont (2010)), they show that trading volume of interest swaps with maturity up to 10 years are 10-times higher than interest rate swaps above 10 years.

To measure exchange-rate risk, we use the currency volatility index of JP Morgan (JPMVXYG7 Index), which is the average implied volatility of the G7 currencies. It is a similar proxy for the currency market risk as the VIX Index is a proxy for the equity market risk. The volatility index began on June 1st 1992.

Since results depend heavily on the choice of the base currency, we regress all currency pairs against each other, once in individual regressions for all 21 currency pairs and once in a fixed-effects cross-panel regression.

5.2 Empirical Analysis of Short-Run UIP

We replicate the standard results for the short-run UIP regression (2). Exhibit 1 presents the regression results for the standard regression with our data set.

The results of the panel regression replicate the standard failure of UIP using short-term interest rates: the R-squared is 0.00, the beta has the wrong sign and is significantly smaller than 0 at 99% significance level with a t-value of -4.04. For the individual currency pairs, the resulting betas are usually negative, but they not estimated very precisely, and thus the estimates have wide confidence intervals. Only USD/GBP and JPY/EUR have a positive beta (0.24 and 0.28). Three currency pairs – USD/JPY, GBP/CHF, and CHF/CAD – have betas which are significantly smaller than 0 at the 95% level, while all others are not significantly different from 0. At the 99% significance level, none is significantly different from 0, while 4 pairs are significantly different from 1. The confidence interval is quite large, which makes a reasonable conclusion difficult. This is in line with the previous literature, which usually finds that the beta coefficient is indistinguishable from zero, and frequently has the wrong sign.

While most previous studies reported negative betas or values around 0, the occasional study also find positive betas. One possible explanation for this discrepancy is that the beta is time-varying. In exhibit 2, we consider the results for the panel regression on a 2-year rolling basis.

Exhibit 1

UIP Standard Regression with 1 Month LIBOR 1987-2012

The table shows the results of regression (2) for each currency pair and the panel regression (with fixed effects) of all pairs, using the 1 month LIBOR level as explanatory and the 1-month change of exchange rate as explained variable in the period from 1987-2012. The reported t-statistics are Newey West estimators (Newey and West (1987), which are adjusted for autocorrelation and heteroscedasticity problems.

Currency Pair	R^2	α		β_{Level}		Confidence Interval 95%	Observations
Panel	**0.00**		**-**	**-1.00**	**(-4.04)**	**[-1.49 -0.52]**	**6552**
USD/AUD	0.00	0.00	(0.53)	-0.93	(-1.03)	[-2.71 0.85]	312
USD/JPY	0.01	-0.01	(-2.34)	-1.88	(-2.01)	[-3.72 -0.04]	312
USD/GBP	0.00	-0.00	(-0.12)	0.24	(0.16)	[-2.60 3.08]	312
USD/CHF	0.01	-0.00	(-1.17)	-1.42	(-1.26)	[-3.64 0.80]	312
USD/CAD	0.00	-0.00	(-0.41)	-0.44	(-0.67)	[-1.73 0.85]	312
USD/EUR	0.00	-0.00	(-0.22)	-0.37	(-0.36)	[-2.36 1.63]	312
AUD/JPY	0.00	-0.00	(-0.54)	-0.73	(-0.70)	[-2.81 1.34]	312
AUD/GBP	0.00	0.00	(0.40)	-1.27	(-1.00)	[-3.79 1.24]	312
AUD/CHF	0.00	-0.00	(-0.90)	-1.18	(-1.08)	[-3.32 0.97]	312
AUD/CAD	0.00	-0.00	(-0.06)	-0.48	(-0.50)	[-2.35 1.39]	312
AUD/EUR	0.00	0.00	(0.11)	-0.36	(-0.43)	[-2.05 1.32]	312
JPY/GBP	0.00	0.00	(0.95)	-0.49	(-0.44)	[-2.65 1.67]	312
JPY/CHF	0.01	0.00	(1.63)	-3.32	(-1.91)	[-6.73 0.09]	312
JPY/CAD	0.00	0.01	(1.29)	-1.54	(-1.03)	[-4.48 1.40]	312
JPY/EUR	0.00	0.00	(0.32)	0.28	(0.15)	[-3.40 3.95]	312
GBP/CHF	0.01	-0.01	(-2.18)	-1.60	(-2.14)	[-3.08 -0.13]	312
GBP/CAD	0.01	-0.00	(-1.55)	-2.56	(-1.70)	[-5.52 0.40]	312
GBP/EUR	0.00	-0.00	(-0.65)	-0.52	(-0.74)	[-1.92 0.87]	312
CHF/CAD	0.02	0.01	(2.25)	-3.02	(-2.16)	[-5.77 -0.27]	312
CHF/EUR	0.01	0.00	(2.48)	-2.26	(-1.95)	[-4.54 0.02]	312
CAD/EUR	0.00	-0.00	(-0.06)	-1.14	(-1.01)	[-3.36 1.08]	312

There are 4 major periods where the beta is negative for many years, contrary to UIP. However, there are also 3 major periods where it is positive for a couple of years. Between 2007 and 2008 the beta sharply increased to a level above 1. This has mainly been driven by the financial crisis in 2008, where a massive unwind of carry-trades lead to a crash of high yielding currencies and to an appreciation of low yielding currencies (see Melvin and Taylor (2009) for details). However, beta turned again negative in 2009 and 2010, which makes the positive beta in 2008/2009 was only a temporary phenomenon.

We did the analysis also for 12 month interest rates, 5 year government bonds and swaps, and 10 year government bonds and swaps. We always take the (annualized) interest rate, divide it by 12 and regress it against the monthly exchange rate return. The results are similar: beta is between -0.95 and -2.28 for the different interest rates, and always significantly smaller than 1 and in most cases also significantly smaller than 0.

Exhibit 2

2-Year Rolling UIP Panel Regression with 1 Month Interest Rate 1987-2012

The figure shows the beta of the 2-year rolling panel regression (no fixed-effects as the horizon is too short) of the 1-month interest rates and shows the periods where beta is significant at 95% significance level. A 2-year rolling regression is the regression (2) for 24 months: the first observation for the monthly regression is the beta over the period from January 1987 to December 1988 and the last point is the beta over the period from January 2011 to December 2012. The significance level is measured with Newey West estimators.

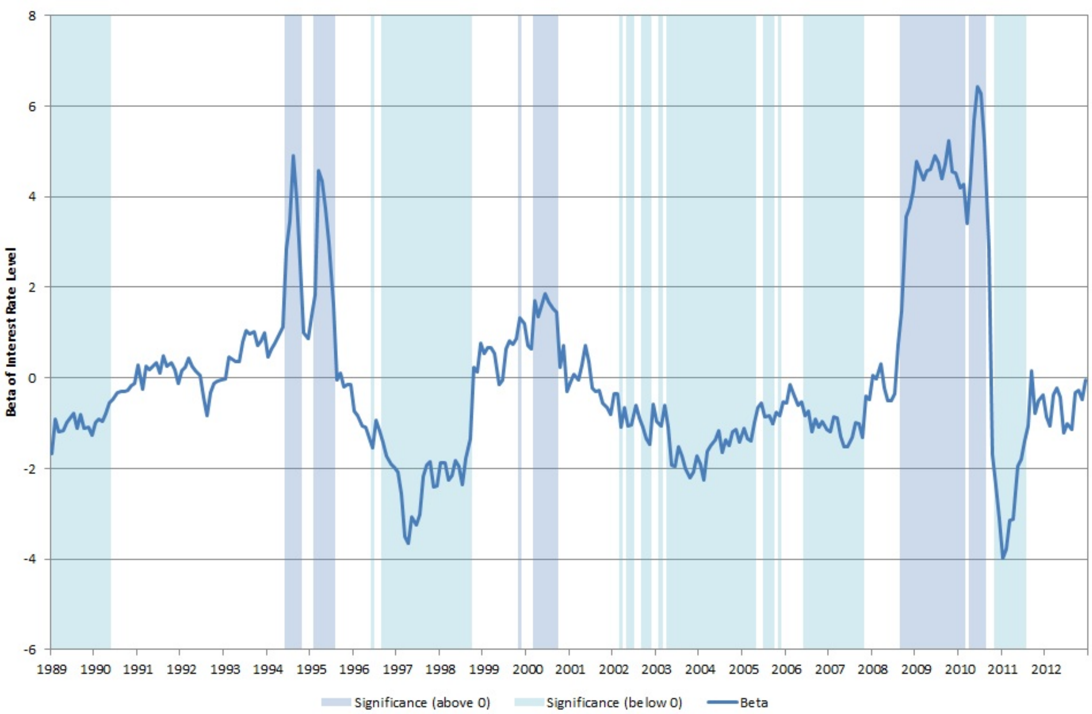


Exhibit 3 presents the results of the regression of 5 year interest rates against exchange rate return over 5 years from 1980-2012. This is the same regression as in Chinn (2006), who found positive betas. For direct comparability, we use the same maturity, the 5 year swap rate. (Chinn used the 5-year government bond rate.) In case the 5 year swap rate is not available, we use the 5 year government rate and otherwise the 12 month interbank rate. We repeated the regression with the 12 month interbank rate and obtained similar results (beta of panel regression is 0.25 with t-value 2.92 for 12 month rate).

Exhibit 3

UIP Long-Term Regression with 5 Year Interest Rates 1980-2012

The table shows the results of regression (2) for each currency pair and the panel regression (fixed-effects) of all pairs, using the 5 year interest level (multiplied by 5) as explanatory and the 5-year change of exchange rate as explained variable in the period from 1980-2012. The data are measured at quarterly frequency, which means only 6 out of 113 observations are non-overlapping periods. The reported t-statistics are Newey West estimators.

Currency Pair	R^2	α		β_{Level}		Confidence Interval 95%	Observations
Panel	**0.02**	**-**		**0.44**	**3.56**	**[0.20 0.68]**	**2373**
USD/AUD	0.02	0.11	(1.00)	-0.52	(-0.92)	[-1.63 0.59]	113
USD/JPY	0.01	-0.09	(-0.99)	0.25	(0.49)	[-0.75 1.25]	113
USD/GBP	0.11	-0.02	(-0.44)	1.24	(1.55)	[-0.34 2.82]	113
USD/CHF	0.01	-0.05	(-0.84)	0.29	(0.80)	[-0.43 1.01]	113
USD/CAD	0.23	-0.06	(-2.04)	1.43	(3.79)	[0.68 2.18]	113
USD/EUR	0.11	0.02	(0.37)	0.96	(2.62)	[0.23 1.69]	113
AUD/JPY	0.02	0.05	(0.34)	0.68	(1.26)	[-0.39 1.74]	113
AUD/GBP	0.04	0.06	(1.21)	0.63	(2.30)	[0.09 1.17]	113
AUD/CHF	0.29	0.13	(2.00)	0.98	(3.33)	[0.40 1.57]	113
AUD/CAD	0.10	-0.07	(-2.03)	-0.61	(-2.07)	[-1.20 -0.03]	113
AUD/EUR	0.32	0.11	(2.09)	1.05	(3.79)	[0.50 1.60]	113
JPY/GBP	0.00	0.36	(1.14)	-0.44	(-0.32)	[-3.16 2.29]	113
JPY/CHF	0.24	0.09	(3.58)	-1.06	(-3.64)	[-1.64 -0.48]	113
JPY/CAD	0.02	0.05	(0.27)	0.73	(0.92)	[-0.84 2.31]	113
JPY/EUR	0.04	0.17	(2.86)	-0.54	(-1.02)	[-1.59 0.51]	113
GBP/CHF	0.02	-0.06	(-0.72)	0.30	(1.07)	[-0.25 0.85]	113
GBP/CAD	0.06	-0.02	(-0.64)	0.76	(1.49)	[-0.25 1.78]	113
GBP/EUR	0.07	-0.01	(-0.09)	0.63	(2.17)	[0.05 1.20]	113
CHF/CAD	0.08	0.02	(0.24)	0.58	(1.85)	[-0.04 1.21]	113
CHF/EUR	0.02	0.01	(0.44)	0.41	(1.50)	[-0.13 0.94]	113
CAD/EUR	0.20	0.07	(1.83)	0.99	(3.72)	[0.46 1.52]	113

The long-term UIP regression has a positive beta in the panel regression. This confirms the results of Chinn, who also reported positive betas. 4 currency pairs are significantly positive at the 99% significance level, and another 3 are significant at the 95% significance level. Only one currency pair (JPY/CHF) has a significantly negative beta at the 99% level and AUD/CAD is significantly negative at the 95% levels. Another 3 pairs have negative betas. 4 currency pairs are significantly different from 1.

However, the positive beta in the panel regression holds only over the whole sample horizon. For example, in the sample between 1990-2012, the resulting beta is -0.05 (-0.17). Thus, the long-term UIP with 5-year interest rates failed to hold for the last 2 decades. Practically speaking, the data horizon is quite short for 5-year regressions, as we have only 33 years of historical data, which results in slightly more than 6 out of 113 non-overlapping periods. Chinn and Quayyum also acknowledge in their latest paper Chinn and Quayyum (2012) that the power of the long-term UIP regression has decreases in the past decade. We tested the 5-year UIP regression for the post-Chinn sample Chinn and Guy (2004) from 2001-2012 and got a beta of -1.49 (t-value -3.24), which is significantly negative at 99% confidence interval.

Still there is evidence that the UIP relationship works better with long-term interest rates and over longer horizons, but the problem is that the data horizon is too short and results are too volatile for a clear statistical evidence. Chinn and Guy (2004) explain the difference between short and long term regression results with the strong influence of the central bank on the short-term interest rates, while long-term interest rates only can be influenced indirectly (apart from the quantitative easing programs of FED, ECB and Bank of England who started buying long-term government bonds in the aftermaths of the crisis in 2008). Thus, long-term interest rates should be less endogenous than short-term ones.

5.3 Empirical Analysis of Modified Uncovered Interest Rate Parity

An explanation for the different results over different periods is that interest differentials are not constant. Since the change of the interest differential also influences the exchange rate, it should therefore be incorporated in the regression as suggested in formula (3) and (5). Exhibit 4 presents the results of regression (3) using the return difference between two currencies' 10-year swap rate over the period 1991-2012.

Exhibit 4

10 Year Swap Return Difference Regression 1991-2012

The table shows the results of regression (3) for each currency pair and the panel regression (fixed-effects) of all pairs, using the monthly 10 year swap return as explanatory and the 1-month change of exchange rate as explained variable in the period from 1991-2012. The reported t-statistics are Newey West estimators.

Currency Pair	R^2	α		β_{Return}		Confidence Interval 95%	Observations
Panel	**0.03**	**-**		**0.34**	**(8.94)**	**[0.27 0.42]**	**5544**
USD/AUD	0.02	-0.00	(-0.51)	0.33	(1.66)	[-0.06 0.72]	264
USD/JPY	0.04	-0.00	(-0.28)	0.28	(2.77)	[0.08 0.48]	264
USD/GBP	0.10	0.00	(0.25)	0.49	(3.46)	[0.21 0.77]	264
USD/CHF	0.08	-0.00	(-0.02)	0.52	(4.21)	[0.27 0.76]	264
USD/CAD	0.00	-0.00	(-0.18)	-0.10	(-0.77)	[-0.36 0.16]	264
USD/EUR	0.12	0.00	(0.23)	0.67	(5.84)	[0.44 0.89]	264
AUD/JPY	0.03	0.00	(0.66)	0.37	(2.03)	[0.01 0.72]	264
AUD/GBP	0.03	0.00	(1.37)	0.30	(1.96)	[0.00 0.59]	264
AUD/CHF	0.04	0.00	(0.67)	0.34	(2.46)	[0.07 0.61]	264
AUD/CAD	0.02	0.00	(0.77)	0.26	(1.53)	[-0.07 0.58]	264
AUD/EUR	0.02	0.00	(1.02)	0.27	(1.95)	[0.00 0.55]	264
JPY/GBP	0.05	0.00	(0.55)	0.43	(3.20)	[0.17 0.69]	264
JPY/CHF	0.06	0.00	(0.21)	0.48	(3.70)	[0.22 0.73]	264
JPY/CAD	0.01	0.00	(0.51)	0.17	(1.11)	[-0.13 0.48]	264
JPY/EUR	0.05	0.00	(0.47)	0.47	(3.51)	[0.20 0.73]	264
GBP/CHF	0.03	-0.00	(-0.45)	0.34	(1.48)	[-0.11 0.78]	264
GBP/CAD	0.03	-0.00	(-0.46)	0.32	(2.43)	[0.06 0.58]	264
GBP/EUR	0.04	0.00	(0.03)	0.42	(1.90)	[-0.02 0.86]	264
CHF/CAD	0.02	0.00	(0.31)	0.29	(1.75)	[-0.04 0.62]	264
CHF/EUR	0.00	0.00	(1.54)	0.09	(0.64)	[-0.18 0.35]	264
CAD/EUR	0.01	0.00	(0.62)	0.24	(1.45)	[-0.09 0.56]	264

The results of regression (3) are favorable for the UIP theory. R-squared for the panel regression is at least 0.03, although this figure is still low. Beta is positive as expected, which means if the swap return difference between two countries is positive, then the exchange rate between those two countries will depreciate. β_{Return} is significantly positive at 99% level (t-value is 8.94). The theoretical risk-neutral value of beta would be 1 as a decrease of the interest rate by 1% should depreciate the currency by the present value of this 10-year change. However, with risk aversion, and other distortions it is not surprising that beta is well below 1.

In the individual regression, only one currency pair (USD/CAD) has a negative beta, which is most likely caused by the close economic relationships of those two countries. 7 currency pairs have positive betas at 99% significance level and another 3 at 95%, leaving half of the pairs that have no significant beta. These results are also robust to the choice of the interest rate maturity (12 months, 5 years) and beta is i both cases positive (1.06 for the 12 months rate and 0.62 for the 5 year swap rate). We also tested regression (2) with the 10-year swap data as input interest rate, excluding the impact of the interest rate change. Although this is a non-investable regression, the resulting β_{Level} is -2.39 and tells us the positive beta is not driven by the different interest rates but by the interest rate return due to interest rate change. Regressing just the change of the interest differential, beta is -1.72, which is as expected. An increase of the foreign interest rate leads to an appreciation of the foreign currency. The increase of the foreign interest rate also leads to a negative swap return, and that is why the β_{Return} is positive.

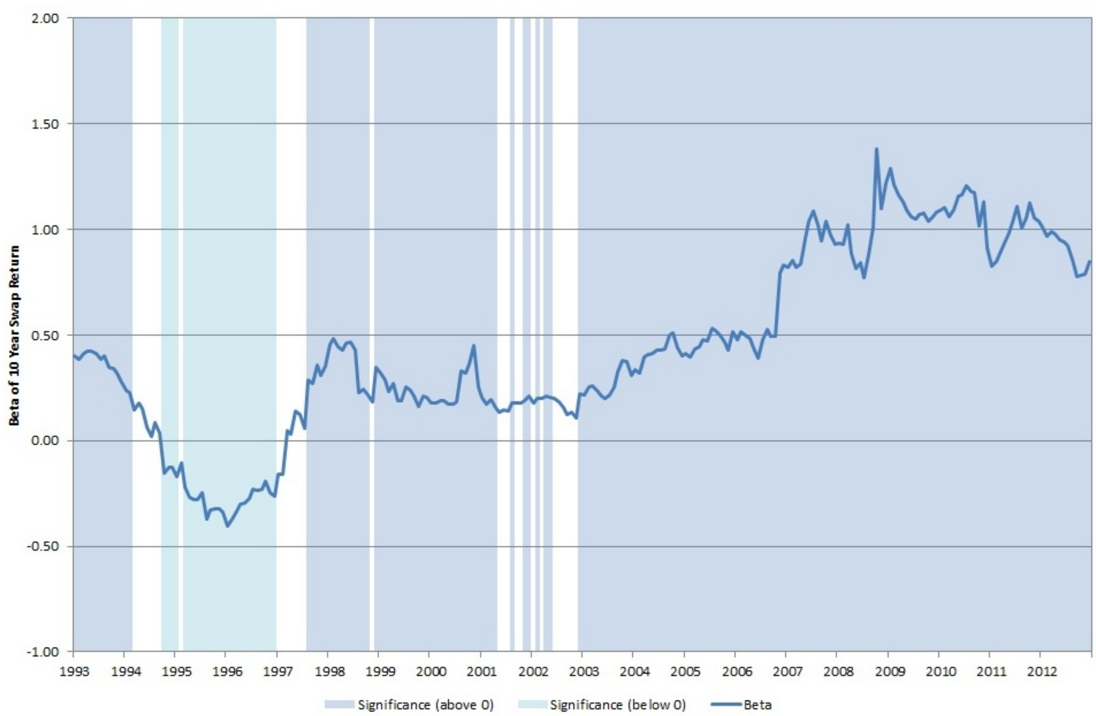
We also tested regression (3) with the 30-year swap rate, where our data start in 2002. β_{Return} is significantly positive (+0.19) at 99% level (t-value is 7.50). Also for shorter maturities, β_{Return} is always significantly positive: 1.06 (4.40) for the 12 month rate and 0.62 (9.08) for the 5-year rate (t-values in parenthesis). We will proceed with the 10-year rate as the data horizon is the longer than for the 30-year rate and it is a better proxy for perpetual bonds than 5-year or 12 month rates.

The relationship became stronger over the sample. Exhibit 5 presents the 2-year rolling regression of the 10-year swap return differences and shows the periods where beta is significant at 95% significance level.

Exhibit 5

2-Year Rolling Regression 10 Year Swap Return Difference 1991-2012

The figure shows the beta of the 2-year rolling panel regression (no fixed-effects as the horizon is too short), using the monthly 10 year swap return as explanatory and the 1-month change of exchange rate as explained variable in the period from 1991-2012. The shaded areas are the periods where beta is significantly different from zero at 95% significance level. A 2-year rolling regression is the regression (3) for 24 months, which means the first point for the 1 month regression is the beta over the period from January 1991 to December 1992 and the last point is the beta over the period from January 2011 to December 2012. The significance level is measured with Newey West estimators.



The 2-year regression started being significantly positive in 1997, which is the regression period from 1995-1997. Before that period it was significantly positive from 1992-1994 and significantly negative from 1994-1996. However, since 1997, beta has always been significantly positive, although at a moderate level between 0 and 0.5 until 2006. Thus, already in 2006 (period 2004-2006), beta became much more positive between 0.5 and 0.75. Since then, it has settled down at levels between 0.75 and 1.25. An important observation is that it did not rise after the financial crisis in 2009 and 2010, contrary to the beta of the UIP regression in exhibit 2.

What happened in the crisis? Before the crisis, interest differentials had been high and currencies with high interest rates had been at elevated values. During the crisis, high interest rate currencies depreciated dramatically, and so did their interest rates (thus the long-term interest return difference had been positive). Thus, during this phase, exchange rates behaved as expected by UIP, which is that high interest rate currencies should depreciate. However, after the financial crisis in 2008, interest rates differentials rose again (thus the long-term interest return difference had been negative) and so did the exchange rates. While UIP in the standard form would have suggested that the AUD-USD exchange rate should have depreciated further, since interest differential was always positive, the exchange rate appreciated strongly. Exhibit 5 shows that the rise can be explained with the rising interest differentials, while the effect of UIP in the standard form is unclear (exhibit 2).

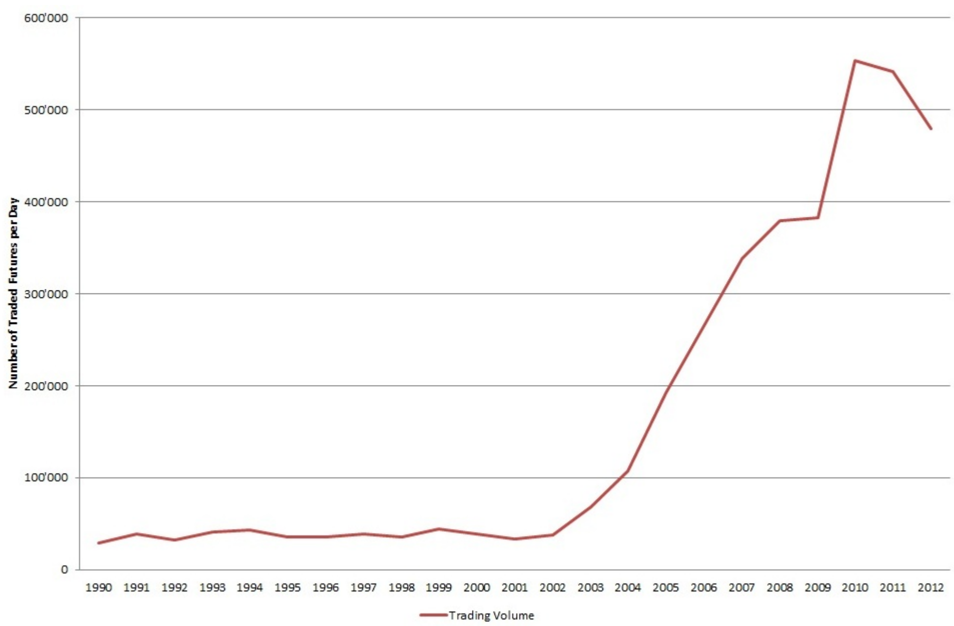
It is an open question why the beta decreased dramatically beginning with the end of 2004-2006 period. The sharp increase in the panel regression was not caused by a single currency, but it occurred for most currencies, and the effect was more pronounced for currencies with high interest differentials. A possible explanation could be that the market has become more efficient, as more active investors invested in currencies. A possible indication for more active investors is the sharp increase in trading volume and open interest in the currency futures market. Although currency futures volumes are only a small fraction of the total currency trading volume, they are typically used by speculative investors. Furthermore, only futures data are available on an annual basis.

The trading volume of the total currency market is reported every three years by Triennial Survey and shows a similar development. Exhibit 6 presents the trading volume of currency futures. The trading volume was stable around 40'000 traded contracts per day until 2002 (roughly worth \$4 billion). However, since 2002 trading volume increased dramatically and reached over 500'000 in 2010.

Exhibit 6

Daily Trading Volume in Currency Futures

The figure shows daily trading volume of the biggest 6 currency futures (all against USD, each future has a value of 100'000 times the exchange rate) since 1990.



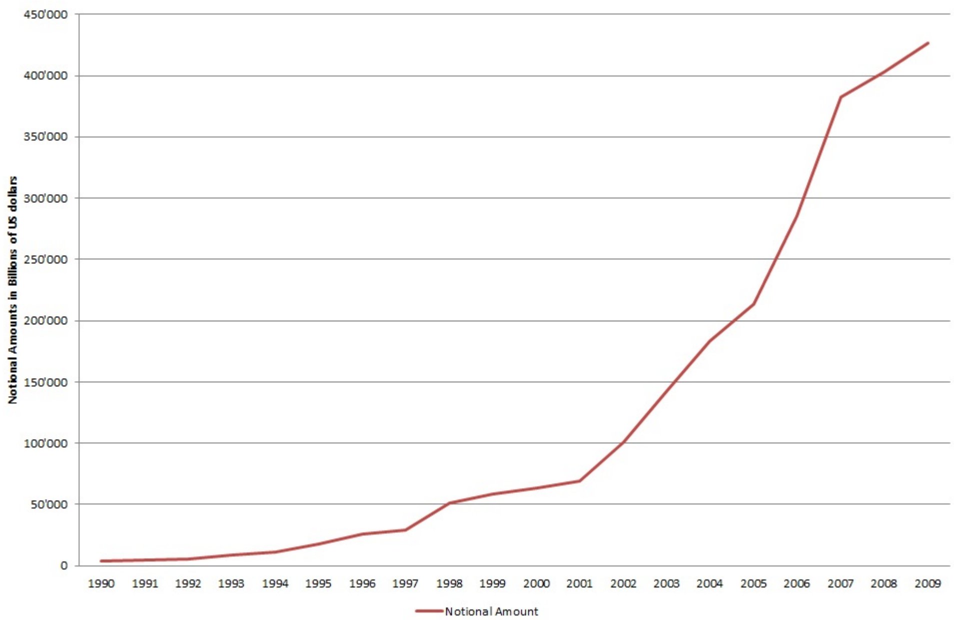
This is consistent with the analysis of King and Rime (2010), who showed that the share of financial institutions in the trading volume of the whole currency market increased dramatically between 2001 and 2010. They argue that the reason for the increase in trading is that financial institutions got better electronic access during the past 10 years. Until 1999, electronic trading was only available for interbank trading (starting in 1992 with Reuters 2000), thus customers had to pay relatively high bid-ask spreads in the nontransparent market. In 1999, Currenex started as the first multibank platform available for customers. Other platforms followed as FXConnect in 2000, BARX in 2001, Autobahn in 2002 and Velocity in 2006.

Meanwhile, the volume of interest rate swaps increased also dramatically, see Exhibit 7. In 1990, the year-end amount of outstanding notional amount was \$ 3400 billion , and this amount increased to \$ 426700 billion in 2009. More recent data are not available. The notional amount includes interest rate swaps, interest rate options and cross-currency swaps. The share of the interest rate swaps was 77% in 1997, more recent data is also not available.

Exhibit 7

Notional Amount of Outstanding Interest Rate Swaps

The figure shows year-end notional amount of interest rate swaps, interest rate options and cross-currency swaps since 1990.



Another problem that distorts the results of the UIP regression is the risk aversion of the investors. As we have seen, a possible way to measure this effect is the regression (4). Exhibit 8 presents the results of this regression, with the G7 implied currency volatility index by JP Morgan as a measure for the volatility and the 1 month interest differential as a measure for whether the interest differential is positive or negative.

The results in exhibit 8 confirm the hypothesis that volatility has a strong impact on the UIP relationship. When the interest differential is positive and volatility increases, the high interest rate currency depreciates, while it appreciates when volatility decreases. The beta from the panel regression is 0.78 and very significantly with a t-value of 10.27, while R-squared is 0.08. On the individual currency pairs, only GBP/CAD and USD/CAD are negative, but insignificant. Another 4 pairs (USD/GBP, USD/CHF, USD/EUR, GBP/EUR and CAD/EUR) have positive insignificant betas, while all others (15 of 21) are significant at 99% level.

Exhibit 8

Change of Implied Volatility Regression 1993-2012

The table shows the results of regression (4) for each currency pair and the panel regression (fixed-effects) of all pairs, using the 1-month change of the implied volatility (multiplied by the sign of the interest differential) as explanatory and the 1-month change of exchange rate as explained variable in the period from 1993-2012. The reported t-statistics are Newey West estimators.

Currency Pair	R^2	α		$\beta_{Volatility}$		Confidence Interval 95%	Observations
Panel	**0.08**	**-**		**0.78**	**(10.27)**	**[0.63 0.93]**	**5040**
USD/AUD	0.15	-0.00	(-0.43)	1.22	(4.13)	[0.64 1.80]	240
USD/JPY	0.11	-0.00	(-0.58)	0.91	(5.39)	[0.58 1.25]	240
USD/GBP	0.07	-0.00	(-0.02)	0.56	(2.94)	[0.18 0.93]	240
USD/CHF	0.00	-0.00	(-0.75)	0.16	(0.59)	[-0.38 0.71	240
USD/CAD	0.01	-0.00	(-0.58)	-0.24	(-0.69)	[-0.91 0.44]	240
USD/EUR	0.03	-0.00	(-0.11)	0.42	(1.38)	[-0.18 1.02]	240
AUD/JPY	0.31	0.00	(0.38)	2.18	(11.37)	[1.80 2.56]	240
AUD/GBP	0.07	0.00	(0.86)	0.74	(5.81)	[0.49 0.99]	240
AUD/CHF	0.23	0.00	(0.08)	1.50	(9.66)	[1.19 1.81]	240
AUD/CAD	0.07	0.00	(0.62)	0.59	(5.17)	[0.37 0.82]	240
AUD/EUR	0.15	0.00	(1.00)	1.05	(5.78)	[0.70 1.41]	240
JPY/GBP	0.17	0.00	(0.92)	1.40	(7.44)	[1.03 1.78]	240
JPY/CHF	0.06	0.00	(0.15)	0.79	(3.83)	[0.38 1.19]	240
JPY/CAD	0.23	0.00	(0.69)	1.72	(8.03)	[1.30 2.14]	240
JPY/EUR	0.15	0.00	(0.90)	1.28	(4.88)	[0.77 1.80]	240
GBP/CHF	0.06	-0.00	(-0.84)	0.57	(4.04)	[0.29 0.85]	240
GBP/CAD	0.01	-0.00	(-0.32)	-0.20	(-1.58)	[-0.46 0.05]	240
GBP/EUR	0.00	0.00	(0.15)	0.08	(0.64)	[-0.17 0.34]	240
CHF/CAD	0.09	0.00	(0.84)	0.90	(4.38)	[0.49 1.30]	240
CHF/EUR	0.12	0.00	(2.12)	0.48	(3.51)	[0.21 0.74]	240
CAD/EUR	0.01	0.00	(0.59)	0.22	(1.13)	[-0.16 0.61]	240

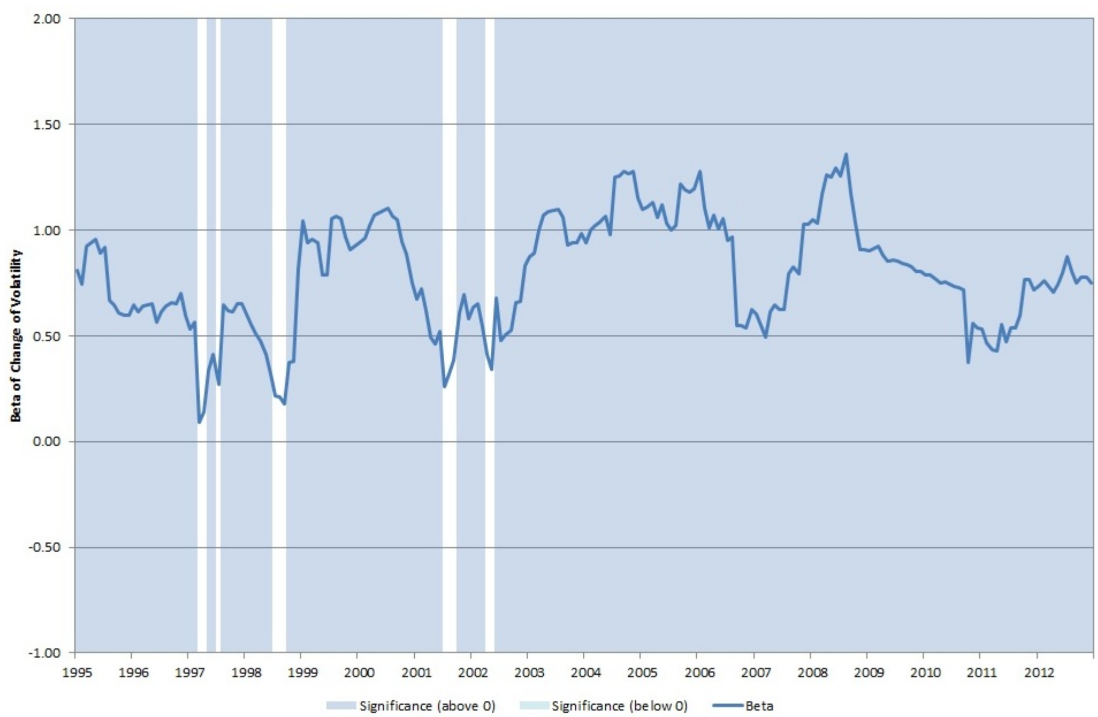
Exhibit 9 presents the results of the 2-year rolling regression of change of implied volatility. The rolling regression reveals that the beta of the change of implied volatility was always positive with values between 0.1 and 1.4. Thus volatility has always had a strong impact on the exchange rate, as expected from the theory of risk aversion. This also confirms the

UIP theory to some part in the sense as there seem to be investors trying to exploit the UIP failure and pushing exchange rates closer to UIP, will abandoning their trades when risk increases.

Exhibit 9

Rolling Beta Change of Implied Volatility Panel Regression 1993-2012

The figure shows the beta of the 2-year rolling panel regression (no fixed-effects as the horizon is too short), regressing the 1-month change of implied volatility (multiplied by the sign of the interest differential) on the 1-month change of exchange rate over the period from 1993-2012. The shaded area are the periods where beta is significant at 95% significance level. A 2-year rolling regression is the regression (??) for 24 months, which means the first point for the 1 month regression is the beta over the period from January 1991 to December 1992 and the last point is the beta over the period from January 2011 to December 2012. The significance level is measured with Newey West estimators.



As we have seen so far, the long-term interest return difference and the change of volatility are generally both very significant, while the level of interest differential is not significant. Thus, it is well worth looking at a multiple regression. However, both β_{Level} and β_{Return} measure the interest rate return, with the distinction β_{Level} measures the return of a short-term interest rate and β_{Return} of a long-term interest rate. As β_{Level} and β_{Return}

are not independent variables, we only include β_{Return} and $\beta_{Volatility}$ in the multilinear regression.

Exhibit 10 presents the results of the multilinear regression (5). The results are similar to those in the single regressions. R-squared is relatively high, 0.10, in contrast to the standard UIP regression that achieves values of 0.00 or 0.01. The 10-year swap return difference and the change of volatility are both highly significant. The Durbin-Watson statistic gives a value of 2.05, which means there is no autocorrelation.

Results can be misleading if variables have unit roots or are cointegrated. We use the Augmented Dickey-Fuller test for unit root and the Johansen cointegration test for cointegration. The unit root test shows that the exchange rate has a unit root. For the other variables it is less clear. The interest differential has a unit root in 17 of 21 currency pairs. The implied volatility has also a unit root. However, using interest rate returns and change of volatility instead of the level, the unit root problem vanishes. Thus, results from the level of interest differential regression might be misleading, while the swap return and the change of volatility should not have the same problem.

The cointegration tests shows that the level of the interest differential and the level of the exchange rate is cointegrated in 15 of 21 currency pairs, which means they have a common trend. The exchange rate return on the level of the interest differential is also cointegrated in 7 of 21 currency pairs. This is again a problem for the standard UIP regression. However, the swap return difference and the exchange rate returns are not cointegrated, which also favors the UIP test presented in this article. Finally, we run a granger causality test. This test shows that exchange rate returns do not predict swap returns or volatility changes, but swap return difference and volatility changes do sometimes predict exchange rate returns (in 10 of 21 for the swap returns and 11 of 21 for the volatility changes). This means we do not have a causality problem.

Exhibit 10

Multilinear Regression 1993-2012

The table shows the results of the multilinear regression (5) for each currency pair and the panel regression (fixed-effects) of all pairs, using the monthly 10-year swap return as interest return (β_{Return}) and the 1-month change of the implied volatility ($\beta_{Volatility}$) as explanatory variables and the 1-month change of exchange rate as explained variable. The period is from 1993-2012. The reported t-statistics are Newey West estimators.

Currency Pair	R^2	α		β_{Return}		$\beta_{Volatility}$		Observations
Panel	**0.10**	**-**		**0.30**	**(7.81)**	**0.75**	**(10.04)**	**5040**
USD/AUD	0.17	-0.00	(-0.60)	0.28	(1.58)	1.16	(4.23)	240
USD/JPY	0.14	-0.00	(-0.24)	0.27	(2.81)	0.90	(5.25)	240
USD/GBP	0.11	-0.00	(-0.19)	0.32	(3.38)	0.53	(2.99)	240
USD/CHF	0.05	-0.00	(-0.45)	0.41	(2.97)	0.11	(0.37)	240
USD/CAD	0.01	-0.00	(-0.57)	-0.05	(-0.36)	-0.24	(-0.71)	240
USD/EUR	0.11	-0.00	(-0.08)	0.55	(4.92)	0.39	(1.38)	240
AUD/JPY	0.34	0.00	(0.93)	0.30	(1.99)	2.12	(11.40)	240
AUD/GBP	0.07	0.00	(0.90)	0.11	(0.74)	0.71	(5.94)	240
AUD/CHF	0.24	0.00	(0.35)	0.20	(1.51)	1.44	(8.28)	240
AUD/CAD	0.10	0.00	(0.85)	0.36	(2.15)	0.54	(5.05)	240
AUD/EUR	0.16	0.00	(1.13)	0.18	(1.31)	1.02	(5.36)	240
JPY/GBP	0.20	0.00	(0.40)	0.34	(2.64)	1.38	(6.94)	240
JPY/CHF	0.11	-0.00	(-0.16)	0.46	(2.84)	0.83	(3.89)	240
JPY/CAD	0.24	0.00	(0.43)	0.18	(1.25)	1.70	(7.67)	240
JPY/EUR	0.18	0.00	(0.43)	0.39	(3.38)	1.27	(4.86)	240
GBP/CHF	0.09	-0.00	(-0.37)	0.36	(1.45)	0.51	(3.43)	240
GBP/CAD	0.02	-0.00	(-0.29)	0.19	(1.47)	-0.18	(-1.35)	240
GBP/EUR	0.06	0.00	(0.46)	0.55	(2.07)	0.06	(0.49)	240
CHF/CAD	0.10	0.00	(0.61)	0.21	(1.15)	0.86	(3.96)	240
CHF/EUR	0.12	0.00	(2.06)	0.07	(0.62)	0.47	(3.71)	240
CAD/EUR	0.02	0.00	(0.64)	0.26	(1.43)	0.23	(1.20)	240

5.4 Sensitivity Analysis

If the average interest differential is small, the results can be distorted because UIP is not the dominant factor in this area. Returns from carry trades are very small if interest differentials are small, or even might be negative if transaction costs are incorporated. Thus it is not worth to exploit the profit opportunities and UIP is not fulfilled in the area around zero. Exhibit 11 presents the results of regression (5) considering only currency pairs where the average interest differential is smaller than 1%, at least 1% and at least 2% respectively.

Exhibit 11

Multilinear Regression Constrained to Average Interest Differential 1993-2012

The table shows the results of the multilinear regression (5) for the panel regression (fixed-effects) considering only currency pairs where the average interest differential is smaller than 1%, at least 1%, and at least 2% respectively, using the monthly 10 year swap return (β_{Return}) and the 1-month change of the implied volatility ($\beta_{Volatility}$) as explanatory variables and the 1-month change of exchange rate as explained variable. The period is from 1993-2012. The reported t-statistics are Newey West estimators.

	R^2	β_{Return}		$\beta_{Volatility}$		Observations
Panel All	0.10	0.30	(7.81)	0.75	(10.04)	5040
Panel $\geq$ 2%	0.19	0.28	(5.14)	1.27	(13.02)	1920
Panel $\geq$ 1%	0.15	0.29	(6.61)	1.02	(12.63)	3360
Panel $<$ 1%	0.03	0.28	(4.5591)	0.22	(2.09)	1680

The higher the interest differential, the higher is the beta of change of volatility. R-squared increases from 0.10 to 0.15 for interest differentials that are at least 1% and to 0.19 for differentials at least 2%. However, R-squared falls to 0.03 when interest differential is smaller than 1%, since the effect of the change of volatility decreases. β_{Return} does not change much with different levels of interest differentials.

Exhibit 12 presents the results of the multilinear regression (5) comparing monthly, weekly and daily data. Both the swap return difference and the change of volatility are also significant at shorter horizons, although R-squared decreases. One problem with shorter data is at the interest rates and exchange rates are not recorded at exactly the same time.

Exhibit 12

Multilinear Regression with Different Regression Periods 1993-2012

The table shows the results of the multilinear regression (5) for the panel regression (fixed-effects) of all currency pairs, using different return periods (monthly, weekly and daily) for 10 year swap return (β_{Return}) and the change of the implied volatility ($\beta_{Volatility}$). The period is from 1993-2012. The reported t-statistics are Newey West estimators.

	R^2	β_{Return}		$\beta_{Volatility}$		Observations
Panel Monthly	0.10	0.30	(7.81)	0.75	(10.04)	5040
Panel Weekly	0.09	0.20	(10.28)	0.72	(12.86)	21903
Panel Daily (average)	0.05	0.11	(3.77)	0.51	(6.95)	105798

Exhibit 13 presents the results of the multiple regression of 10-year swap return difference of month t and t-1, as well as the change of the volatility.

Exhibit 13

Multilinear Regression with Lagged Swap Return Difference 1993-2012

The table shows the results of the multilinear regression (5) for the panel regression (fixed-effects) of all currency pairs, using additionally the lagged monthly 10 year swap return $\beta_{Return}(t-1)$ and the lagged monthly change of the implied volatility ($\beta_{Volatility}(t-1)$) as explanatory variables. The period is from 1993-2012. The reported t-statistics are Newey West estimators.

	R^2	$\beta_{Return}(t)$		$\beta_{Return}(t-1)$		$\beta_{Volatility}(t)$		$\beta_{Volatility}(t-1)$		Observations
Panel	0.11	0.31	(7.95)	0.09	(3.00)	0.77	(9.77)	0.20	(3.03)	5019

The regression results suggest that the 10-year swap return difference and the change of the implied volatility effect not only the current exchange rate, but also the exchange rate of the next month, although there is no autocorrelation in the swap return and the change of the implied volatility as the Durbin-Watson tests unveils. However, exchange rates have unit roots and are autocorrelated, which is probably the reason for this result. If we use just the lagged variables, R-squared reduces to 0.00, but the values of the lagged variables are similar 0.08 for β_{Return} and 0.14 $\beta_{Volatility}$ respectively.

6 Conclusion

We reconsider the ability of interest rates to explain short-term changes in exchange rates. We show that while – as was well-documented in the previous literature – short-term interest rates do not have much explanatory power for exchange rates, that short-term changes in long-term interest rates do. We test this with a hypothesis with a UIP-like regression, and show that changes in long-term bond prices do correspond to changes in exchange rates. Furthermore, we show that time-varying exchange-rate risk plays an important part in explaining changes in exchange rates.

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