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Angaben zur Veröffentlichung / Publication details:

Leonhardt, A., Andreas W. Rathgeber, Johannes Stadler, and Stefan Stöckl. 2015. "Pricing fx forwards in OTC markets – new evidence for the pricing mechanism when faced with counterparty risk." *Applied Economics* 47 (27): 2860–77. https://doi.org/10.1080/00036846.2015.1011309.

Applied Economics, 2015
Vol. 47, No. 27, 2860–2877, http://dx.doi.org/10.1080/00036846.2015.1011309

Pricing fx forwards in OTC markets – new evidence for the pricing mechanism when faced with counterparty risk

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By using daily foreign exchange (fx) market data for five major currency pairs, this article shows that, especially since the beginning of the financial crisis, pricing of fx forwards has not matched the pricing formula derived from the covered interest rate parity (CIP). This corresponds to previous empirical results. Therefore, the CIP leads to systematic over- or underpricing. Overall, four statistically significant explanatory factors for this systematic over- or underpricing have been identified – the volatility in the difference between the interest rate levels, the spot price, the fx forward spread and the counterparty risk. In particular, the high significance of the counterparty risk demonstrates that pricing models for fx forwards should be reviewed.

Keywords: counterparty risk; market microstructure; OTC markets; pricing fx forwards; risk premium

JEL Classification: G15

I. Introduction

Today's pricing of foreign exchange (fx) forwards remains largely based on the fundamentals set by the financial theory of the law of one price (LOP) and market efficiency (Fama, 1965; Samuelson, 1965; and Fama, 1970). Under these principles, fx forward pricing is defined by pricing two equal risk-free securities denominated in different currencies, known as the covered interest rate parity (CIP). This equality insures no arbitrage profits. After Keynes (1925), a lot of studies have dealt with the validity of the CIP. Up to the current financial crisis and the European sovereign debt crisis, the overall literature on the CIP provides fairly strong empirical support in favour of the CIP and, thus, the CIP-based

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Most part of A. Leonhardt's work on this article was done during his time at DWS Holding & Service GmbH, Deutsche Bank Group.

pricing[1] (see Sarno and Taylor (2001) for a literature overview). Therefore, it is not surprising that the CIP has been widely used by practitioners to price fx forwards. This might change during times of crisis as recent studies – Baba and Packer (2009), Coffey *et al.* (2009), Genberg *et al.* (2009) and Mancini-Griffoli and Ranaldo (2011) – have observed deviations between fx forward market prices and their theoretical (the CIP-based) values.

Literature provides several potential reasons for this observed bias. Basically, there are three explanations for the measured bias between the market priced fx forward and the pricing derived from the CIP. Frenkel and Levich (1975, 1977, 1981) attribute the CIP deviation to the existence of transaction costs. Deardorff (1979) and Callier (1981) extend this explanation introducing the concept of neutral band created by explicit transaction costs. Capital controls and different tax regulations for foreign and national investments are also covered by this neutral band as shown by Dooley and Isard (1980) and Blenman (1991). Under these premises, deviation from the CIP would still be in line with the notion of no-arbitrage and LOP. But Clinton (1988) shows that this neutral band is actually very small. Another possible explanation is that the arbitrage opportunities offered by the deviation from the CIP (above the transaction cost band) are not exploited. Market microstructure theory by, for example, Stoll (1978), O'Hara and Oldfield (1986), Kumar and Seppi (1994) and Garleanu and Pedersen (2011) give explanations under which circumstances the LOP does not hold and arbitrage opportunities exist. Roll *et al.* (2007) show that market illiquidity and the corresponding implicit transaction costs are a source for deviation from LOP and, thus, arbitrage opportunities. However, for the fx forward market numerous studies such as Rhee and Chang (1992), Fletcher and Taylor (1996) and Juhl *et al.* (2006) empirically show that solely a few arbitrage opportunities exist or at least vanish within short time (Balke and Wohar (1998)). Based on high-frequency data Akram *et al.* (2008) support, these earlier findings as the arbitrage opportunities disappear within minutes in their study. A final potential explanation is that a risk premium is directly priced in fx forward transactions compensating market participants for taking up the risk within the arbitrage strategy (see Shleifer and Vishny, 1997). Previous studies by Taylor (1987, 1989) based on high-frequency data do not provide much support for this explanation as only a few CIP violations appear during times of financial markets turmoil. However, more recent studies such as Baba and Packer (2009), Coffey *et al.* (2009), Genberg *et al.* (2009), Fong *et al.* (2010) and Mancini-Griffoli and Ranaldo (2011) analyse the current financial crisis and observe some permanent CIP deviations. All of them find out high explanatory power of different risk proxies such as the bid–ask spread or the counterparty risk for the observed pricing biases.

Although the importance of market illiquidity on the existence of arbitrage opportunity (see Kumar and Seppi, 1994 or Roll *et al.*, 2007) and asset pricing (see Amihud and Mendelson, 1986) have been investigated in literature, these aspects have been ignored for fx forward markets as they were considered as highly liquid and fairly priced. Therefore, liquidity or premium/discount[2] aspects in connection with pricing issues have been ignored mostly, in contrast to stock markets, where Archaya and Pedersen (2005) introduce a capital asset pricing model which includes liquidity. Jankowitsch *et al.* (2011) introduce a new market microstructure framework for over-the-counter (OTC) bond markets which explains liquidity-induced price dispersions. As counterparty risk does not play any role in trading bonds, no modelling was required.

By using daily fx market data for five currency pairs (EURUSD, EURCHF, EURGBP, EURJPY and USDJPY), we show that market pricing of fx forwards for these markets have not matched the pricing formula derived from the CIP since the beginning of the financial crisis in 2008. Theoretically funded on Shleifer and Vishny (1997)'s work on risk involving arbitrage transactions, we use risk indicators to explain deviations from the CIP pricing. In doing so, we apply the market microstructure framework by Jankowitsch *et al.* (2011). The market microstructure analysis gives insights into how and when market structure, uncertainty and information processing impacts an availability and risk of fx arbitrage

[1] Contrary to the empirical research on the validity of the CIP, the research on the uncovered interest rate parity (UIP) looking at the bias between fx forward predicted fx spot price and realized future fx spot price comes to the conclusion that UIP does not hold. (see Hodrick (1987), Froot and Thaler (1990) or Engel (1996) for a literature overview.)

[2] Premium stands for premium/discount in all further notions in this article.

transactions and, thus, fx forward pricing. For developing the econometric model, we use four risk factors – the volatility of the interest rate difference, the spot price, the fx forward spreads and the difference between intraday and short-term interbank lending rates – explaining the observed pricing premium. As each risk factor represents uncertainty and increasing information asymmetry in the market, our exogenous variables support the information models developed by Glosten and Milgrom (1985) and Kyle (1985). Our findings also support the market microstructure models based on the existence of the dealer's inventory problem, as developed by Garman (1976), Stoll (1978), Amihud and Mendelson (1980), Ho and Stoll (1981) and many others, since our risk factors have an effect on the dealer's inventory risk exposure, capital constraints and hedging possibility.

Our empirical work contributes to the previous literature on the CIP deviation and fx forward pricing as it uses a market microstructure framework to develop the endogenous variables for explaining the pricing dispersion. The article is closely related to the work of Baba *et al.* (2008), Baba and Packer (2009) and Genberg *et al.* (2009). These studies also link the CIP deviation to the counterparty risk premium and market liquidity. One key difference is that we introduce two further risk premium factors (the volatility in the spot price and interest rates) based on the used market microstructure. Furthermore, in contrast to Baba and Packer (2009), we prefer the volatility approach in our model as we want to emphasize the risk component. In addition, we use instead the applied EGARCH(1,1) model by Baba and Packer (2009) a GARCH(1,1) model and in the mean equation an autoregressive process with order two as we face some autocorrelation effects in our sample. Fong *et al.* (2010) also identify market liquidity and counterparty risk as key variables for the CIP deviation by using bid and ask fx quotes and a set of different market liquidity proxies. Mancini-Griffoli and Ranaldo (2011) have a slightly different approach for modelling and analysing the CIP deviation, since it considers current funding costs at the moment of the arbitrage trade. Their empirical results support the notion that funding constraints/difficulties during the current crisis have limited the scope of arbitrage trading, thereby leaving CIP deviations unexploited.

This article is organized as follows. Section II adjusts the market microstructure for OTC bond markets to fx forward markets and develops four hypotheses. Section III describes the applied methodology of the empirical analysis and the empirical results. Section IV discusses the results against the background of the related literature and concludes the article.

II. Market Microstructure and Hypotheses

Jankowitsch *et al.* (2011) develop a market microstructure for OTC markets. This market microstructure is only valid for the OTC bond market where market makers do not face any counterparty risk. Based on this market microstructure, we develop a market microstructure for fx forward transactions. In accordance with Jankowitsch *et al.* (2011), we use $p_{i,j}^a$, respectively (resp.) $p_{i,j}^b$ for modelling the ask resp. the bid price for asset i quoted by dealer j with i and $j \in \mathbb{N}^+$:

$$\begin{aligned} p_{i,j}^a &= m_i + f^a(h(s_{i,j})) \quad resp. \\ p_{i,j}^b &= m_i - f^b(h(s_{i,j})) \end{aligned} \tag{1}$$

For each fx forward there is a market price m_i calculated as the mean of all dealer quotes $m_{i,j}$. As m_i expresses a market price, it already includes public speculations. The holding cost function $h(s_{i,j})$ represents the j-th dealer's individual holding resp. inventory and funding costs of the i-th asset position $s_{i,j}$. The function f^a resp. f^b simply transforms all relevant costs into the spreads.

In times of turmoil on the financial markets, increasing credit spreads, credit rating downgrades and, thus, higher costs for taking counterparty risks, so basically the existence of counterparty risk in a OTC fx forward transaction need to be taken into account. As fx forwards are used for hedging, they are an essential part of investment strategies. The effectiveness of this investment strategy might be destroyed by a defaulting counterparty and therefore, cause further costs as there is a probability that the profits from fx forwards are lost due to the probability of a counterparty default. That is why the counterparty's cost of default must be integrated in the pricing mechanism of the fx forward. Therefore, we introduce a new credit risk cost parameter $cr_{i,j,l} \in [0,1]$ measuring the credit risk, which dealer j takes in dealing asset i with the counterparty l. The credit risk costs are finally reflected by $cr_{i,j,l} * s_{i,j,l}$. This pricing adjustment can be interpreted as a risk premium dealer j faces when trading asset i with counterparty l. The higher the default risk, the higher the risk premium will be. While Jankowitsch *et al.* (2011) modelled the holding cost function $H(s_i) = \frac{\alpha * s_i^2}{4}$ resp. $H'(s_i) = h(s_i) = \frac{\alpha * s_i}{2}$ with the risk aversion parameter $\alpha > 0$, we adjust this function to $H(s_{i,j,l}) = \frac{\alpha * s_{i,j,l}^2}{\beta} + cr_{i,j,l} * s_{i,j,l}$ resp. $H'(s_{i,j,l}) = h(s_{i,j,l}) = \frac{2 * \alpha * s_{i,j,l}}{\beta} + cr_{i,j,l}$ with $\alpha > 0$ and the parameter $\beta > 0$ simply representing the slope of the functions. Finally, we get for the ask resp. bid price

$$\begin{aligned} p^a_{i,j,l} &= m_i + f^a(h(s_{i,j,l}, cr_{i,j,l})) \quad \textit{resp.} \\ p^b_{i,j,l} &= m_i - f^b(h(s_{i,j,l}, cr_{i,j,l})) \end{aligned} \tag{2}$$

Based on this new market microstructure, we verify the integrity of the common CIP fx forward valuation formula (3). The forward price $F^M_{c_1,c_2,t}$ with maturity at time M, c_1 and c_2 as the corresponding currencies at time t, only depends on the spot price $S_{c_1,c_2,t}$ and the difference between the interest rate levels $r^M_{c_1,t}$ and $r^M_{c_2,t}$ of the currency pair c_1, c_2 at time t with maturity at time M. For all our calculations, we apply the CIP forward pricing formula as used, for example, by Fama (1984):

$$F^M_{c_1,c_2,t} = S_{c_1,c_2,t} * \frac{1 + r^M_{c_2,t}}{1 + r^M_{c_1,t}} \tag{3}$$

We compare *fairpips*[3] representing the difference between $F^M_{c_1,c_2,t}$ and $S_{c_1,c_2,t}$ with the *dealpips* for the relevant prices quoted in Bloomberg by brokers and define it as a premium according to Baba and Packer (2009) and Mancini-Griffoli and Ranaldo (2011). With the help of this market microstructure, which we adapt to fx forward transactions, and the related literature, we develop four hypotheses.

Interest rates are an essential part of forward prices. Verdelhan (2010) mentions that consumption growth shocks could affect interest and spot price markets and also generate excess returns. Furthermore, Gutirrez and Vergote (2011) identify large movements in interest rate markets during the European Central Bank (ECB) Governing Council days being the result of uncertainty about the policy rate decisions and future EURIBOR developments. For taking these risks, market makers set quotes covering the volatility risk. Therefore, our first hypothesis is formulated as follows:

H1a: The higher the volatility in the interest rate markets, the higher the volatility in the fx forward premiums.

The spot price as the underlying price is another consulted determinant of the fx forward contract. Corte *et al.* (2011) investigate the empirical relation between the fx spot- and fx forward-implied volatility and found out that the fx forward-implied volatility is a systematically biased predictor, which overestimates movements in future fx spot-implied volatility. These findings are in accordance with a trend in fx markets that there is not only fx spot and forward currency speculation but also fx spot and forward volatility speculation in dealing, the so-called fx forward volatility agreements. Again this uncertainty leads to the demand for premiums by market makers and consequently to the following hypothesis:

H1b: The higher the volatility in the fx spot price market, the higher the volatility in the fx forward premiums.

Basically, spreads in OTC markets are determined by the market demand curve, the competitiveness of the market and the agency costs according to Demetz (1968) and Benston and Hagerman (1974). The market demand curve plays an important role, particularly in uncertain times when investors regard one currency as a safe haven. The oversupply or the excess demand of a currency can be seen on spreads. Amihud and Mendelson (1986) develop an asset pricing framework including spreads and state that the expected return of an asset is an increasing and concave function of the spread. Market-making problems (reducing liquidity hence increasing spread volatility) such as higher risk aversion, difficulty to hedge positions, search cost and increased information asymmetry are the reason for higher risk premiums

[3] Pips are a common notation in fx trading: 1 pip = 0.0001.

via higher quoted spreads. Thus, spreads are an indicator for nervous markets and the occurrence of premiums in the respective market and for that reason our next hypothesis is formulated as follows:

H2: The higher the volatility of the fx forward spreads, the higher the volatility in the fx forward premiums.

The fourth hypothesis is the result of our adjustment of the market microstructure for fx forward markets and our idea for capturing the counterparty risk in fx forward transactions. Linzert and Schmidt (2011)'s findings from an empirical analysis indicate that a liquidity deficit increase induces the Euro OverNight Index Average (EONIA) spread to rise significantly. Furthermore, tight liquidity conditions and market makers' uncertainty about the counterparty's liquidity and credit rating situation put further pressure on this indicator. This uncertainty leads to a risk adjustment of the fx forward premiums depending on the long and short positions by the dealers and to our final hypothesis:

H3: The higher the volatility of interbank market risk, the higher the volatility in the fx forward premiums.

III. Model and Empirical Results

Regression model

In order to explain the determinants of changes in premiums, we use an ARMAX model with GARCH effects (see Baillie, 1980; Engle, 1982; Bollerslev, 1986; and Box *et al.*, 1987). Changes are equivalent to shocks, which we measure with the annualized five days volatility. In contrast to Baba and Packer (2009) and Mancini-Griffoli and Ranaldo (2011), we prefer the volatility approach in our model as we want to emphasize the risk component in our model. Furthermore, in contrast to the applied EGARCH(1,1) model by Baba and Packer (2009), we use a GARCH(1,1) model and add in the mean equation an autoregressive process with order two as we face some autocorrelation effects in our data set. The information criteria by Schwarz (1978) and Hannan and Quinn (1979) help us to determine the AR model. Finally, we test our four hypotheses with the following model:

$$\begin{aligned}\sigma(premium_t) = {} & \Phi_1\sigma(premium_{t-1}) \\ & + \Phi_2\sigma(premium_{t-2}) \\ & + \beta_1\sigma(diffinterest_t) \\ & + \beta_2\sigma(spotprice_t) \\ & + \beta_3\sigma(fxspread_t) \\ & + \beta_4\sigma(riskbank_t) + \varepsilon_t\end{aligned} \tag{4}$$

and

$$\sigma_t^2 = \kappa + G\sigma_{t-1}^2 + A\varepsilon_{t-1}^2 \tag{5}$$

For the validation of our model, we operationalize the variables used as follows. We apply the ICE LIBOR interest rate quotes (*diffinterest*) with the matching maturities and the *spotprice* of the underlying in order to price the forward contracts. The parameter *diffinterest* represents the difference between the interest rate level of the respective bought and sold currency. The corresponding bid and ask prices (*fxspread*) give us additional information about the quotes. With respect to our counterparty risk adjustment in the market microstructure, the parameter *riskbank* is calculated as the difference between the EUR LIBOR and EONIA Swap Index.

Database and descriptive statistics

All our data consist of daily last price quotes provided by Bloomberg and cover the EURUSD, EURCHF, EURGBP, EURJPY and USDJPY fx market from 1 January 2001 to 31 August 2011. For all spot prices, we use the closing prices, for the fx forward prices we use $0.5(bid + ask)$ from the market maker perspective. The analysis focuses on fx forward transactions with a maturity of 3, 6, 9 and 12 months. For ensuring the same time stamps particularly in the interest rates, we use the ICE LIBOR (formerly known as BBA LIBOR) quotes (EUR, USD, CHF, GBP, JPY) fixed at 11 am London time. Therefore, the fx spot prices (*spotprice*) and the fx forward price quotes all have the same time stamp which ensures, that we can use the common CIP valuation formula for pricing fx forwards and comparing them with the quotes from Bloomberg (*premium*).

We also discover (also see Fig. A1 in the 'Appendix' section) that the common CIP valuation is no longer applicable and we identify differences between *fairpips* and *dealpips*. A closer look shows the deviations from the CIP valuation after Lehman Brothers first raised capital in April 2008. After Lehman Brothers' default in September 2008, fx forward and fx spot markets were highly volatile. Dealers always got a premium of about 40 pips[4] in the peak after Lehman and an average of about 10 pips from 2008 to August 2011 for buying USD against EUR. When dealers chose contracts with longer maturities, they demanded higher premiums. We find out that in the period between 2001 and mid-2008 all forward contracts could be priced by using the CIP and investors were not affected by any premiums in fx forward markets. For that reason we do not include the period from 1 January 2001 to 30 June 2008 in our regression analysis and the following descriptive statistics. Table A1 in the 'Appendix' gives an overview of the premiums in the timeframes 1 January 2001–30 June 2008 and 1 July 2008–31 August 2011 for all currency pairs and maturities. These facts are in line with Baba and Packer (2009) and Mancini-Griffoli and Ranaldo (2011), who linked the appearance of pricing deviations with crises.

Table 1 gives an overview of the descriptive statistics for the EURUSD market data, which is finally used in the model (for all maturities), while descriptive statistics of all other markets can be found in Tables A2–A5 in the 'Appendix'. For our data set, we also reject the hypothesis (see, for instance, Hansen and Hodrick, 1980 or Engel, 1996) that fx forward rates are an estimator for future fx spot prices and therefore that UIP does not hold. We take the fx forward price at time t and compare it with the spot price at $t+90, t+180, t+270$ resp. $t+360$. The realized deviation $dev_t = |\frac{S_{c1,c2,t+M}-F^M_{c1,c2,t}}{S_{c1,c2,t+M}}|$ is measured relatively to the spot price. For demonstrating the failure of UIP pricing, we apply an approximate Gauss test with the null hypothesis $H_0 : \mu^{dev} = 0$, the alternative hypothesis $H_1 : \mu^{dev} \neq 0$ at a significance level of 0.01%. The results (see Table 2) exemplarily verify the rejection of all null hypotheses for the EURUSD market for all maturities, whereby V represents the value of the test statistic of the approximate Gauss test. As the other markets' results are basically similar, we do not show them. For a better understanding, Fig. A2 in the 'Appendix' shows our results of the deviations for the EURUSD market as an example. (As the results for the other markets are basically the same, we do not show them.)

Table 1. Descriptive statistics (EURUSD; all maturities)

Market	Maturity	Parameter	μ	σ	Min	Max	Observations
EURUSD	3 months	diffinterest	–0.78	0.56	–2.21	–0.10	827
EURUSD	3 months	spotrate	1.38	0.08	1.19	1.59	827
EURUSD	3 months	FXspread	1.03	2.01	0.00	28.62	827
EURUSD	3 months	riskbank	0.48	0.40	0.09	2.05	827
EURUSD	6 months	diffinterest	–0.76	0.55	–2.18	0.13	827
EURUSD	6 months	spotrate	1.38	0.08	1.19	1.59	827
EURUSD	6 months	FXspread	1.93	2.48	0.00	22.72	827
EURUSD	6 months	riskbank	0.68	0.41	0.19	2.22	827
EURUSD	9 months	diffinterest	–0.72	0.61	–2.28	0.24	827
EURUSD	9 months	spotrate	1.38	0.08	1.19	1.59	827
EURUSD	9 months	FXspread	3.02	2.93	0.00	15.53	827
EURUSD	9 months	riskbank	0.76	0.42	0.22	2.29	827
EURUSD	12 months	diffinterest	–0.66	0.67	–2.39	0.35	827
EURUSD	12 months	spotrate	1.38	0.08	1.19	1.59	827
EURUSD	12 months	FXspread	3.38	3.18	0.00	25.57	827
EURUSD	12 months	riskbank	0.82	0.43	0.25	2.38	827

[4] Measured relatively with the spot price as a basis.

Table 2. Descriptive statistics deviation UIP pricing and future spot price (EURUSD; all maturities)

Maturity	μ^{dev}	σ^{dev}	V	Rejection interval
3 months	5.2803	3.6767	41.3004	$(-\infty; -3.8906) \cup (3.8906; \infty)$
6 months	8.1767	4.9114	47.8768	$(-\infty; -3.8906) \cup (3.8906; \infty)$
9 months	8.7322	5.3749	46.7210	$(-\infty; -3.8906) \cup (3.8906; \infty)$
12 months	8.8841	4.8669	52.4949	$(-\infty; -3.8906) \cup (3.8906; \infty)$

Empirical results and robustness tests

First we analyse the total timeframe (July 2008–August 2011) and then we conduct a robustness check of our model. That means that we divide the total timeframe into three nonoverlapping timeframes (July 2008–June 2009, July 2009–June 2010 and July 2010–August 2011). We choose these three timeframes as the first one includes the peak of the financial crisis, the second one a more or less normal time and the third one the European sovereign debt crisis. Table 3 shows the results for the 3 months forward contracts (for all currency pairs). The results for the 6, 9 and 12 months contracts can be found in Tables A6, A7 and A8, respectively, in the 'Appendix'.

The total timeframe results for all currency pairs confirm our four hypotheses (H1a–H3) with high significance levels and high R^2 (waves between 86% and 93%). The results' significance levels in particular serve to highlight the quality of the model. H1a and H1 b include the basic parameters of the CIP fx forward pricing. Their significance in all currency pairs and overall maturities demonstrate that in highly volatile times it is not really possible to precisely assess fx forward contracts with the CIP. As a result, volatile times lead to higher risk premiums caused by extended quotes depending on the trader side when they react with an increase in the spreads on nervous fx spot and forward markets. The explanatory factor counterparty risk (H3) is highly significant at a 2.5% significance level for nearly all maturities and all currency pairs. This fact shows the importance of integrating counterparty risk (H3) into the market microstructure of fx forward markets and confirms that counterparty risk could no longer be neglected in fx forward markets.

A comparison of the results for the three different timeframes (July 2008–June 2009, July 2009–June 2010, July 2010–August 2011) and the total timeframe (July 2008–August 2011) shows that the results are robust and provides some additional information. While over the total timeframe, the regression results for all parameters are almost always highly significant at a 2.5% significance level, the estimation for a sub-period is not always highly significant. That means, that we could find periods, where the determinants for premiums in fx forward markets change or interest rate, spot market or interbank market factors are non-volatile and stable. As a result, R^2 is ranging between 70% and 92%. However, we also must take the smaller sample size of the sub-periods into account. This means, that the effects could also be weaker as we consider less observations. All in all, it could be said that the results are often stable in the case of variations in timeframes. A detailed view into every hypothesis and the happenings during the respective period can be very useful. After the collapse of Lehman Brothers in September 2008, fast-dropping stock markets and a bad economic situation, the ECB as well as the Federal Reserve (FED) cut the interest rate levels extremely and thereby caused high volatility on the interest rate markets. This uncertainty also affected the pricing of fx forwards with the basic parameter of our hypothesis H1a. This effect particularly appears when we compare our estimated parameters of *diffinterest* for a short- and long-term contract. In the EURUSD market, we estimate smaller parameters in the first sub-period of the 3 months contract compared to the others contracts. Therefore, a longer maturity includes higher interest rate risks and market makers demand higher premiums. However, during the third sub-period, interest rate markets calmed down and we lose explanatory power in our model for this hypothesis. Furthermore, for example, the Swiss Franc is often considered as a safe haven during crisis where often a flight to quality could be observed (see, for example, Santis, 2012). That is why the estimated parameters are better in the first sub-period (Lehman Brothers collapse) and third sub-period (European sovereign debt crisis) compared to the second sub-period. Due to these facts, the spot price volatility increases especially in these periods and complicates fx forward

Table 3. Results for all currency pairs: maturity – 3 months

Market	Period	Φ_1	Φ_2	β_1	β_2	β_3	β_4	κ	G	A	R^2	DW	Observations
EURUSD	all	1.1556***	−0.29342***	0.59256*	2.3604***	0.016878	2.2587***	0.14762***	0.76757***	0.23243***	0.91951	1.5679	827
		(0.027926)	(0.026755)	(0.44581)	(0.67516)	(0.022702)	(0.41108)	(0.042831)	(0.025291)	(0.054899)			
EURUSD	t_1	1.1494***	−0.30278***	1.2019**	2.7019*	0.10896***	2.4277***	0.28514**	0.79554***	0.20446***	0.91585	1.5256	261
		(0.0516)	(0.050951)	(0.66486)	(1.6492)	(0.051017)	(0.83978)	(0.1534)	(0.044272)	(0.078556)			
EURUSD	t_2	1.1094***	−0.24729***	0.9905	1.6294***	0.039931*	0.63272	0.062063	0.8677***	0.1323*	0.84165	1.8877	261
		(0.040979)	(0.040142)	(1.1521)	(0.78448)	(0.02436)	(0.7187)	(0.048655)	(0.050908)	(0.09674)			
EURUSD	t_3	1.0521***	−0.28802***	−1.8241*	7.9148***	−0.010575	3.8784***	3.5835*	0.096023	0.90398*	0.70787	2.1805	305
		(0.056924)	(0.052373)	(1.2168)	(1.46)	(0.07032)	(0.8182)	(2.2579)	(0.093336)	(0.59748)			
EURCHF	all	1.1183***	−0.26109***	0.5238	3.2726***	0.050702***	1.7496***	0.084143***	0.83521***	0.16479***	0.87628	2.1352	827
		(0.028185)	(0.026846)	(0.52287)	(0.96141)	(0.015365)	(0.42068)	(0.027233)	(0.023516)	(0.037714)			
EURCHF	t_1	1.1274***	−0.30962***	0.67535	12.16***	0.12941***	1.3332**	0.21686*	0.83467***	0.16532***	0.88838	2.2526	261
		(0.054381)	(0.04929)	(0.92577)	(2.8407)	(0.020502)	(0.73774)	(0.1364)	(0.047714)	(0.070724)			
EURCHF	t_2	1.0984***	−0.27086***	0.63975	6.0303***	0.010968	2.3022***	0.15484*	0.75613***	0.24387*	0.89364	1.3449	261
		(0.048771)	(0.046353)	(1.3271)	(2.1285)	(0.024695)	(0.96938)	(0.098955)	(0.06649)	(0.15862)			
EURCHF	t_3	1.066***	−0.22385***	−1.5507	3.5674***	0.0030471	3.3464***	0.25857**	0.80689***	0.19311***	0.80982	2.1744	305
		(0.044867)	(0.042563)	(1.3121)	(1.5924)	(0.040903)	(0.81099)	(0.15247)	(0.064332)	(0.088872)			
EURGBP	all	1.1452***	−0.28057***	0.58834	1.9694**	0.063536**	1.8025***	0.053695***	0.82136***	0.17864***	0.91071	1.9101	827
		(0.028527)	(0.027172)	(0.47676)	(1.1679)	(0.032623)	(0.33801)	(0.017435)	(0.024263)	(0.038)			
EURGBP	t_1	1.1874***	−0.35688***	1.4104***	10.132***	0.21914***	0.37349	0.26513**	0.78861***	0.21139***	0.89596	1.9897	261
		(0.053089)	(0.048874)	(0.71455)	(3.0186)	(0.069743)	(0.82906)	(0.13761)	(0.048375)	(0.077298)			
EURGBP	t_2	1.073***	−0.20974***	0.018101	1.9073**	0.056475*	1.3578***	0.041171**	0.77187***	0.22813***	0.74381	2.193	261
		(0.049795)	(0.048779)	(0.75923)	(1.1133)	(0.036496)	(0.56938)	(0.023037)	(0.047627)	(0.1141)			
EURGBP	t_3	1.088***	−0.28519***	−2.5108***	7.561***	−0.022723	4.3339***	2.5241**	0.013878	0.28934*	0.78104	2.1059	305
		(0.050646)	(0.045788)	(1.2659)	(2.7899)	(0.0991)	(0.66858)	(1.2891)	(0.21981)	(0.2229)			
EURJPY	all	1.1417***	−0.27068***	−0.00896*	0.0001973***	−8.0085e-05	0.02962***	4.899e-06***	0.84229***	0.15771***	0.90939	1.8614	826
		(0.030599)	(0.029079)	(0.0063349)	(5.4364e-05)	(0.00021513)	(0.0039575)	(1.8321e-06)	(0.021938)	(0.034982)			
EURJPY	t_1	1.0962***	−0.17757***	−0.0005932	0.00011946	0.00018871	0.018684***	4.7779e-05	0.89308***	0.10692*	0.88806	1.8848	261
		(0.049857)	(0.049825)	(0.0095659)	(0.00019332)	(0.00033212)	(0.0078536)	(3.8514e-05)	(0.039648)	(0.069997)			
EURJPY	t_2	1.0973***	−0.26723***	−0.024863***	0.0002296***	−0.00023003	0.045242***	8.759e-06**	0.68874***	0.31126***	0.80811	1.9489	261
		(0.057769)	(0.054351)	(0.011528)	(6.0009e-05)	(0.00019781)	(0.0087071)	(5.0464e-06)	(0.088815)	(0.14972)			
EURJPY	t_3	1.1432***	−0.31074***	−0.01748	0.00042603***	0.00095665*	0.029387***	4.8707e-05	0.72325***	0.11352**	0.79054	1.8061	304
		(0.053945)	(0.04775)	(0.01449)	(0.0001565)	(0.00072541)	(0.0077094)	(3.8436e-05)	(0.16136)	(0.06551)			
USDJPY	all	1.1879***	−0.30925***	0.032701***	0.00026329***	3.0323e-05	0.0051926***	6.2367e-06***	0.80115***	0.19885***	0.92183	1.8213	826
		(0.027466)	(0.026362)	(0.0044208)	(8.1858e-05)	(0.00016001)	(0.0021943)	(1.8909e-06)	(0.0238)	(0.044667)			
USDJPY	t_1	1.1132***	−0.30788***	0.048614***	0.00044048*	0.0047287***	0.00444	3.855e-05***	0.74146***	0.25854***	0.91021	1.7823	261
		(0.051482)	(0.047656)	(0.0073874)	(0.00028194)	(0.0013573)	(0.0074069)	(1.8792e-05)	(0.050013)	(0.095785)			
USDJPY	t_2	1.2058***	−0.32981***	0.010541	0.00030473***	−2.8711e-05	0.0093572*	1.2317e-05**	0.60728***	0.39272**	0.87542	1.7658	261
		(0.052802)	(0.051447)	(0.009168)	(0.00010927)	(0.00013861)	(0.0069369)	(7.3654e-06)	(0.11105)	(0.228)			
USDJPY	t_3	1.1911***	−0.32149***	0.014655	0.00033559**	0.0003228	0.0044953*	8.5129e-06*	0.79785***	0.20215***	0.82744	1.9986	304
		(0.043626)	(0.042094)	(0.016761)	(0.00017899)	(0.0006134)	(0.0031815)	(5.3025e-06)	(0.051084)	(0.10169)			

Notes: *10% significance level, **5% significance level, **2.5% significance level. DW, Durbin-Watson value. Values in () represent SE.

pricing. Similar to H1b, we get the best results for H2 during the crisis, especially during the first sub-period. In this time period, we recognize widening spreads as a result of nervous markets. Since the collapse of Lehman Brothers, the awareness of counterparty risk is back in the financial sector. Looking at the development of nearly all significant parameters of H3, we can see a rising trend of the estimated parameter *riskbank* for nearly all currencies and maturities within our three sub-periods. All in all, these facts even confirm that counterparty risk is a factor gaining importance for explaining the deviations from the CIP pricing.

IV. Discussion and Conclusion

After analysing the structure of an fx forward contract and the growing counterparty risk in the financial sector, we adjust the OTC bond market microstructure by Jankowitsch *et al.* (2011) and integrate a counterparty risk parameter. Based on this market microstructure, we compare the fx forward price derived from the CIP and the quoted prices in Bloomberg and we identify time-varying premiums and discounts. We explain these effects with the help of a ARMAX model with GARCH effects, whereby we find four statistically highly significant explanatory factors (volatility in the difference between the interest rate levels, the spot price, the fx forward spread and the counterparty risk). In particular, the significance of the explanatory factor counterparty risk with regard to the financial crisis and the European sovereign debt crisis confirms that pricing models for fx forwards must be reviewed and that problems in the interbank market also affect the OTC markets.

Furthermore, in contrast to the papers of Baba *et al.* (2008), Baba and Packer (2009) and Genberg *et al.* (2009), we have to emphasize as our contribution to the current literature that we introduce two further risk premium factors (the volatility in the spot price and interest rates) based on the used market microstructure. Moreover, in contrast to Baba and Packer (2009), we prefer the volatility approach in our model as we want to emphasize the risk component. In addition, we only use a GARCH(1,1) model instead of the applied EGARCH(1,1) model by Baba and Packer (2009), but extend the mean equation by an autoregressive process with order two as we face some autocorrelation effects in our sample. All in all, the risk adaption of fx forward prices could be a hint of rational market behaviour by market participants and efficient fx forward markets.

However, we know that we only integrate a proxy for measuring the counterparty risk in our model and do not, for instance, use precise credit default spreads measuring idiosyncratic risks. During times of varying credit risks within the banking sector, it would possibly be more accurate to use credit default spreads of both parties within fx forward contracts. Unfortunately, our data set does not provide any information about these details. Sorensen and Bollier (1994), for example, offer a suggestion for pricing counterparty default risk in swap contracts. All in all, our model gives an overview of fx forward markets and is not applicable to individual pricing issues. Among other things, it strongly supports the argument that the counterparty risk has to be considered in the pricing mechanism.

To sum up, pricing of fx forwards require the consideration of multiple levels of risk which become relevant under market turmoil. Under these circumstances, market microstructure aspects such as hedging costs, inventory problems, information asymmetries and market heterogeneities are relevant to pricing and, therefore, our findings should ensure a better understanding of fx forward markets.

Acknowledgements

The authors would like to thank the Risk & Control Management Department of DWS Holding & Service GmbH, Deutsche Bank Group, for data support and Christian Schöppe (DWS Investments, Deutsche Bank Group) for the very helpful advice on this topic.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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Appendix

Table A1. Absolute differences between fair- and dealpips for all currencies and maturities

		1 January 2001 – 30 June 2008				1 July 2008 – 31 August 2011			
Currency	Maturity	μ	σ	Min	Max	μ	σ	Min	Max
EURUSD	3 months	1.26	1.70	0.00	10.22	9.41	6.93	0.22	64.14
EURUSD	6 months	1.74	1.91	0.00	14.14	17.86	12.91	0.34	94.95
EURUSD	9 months	3.28	3.91	0.00	29.40	23.81	20.79	0.01	120.50
EURUSD	12 months	5.75	7.26	0.00	53.66	30.76	28.99	0.06	170.71
EURCHF	3 months	1.02	0.83	0.00	6.35	3.75	4.17	0.02	26.49
EURCHF	6 months	1.43	1.26	0.00	10.25	11.45	7.38	0.05	57.55
EURCHF	9 months	2.00	2.05	0.00	17.82	14.59	12.81	0.05	90.77
EURCHF	12 months	3.14	3.46	0.00	30.48	17.16	18.24	0.01	120.97
EURPFUND	3 months	2.04	1.00	0.00	10.75	4.77	3.16	0.05	24.15
EURPFUND	6 months	4.64	1.87	0.00	15.30	9.80	6.41	0.01	41.79
EURPFUND	9 months	8.05	3.00	0.05	23.44	11.99	9.44	0.03	61.33
EURPFUND	12 months	12.13	4.23	0.14	32.98	13.76	12.70	0.00	78.41
EURJPY	3 months	0.02	0.01	0.00	0.17	0.04	0.05	0.00	0.37
EURJPY	6 months	0.03	0.06	0.00	2.04	0.09	0.13	0.00	0.78
EURJPY	9 months	0.05	0.38	0.00	15.69	0.13	0.23	0.00	1.23
EURJPY	12 months	0.06	0.09	0.00	1.89	0.20	0.31	0.00	1.70
USDJPY	3 months	0.02	0.03	0.00	1.28	0.06	0.05	0.00	0.59
USDJPY	6 months	0.03	0.06	0.00	2.47	0.11	0.07	0.00	0.68
USDJPY	9 months	0.03	0.02	0.00	0.27	0.16	0.11	0.00	0.81
USDJPY	12 months	0.06	0.12	0.00	4.75	0.20	0.14	0.00	0.84

Notes: For comparing the pips, we used the relative measure $\frac{pips_t}{S_{c_1,c_2,t}}$.
For EURJPY, USDJPY, we used the decimal quotation instead of the pips.

Table A2. Descriptive statistics (EURCHF: all maturities)

Market	Maturity	Parameter	μ	σ	Min	Max	Observations
EURCHF	3 months	diffinterest	−1.03	0.64	−2.68	−0.33	827
EURCHF	3 months	spotrate	1.42	0.13	1.03	1.63	827
EURCHF	3 months	FXspread	2.86	3.67	0.44	25.28	827
EURCHF	3 months	riskbank	0.48	0.40	0.09	2.05	827
EURCHF	6 months	diffinterest	−1.17	0.56	−2.54	−0.55	827
EURCHF	6 months	spotrate	1.42	0.13	1.03	1.63	827
EURCHF	6 months	FXspread	5.83	5.36	1.57	31.94	827
EURCHF	6 months	riskbank	0.68	0.41	0.19	2.22	827
EURCHF	9 months	diffinterest	−1.16	0.54	−2.43	−0.56	827
EURCHF	9 months	spotrate	1.42	0.13	1.03	1.63	827
EURCHF	9 months	FXspread	9.11	6.36	3.87	34.37	827
EURCHF	9 months	riskbank	0.76	0.42	0.22	2.29	827
EURCHF	12 months	diffinterest	−1.13	0.54	−2.35	−0.52	827
EURCHF	12 months	spotrate	1.42	0.13	1.03	1.63	827
EURCHF	12 months	FXspread	10.67	6.95	4.90	42.80	827
EURCHF	12 months	riskbank	0.82	0.43	0.25	2.38	827

Table A3. Descriptive statistics (EURGBP: all maturities)

Market	Maturity	Parameter	μ	σ	Min	Max	Observations
EURPFUND	3 months	diffinterest	−0.01	0.40	−0.73	1.17	827
EURPFUND	3 months	spotrate	0.87	0.04	0.77	0.98	827
EURPFUND	3 months	FXspread	1.11	1.49	0.18	10.30	827
EURPFUND	3 months	riskbank	0.48	0.40	0.09	2.05	827
EURPFUND	6 months	diffinterest	−0.02	0.39	−0.69	1.18	827
EURPFUND	6 months	spotrate	0.87	0.04	0.77	0.98	827
EURPFUND	6 months	FXspread	2.41	2.65	0.54	13.92	827
EURPFUND	6 months	riskbank	0.68	0.41	0.19	2.22	827
EURPFUND	9 months	diffinterest	0.04	0.38	−0.62	1.19	827
EURPFUND	9 months	spotrate	0.87	0.04	0.77	0.98	827
EURPFUND	9 months	FXspread	3.51	3.38	0.22	25.10	827
EURPFUND	9 months	riskbank	0.76	0.42	0.22	2.29	827
EURPFUND	12 months	diffinterest	0.08	0.37	−0.60	1.19	827
EURPFUND	12 months	spotrate	0.87	0.04	0.77	0.98	827
EURPFUND	12 months	FXspread	4.50	3.93	1.53	21.31	827
EURPFUND	12 months	riskbank	0.82	0.43	0.25	2.38	827

Table A4. Descriptive statistics (EURJPY: all maturities)

Market	Maturity	Parameter	μ	σ	Min	Max	Observations
EURJPY	3 months	diffinterest	−1.21	1.15	−4.30	−0.33	826
EURJPY	3 months	spotrate	124.82	14.22	105.97	169.49	826
EURJPY	3 months	FXspread	2.10	3.45	0.40	28.89	826
EURJPY	3 months	riskbank	0.48	0.40	0.09	2.05	826
EURJPY	6 months	diffinterest	−1.28	1.14	−4.31	−0.43	826
EURJPY	6 months	spotrate	124.82	14.22	105.97	169.49	826
EURJPY	6 months	FXspread	4.09	4.85	1.03	32.48	826
EURJPY	6 months	riskbank	0.68	0.41	0.19	2.22	826
EURJPY	9 months	diffinterest	−1.29	1.14	−4.27	−0.42	826
EURJPY	9 months	spotrate	124.82	14.22	105.97	169.49	826
EURJPY	9 months	FXspread	6.25	5.70	2.36	37.00	826
EURJPY	9 months	riskbank	0.76	0.42	0.22	2.29	826
EURJPY	12 months	diffinterest	−1.33	1.13	−4.30	−0.43	826
EURJPY	12 months	spotrate	124.82	14.22	105.97	169.49	826
EURJPY	12 months	FXspread	7.61	6.38	0.89	43.39	826
EURJPY	12 months	riskbank	0.82	0.43	0.25	2.38	826

Note: For EURJPY we used the decimal quotation instead of the pips.

Table A5. Descriptive statistics (USDJPY: all maturities)

Market	Maturity	Parameter	μ	σ	Min	Max	Observations
USDJPY	3 months	diffinterest	−0.42	0.72	−3.74	0.07	827
USDJPY	3 months	spotrate	90.41	7.89	76.55	110.54	827
USDJPY	3 months	FXspread	1.00	1.74	0.15	15.00	827
USDJPY	3 months	riskbank	0.52	0.38	0.14	2.07	827
USDJPY	6 months	diffinterest	−0.51	0.75	−3.22	0.08	827
USDJPY	6 months	spotrate	90.41	7.89	76.55	110.54	827
USDJPY	6 months	FXspread	1.67	2.12	0.28	15.01	827
USDJPY	6 months	riskbank	0.71	0.39	0.24	2.23	827
USDJPY	9 months	diffinterest	−0.57	0.71	−3.04	0.00	827
USDJPY	9 months	spotrate	90.41	7.89	76.55	110.54	827
USDJPY	9 months	FXspread	2.41	2.38	0.75	16.45	827
USDJPY	9 months	riskbank	0.78	0.41	0.28	2.29	827
USDJPY	12 months	diffinterest	−0.67	0.66	−2.91	−0.11	827
USDJPY	12 months	spotrate	90.41	7.89	76.55	110.54	827
USDJPY	12 months	FXspread	3.21	2.67	0.99	17.39	827
USDJPY	12 months	riskbank	0.84	0.42	0.33	2.39	827

Note: For USDJPY we used the decimal quotation instead of the pips.

Table A6. Results for all currency pairs: maturity – 6 months

Market	Period	Φ_1	Φ_2	β_1	β_2	β_3	β_4	κ	G	A	R^2	DW	Observations
EURUSD	all	1.119***	−0.29213***	2.8085***	6.2037***	0.0034318	5.5708***	0.1438***	0.89036***	0.10964***	0.93061	1.5264	827
		(0.027449)	(0.025171)	(0.84816)	(1.5964)	(0.020985)	(0.93324)	(0.060056)	(0.016563)	(0.02418)			
EURUSD	t_1	1.1042***	−0.31446***	2.2973***	6.9302***	0.32019***	3.5874***	1.1633***	0.78509***	0.21491***	0.92431	1.4857	261
		(0.052895)	(0.048186)	(1.0256)	(3.0911)	(0.077662)	(1.6226)	(0.58664)	(0.04663)	(0.082076)			
EURUSD	t_2	1.0661***	−0.23428***	3.0721*	3.0839	0.011261	5.1984***	0.23133*	0.86244***	0.13756**	0.85579	1.6724	261
		(0.050099)	(0.046701)	(1.9498)	(2.4531)	(0.027232)	(1.6267)	(0.16046)	(0.052622)	(0.082406)			
EURUSD	t_3	1.0662***	−0.33959***	−3.695	15.5692***	0.21583***	9.588***	2.6986	0.73538***	0.22196*	0.78101	2.1214	305
		(0.051371)	(0.043861)	(3.1192)	(3.7667)	(0.088582)	(1.9813)	(2.194)	(0.14872)	(0.15164)			
EURCHF	all	1.1491***	−0.31185***	2.8468***	4.4299***	0.065219***	4.5266***	0.36356***	0.82087***	0.17913***	0.86093	2.123	827
		(0.028866)	(0.026775)	(1.0569)	(1.7589)	(0.01875)	(0.81942)	(0.12177)	(0.028978)	(0.038973)			
EURCHF	t_1	1.128***	−0.33983***	1.451	12.7224**	0.11719***	8.0308***	1.0278**	0.76409***	0.23591***	0.8773	2.0367	261
		(0.057227)	(0.050839)	(1.7833)	(6.8944)	(0.023085)	(1.4551)	(0.60603)	(0.065306)	(0.08645)			
EURCHF	t_2	1.1632***	−0.34911***	4.2044*	12.4922***	0.053422*	4.9265***	0.40758**	0.75435***	0.24565**	0.888	1.4578	261
		(0.049167)	(0.04698)	(3.0647)	(4.9344)	(0.034881)	(1.9623)	(0.23384)	(0.074962)	(0.1286)			
EURCHF	t_3	1.0827***	−0.23644***	1.393	3.1476	0.067279*	4.1221***	2.2037*	0.76066***	0.23934*	0.76085	2.2459	305
		(0.048909)	(0.045437)	(2.2044)	(3.0009)	(0.04196)	(1.4812)	(1.5678)	(0.10572)	(0.14794)			
EURGBP	all	1.1396***	−0.31485***	3.7227***	11.1048***	0.0083281	4.2816***	0.29666***	0.84716***	0.15284***	0.90774	1.9155	827
		(0.027072)	(0.024742)	(1.0133)	(2.3353)	(0.034745)	(0.71162)	(0.11388)	(0.025707)	(0.041162)			
EURGBP	t_1	1.1517***	−0.32769***	4.2736***	16.2864***	0.19126**	1.2467	1.1262**	0.78346***	0.21654***	0.88968	1.9354	261
		(0.04786)	(0.043317)	(1.5247)	(5.0778)	(0.10393)	(1.2633)	(0.63472)	(0.052052)	(0.099409)			
EURGBP	t_2	1.101***	−0.27025***	2.6883**	7.4514***	0.0094438	3.3595***	0.18286*	0.80656***	0.19344**	0.79026	1.7468	261
		(0.05139)	(0.047259)	(1.5347)	(2.625)	(0.032765)	(1.4181)	(0.12696)	(0.058408)	(0.10472)			
EURGBP	t_3	1.0728***	−0.3288***	0.16795	27.1256***	0.09664	7.1133***	3.2768	0.62732***	0.34622	0.79125	2.0601	305
		(0.049167)	(0.043653)	(2.9429)	(6.1549)	(0.13022)	(1.5055)	(2.8043)	(0.15016)	(0.28474)			
EURJPY	all	1.0814***	−0.23007***	−0.0036236	0.00043395***	8.3582e-05	0.068423***	1.552e-05***	0.92634***	0.073658***	0.89072	1.8466	826
		(0.028312)	(0.026408)	(0.013783)	(0.00011996)	(0.00028152)	(0.0087031)	(6.8893e-06)	(0.014128)	(0.021323)			
EURJPY	t_1	1.0748***	−0.24909***	0.0039362	0.00068025**	0.00052405	0.081668***	0.00020656*	0.8792***	0.1208*	0.87189	1.9214	261
		(0.052959)	(0.049658)	(0.016394)	(0.00036235)	(0.00041672)	(0.016633)	(0.00015978)	(0.045647)	(0.077073)			
EURJPY	t_2	1.0204***	−0.11201***	−0.09912***	0.00045441***	−0.00011839	0.046709***	0.0012481	0.095243	0.90476	0.70708	1.7009	261
		(0.051012)	(0.049249)	(0.033519)	(0.00014433)	(0.00029633)	(0.018117)	(0.0036111)	(0.24279)	(2.6246)			
EURJPY	t_3	1.0384***	−0.23851***	−0.034447	0.0010075***	0.001892**	0.072077***	0.00019723	0.74156***	0.086416	0.76284	1.8279	304
		(0.053673)	(0.049392)	(0.028172)	(0.00029694)	(0.0011238)	(0.016175)	(0.00018958)	(0.20496)	(0.074777)			
USDJPY	all	1.1056***	−0.24863***	0.065137***	0.00039046***	0.00016154	0.015651***	1.8035e-05***	0.8409***	0.1591***	0.91651	1.8141	826
		(0.028741)	(0.02766)	(0.0073975)	(0.0001832)	(0.00018971)	(0.0047477)	(5.8156e-06)	(0.021433)	(0.036327)			
USDJPY	t_1	1.0609***	−0.22215***	0.082871***	5.6183e-05	0.00049556	0.0026047	0.00018773**	0.79788***	0.20212***	0.89344	1.715	261
		(0.051808)	(0.049562)	(0.01213)	(0.00059709)	(0.001891)	(0.015052)	(0.00010446)	(0.049405)	(0.092411)			
USDJPY	t_2	1.0223***	−0.19321***	0.059732***	0.0002135	0.0003189*	0.055683***	3.9765e-05**	0.76002***	0.19516**	0.87095	1.5876	261
		(0.062258)	(0.061081)	(0.019698)	(0.00029686)	(0.00023213)	(0.018539)	(2.138e-05)	(0.090361)	(0.10058)			
USDJPY	t_3	1.1853***	−0.32302***	0.09342***	0.00048396*	−4.7233e-05	0.011823***	8.589e-06**	0.83333***	0.16667***	0.84071	1.9181	304
		(0.044221)	(0.041941)	(0.031595)	(0.00033826)	(0.0003406)	(0.0052278)	(4.9977e-06)	(0.039852)	(0.058956)			

Notes: *10% significance level, **5% significance level, ***2.5% significance level. DW, Durbin-Watson value. Values in () represent SE.

Table A7. Results for all currency pairs: maturity – 9 months

Market	Period	Φ_1	Φ_2	β_1	β_2	β_3	β_4	κ	G	A	R^2	DW	Observations
EURUSD	all	1.0735***	−0.26753***	6.0758***	11.4783***	0.018692	11.0244***	1.8777***	0.80923***	0.19077***	0.91751	1.7248	827
		(0.031814)	(0.029103)	(1.1591)	(3.2529)	(0.018282)	(1.5755)	(0.65215)	(0.031803)	(0.046642)			
EURUSD	t_1	1.0503***	−0.24528***	7.3747***	10*	0.080783	8.0449***	6.375**	0.71266***	0.28734***	0.91046	1.564	261
		(0.059331)	(0.054069)	(1.6635)	(7.2278)	(0.079321)	(2.8703)	(3.5022)	(0.061102)	(0.11836)			
EURUSD	t_2	1.0415***	−0.23317***	8.3358***	9.4456**	0.007201	10.5627***	0.2269	0.94624***	0.034922*	0.8233	1.7738	261
		(0.054971)	(0.053162)	(3.3247)	(5.0771)	(0.021534)	(3.3603)	(0.27844)	(0.041462)	(0.021584)			
EURUSD	t_3	1.0555***	−0.33374***	−4.2522	26.3207***	0.18499***	17.6156***	5.477**	0.68985***	0.25961***	0.76342	2.0419	305
		(0.055381)	(0.046822)	(4.5234)	(6.2076)	(0.094341)	(3.2327)	(3.0926)	(0.11109)	(0.11688)			
EURCHF	all	1.1035***	−0.27491***	6.3096***	8.9135***	0.050185***	7.4605***	0.39396***	0.88466***	0.11534***	0.86875	1.9767	827
		(0.02785)	(0.025945)	(1.7338)	(2.9259)	(0.020143)	(1.3161)	(0.17154)	(0.018743)	(0.024123)			
EURCHF	t_1	1.0035***	−0.21117***	5.816***	21.6312***	0.10014***	9.3727***	2.407*	0.82075***	0.17925***	0.87956	1.8692	261
		(0.056907)	(0.053762)	(2.7299)	(9.8207)	(0.046302)	(2.5011)	(1.6244)	(0.056626)	(0.075978)			
EURCHF	t_2	1.1189***	−0.27778***	11.3551**	2.3955	0.10122***	5.076*	0.79769**	0.78828***	0.21172***	0.85475	1.7368	261
		(0.052287)	(0.049113)	(6.2825)	(9.4332)	(0.035916)	(3.3876)	(0.47606)	(0.063926)	(0.1029)			
EURCHF	t_3	1.0838***	−0.3069***	6.2463***	12.3882***	0.017865	10***	3.5226	0.79818***	0.20182**	0.79642	1.9512	305
		(0.044977)	(0.041569)	(2.9109)	(4.6554)	(0.03539)	(2.3741)	(2.8144)	(0.10888)	(0.1214)			
EURGBP	all	1.1215***	−0.32976***	6.6984***	28.9129***	0.088418***	8.2408***	1.6383***	0.79907***	0.20093***	0.90502	1.9884	827
		(0.029385)	(0.026874)	(1.5775)	(4.0075)	(0.036813)	(1.1763)	(0.5835)	(0.037194)	(0.057458)			
EURGBP	t_1	1.0996***	−0.31925***	8.3461***	21.4067***	0.4623***	3.8276***	4.3452**	0.7746***	0.2254**	0.89761	1.9348	261
		(0.053711)	(0.048828)	(2.035)	(7.8247)	(0.1337)	(1.912)	(2.6112)	(0.073955)	(0.12071)			
EURGBP	t_2	1.1302***	−0.31417***	4.2046	21.8334***	0.048714	8.4709***	3.5568*	0.56256***	0.26714*	0.8024	1.771	261
		(0.055668)	(0.051162)	(3.7402)	(5.7661)	(0.10083)	(2.6583)	(2.4931)	(0.20045)	(0.17939)			
EURGBP	t_3	1.0677***	−0.34733***	1.4517	58.5956***	0.10984***	11.63***	5**	0.64739***	0.3088***	0.78059	2.2028	305
		(0.051418)	(0.044853)	(4.7207)	(9.5617)	(0.047081)	(2.5661)	(2.8306)	(0.11459)	(0.15688)			
EURJPY	all	1.1007***	−0.27369***	0.0001161	0.00084074***	0.00068301*	0.11442***	0.00019687***	0.85054***	0.14946***	0.87471	1.8887	826
		(0.027553)	(0.025775)	(0.018763)	(0.00022164)	(0.0005079)	(0.013651)	(8.1742e-05)	(0.029919)	(0.054221)			
EURJPY	t_1	1.0978***	−0.30849***	0.021935	0.0014007***	0.00091106	0.11047***	0.000488*	0.86193***	0.13807**	0.858	1.9087	261
		(0.048016)	(0.046001)	(0.026243)	(0.00050497)	(0.00076576)	(0.02425)	(0.00036119)	(0.046099)	(0.081055)			
EURJPY	t_2	1.1201***	−0.25749***	−0.082003*	0.00028689	0.00081412	0.13694***	8.249e-05	0.88288***	0.11712	0.74063	1.9139	261
		(0.047376)	(0.045615)	(0.053262)	(0.00029116)	(0.00081478)	(0.035351)	(9.6588e-05)	(0.077092)	(0.10823)			
EURJPY	t_3	1.0306***	−0.2646***	−0.025348	0.0025186***	2.7091e-05	0.14052***	0.00045692	0.75702***	0.12477*	0.74819	2.0208	304
		(0.051569)	(0.046142)	(0.040537)	(0.00056025)	(0.0017133)	(0.026302)	(0.00035781)	(0.14994)	(0.095287)			
USDJPY	all	1.0713***	−0.20543***	0.067998***	0.00084404***	0.0025677***	0.021578***	0.00010996***	0.81713***	0.18287***	0.89376	2.1044	826
		(0.030826)	(0.029424)	(0.01108)	(0.00038017)	(0.00097773)	(0.0096279)	(3.6486e-05)	(0.030003)	(0.047072)			
USDJPY	t_1	0.99163***	−0.13903***	0.10208***	0.00044363	0.0025652	0.0013417	0.00055307*	0.83196***	0.16804***	0.85958	2.0003	261
		(0.059034)	(0.055073)	(0.020651)	(0.0011973)	(0.0021444)	(0.026006)	(0.00034263)	(0.051858)	(0.078379)			
USDJPY	t_2	0.9787***	−0.081523*	0.006916	0.0013976***	0.0014074	0.026418	0.00012451	0.82439***	0.17561*	0.83916	1.6802	261
		(0.05825)	(0.057029)	(0.0239)	(0.00057225)	(0.0015764)	(0.028534)	(0.00010024)	(0.09061)	(0.13082)			
USDJPY	t_3	1.191***	−0.3416***	0.090686***	0.00049322	0.0049325***	0.027037***	0.00013489**	0.76967***	0.23033***	0.82218	1.9634	304
		(0.046313)	(0.044007)	(0.045314)	(0.00075904)	(0.0021802)	(0.012078)	(7.9201e-05)	(0.072542)	(0.11487)			

Notes: *10% significance level, **5% significance level, ***2.5%significance level. DW, Durbin-Watson value. Values in () represent SE.

Table A8. Results for all currency pairs: maturity – 12 months

Market	Period	Φ_1	Φ_2	β_1	β_2	β_3	β_4	κ	G	A	R^2	DW	Observations
EURUSD	all	0.98617***	−0.26977***	17.7087***	6.5488***	0.016129	7.9202***	1.5629***	0.75096***	0.24904***	0.92232	1.6734	827
		(0.030886)	(0.027127)	(1.1686)	(2.382)	(0.015451)	(1.1261)	(0.49493)	(0.038069)	(0.063525)			
EURUSD	t_1	0.93888***	−0.25287***	18.5819***	10*	−0.0017361	12.1499***	8.3051**	0.71765***	0.28235***	0.89855	1.5436	261
		(0.057735)	(0.04974)	(1.9706)	(6.1863)	(0.06233)	(2.7199)	(4.4893)	(0.077731)	(0.11803)			
EURUSD	t_2	0.85388***	−0.25287***	29.6711***	2.5488	0.023929	9.8111***	3.3241***	0.12996	0.87004***	0.82702	1.9581	261
		(0.058252)	(0.047562)	(2.4977)	(3.3744)	(0.018885)	(2.275)	(1.0607)	(0.127)	(0.36209)			
EURUSD	t_3	1.0347***	−0.25282***	3.4179*	9.2154***	0.0483**	7.2543***	5**	0.53631***	0.29015**	0.78426	2.0524	305
		(0.057496)	(0.052997)	(2.5462)	(4.2582)	(0.028332)	(1.9843)	(2.7873)	(0.15683)	(0.1515)			
EURCHF	all	1.1197***	−0.29062***	10.0021***	5.7524***	0.020589*	3.3175***	0.57136***	0.83716***	0.16284***	0.87806	1.9963	827
		(0.028547)	(0.026163)	(1.4231)	(2.0674)	(0.013974)	(0.88456)	(0.18837)	(0.025509)	(0.040198)			
EURCHF	t_1	1.0879***	−0.33408***	10.0421***	17.0401***	0.11756***	6.8853***	1.8265**	0.74054***	0.25946***	0.8851	1.9497	261
		(0.059693)	(0.051774)	(2.1973)	(5.6193)	(0.023684)	(1.6727)	(1.0423)	(0.064075)	(0.096069)			
EURCHF	t_2	1.0974***	−0.333***	21.0663***	17.5389***	0.012426	3.0645*	0.54879*	0.83736***	0.16249*	0.88164	1.414	261
		(0.050771)	(0.046561)	(4.2491)	(5.7104)	(0.01928)	(1.9621)	(0.39184)	(0.063525)	(0.10937)			
EURCHF	t_3	1.0787***	−0.22745***	4.1361*	7.2887***	0.0018815	2.3954**	4.6672	0.68437***	0.31563	0.77292	2.1536	305
		(0.04497)	(0.04158)	(2.6932)	(3.2863)	(0.026772)	(1.4299)	(4.2487)	(0.11647)	(0.28468)			
EURGBP	all	1.0955***	−0.30769***	10.3799***	8.6692***	0.089261***	3.8268***	0.50252***	0.83211***	0.16789***	0.8889	2.0307	827
		(0.027125)	(0.024671)	(1.3008)	(2.5923)	(0.020835)	(0.75875)	(0.17712)	(0.024459)	(0.045621)			
EURGBP	t_1	1.0261***	−0.27062***	14.4039***	10*	0.16274***	3.0274***	1.8361**	0.81211***	0.18789***	0.88039	1.9765	261
		(0.047155)	(0.041712)	(2.4877)	(6.3507)	(0.063035)	(1.5143)	(1.0675)	(0.040705)	(0.087304)			
EURGBP	t_2	1.1357***	−0.36052***	10.9761***	4.7844*	0.07126***	5.7339***	0.38268*	0.76146***	0.23854**	0.85584	1.7135	261
		(0.050815)	(0.046511)	(2.5344)	(3.1683)	(0.023739)	(1.5267)	(0.27597)	(0.089614)	(0.13884)			
EURGBP	t_3	1.0435***	−0.30766***	−2.6756	21.3887***	0.12474***	7.71***	5***	0.084454	0.84851***	0.77704	1.8274	305
		(0.059669)	(0.054901)	(2.5742)	(5.5611)	(0.049642)	(1.2968)	(1.9718)	(0.099095)	(0.34578)			
EURJPY	all	1.1239***	−0.30073***	0.097031***	0.00032061***	0.00062638***	0.041383***	2.9283e-05***	0.86881***	0.13119***	0.90634	1.7932	826
		(0.02793)	(0.025901)	(0.013932)	(0.00012483)	(0.00021533)	(0.009211)	(1.1512e-05)	(0.02177)	(0.034106)			
EURJPY	t_1	1.1765***	−0.43031***	0.14698***	0.0010988***	0.00054958	0.049745***	0.00016049*	0.89742***	0.097752**	0.88677	1.9172	261
		(0.055289)	(0.049716)	(0.023883)	(0.00043197)	(0.00043058)	(0.02077)	(0.00012262)	(0.040505)	(0.050778)			
EURJPY	t_2	1.0812***	−0.21664***	0.08678**	8.8829e-05	0.00034097*	0.032202*	0.00013017	0.58986***	0.41014	0.7008	1.77	261
		(0.054232)	(0.050804)	(0.045848)	(0.00015035)	(0.00025597)	(0.022406)	(0.00010746)	(0.12726)	(0.3736)			
EURJPY	t_3	1.1105***	−0.21721***	0.069146***	0.00041911*	0.00055802	0.0095764	0.0039923	0	0.71655	0.75441	1.9138	304
		(0.048855)	(0.048124)	(0.020197)	(0.00028575)	(0.00051147)	(0.013124)	(0.0081552)	(0.13115)	(1.5722)			
USDJPY	all	0.95205***	−0.22859***	0.2209***	0.00077855***	0.00074346**	0.012896**	3.0982e-05***	0.81052***	0.18948***	0.92178	2.0331	826
		(0.028261)	(0.025254)	(0.011895)	(0.00030613)	(0.00042589)	(0.0068161)	(1.0608e-05)	(0.024594)	(0.037943)			
USDJPY	t_1	0.74305***	−0.13499***	0.3158***	−0.00066912	0.0034332***	0.043877***	0.00028243*	0.81329***	0.18671***	0.89496	1.7773	261
		(0.054187)	(0.045735)	(0.02187)	(0.00098997)	(0.0016589)	(0.022331)	(0.00017821)	(0.058189)	(0.075353)			
USDJPY	t_2	0.63738***	−0.18595***	0.40814***	0.0024545***	0.00043369	0.032168	0.00019284***	0.35533***	0.50141***	0.81165	1.4074	261
		(0.066352)	(0.055211)	(0.02894)	(0.00051037)	(0.0010116)	(0.026921)	(8.0951e-05)	(0.15284)	(0.16549)			
USDJPY	t_3	1.1607***	−0.31723***	0.12487***	0.00031494	0.00027164	0.0089302*	1.1371e-05**	0.83724***	0.16276***	0.83824	1.8569	304

Notes: *10% significance level, **5% significance level, ***2.5% significance level. DW, Durbin-Watson value. Values in () represent SE.

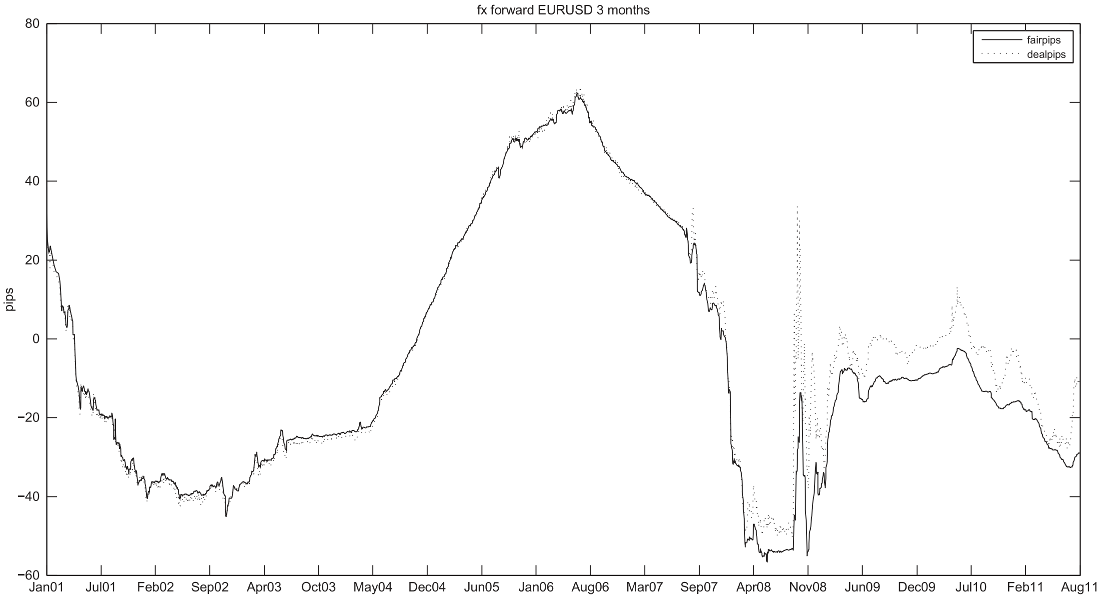
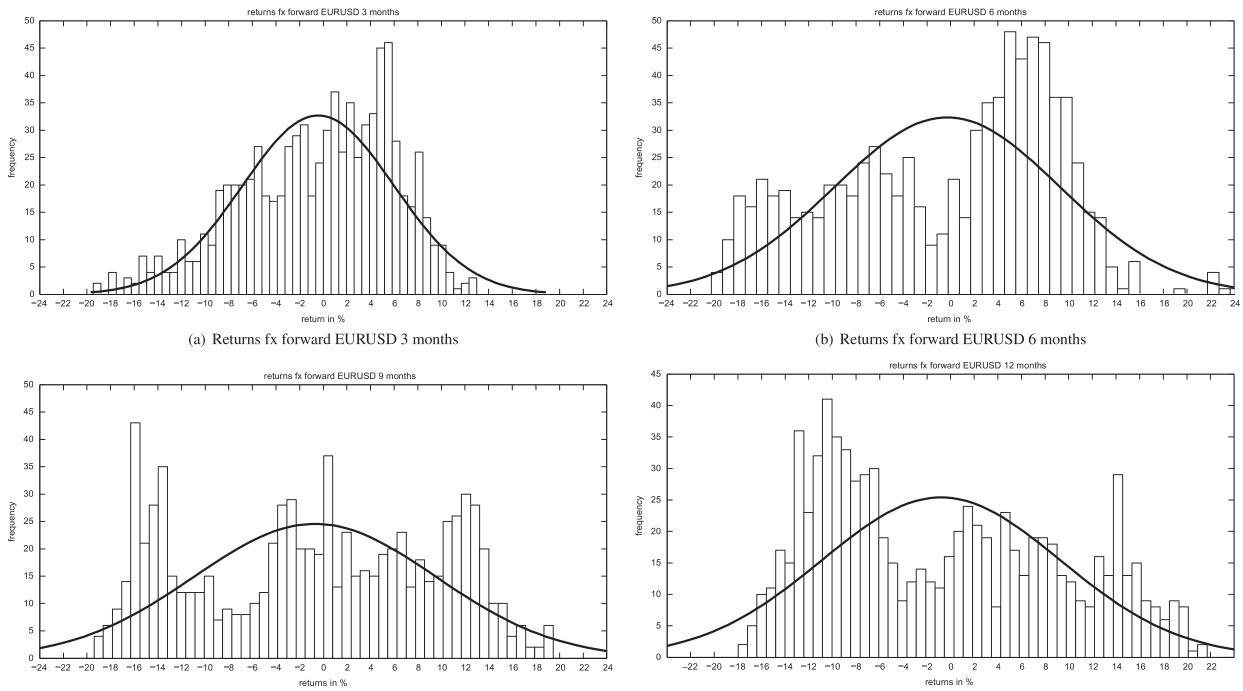


Fig. A1. Comparison of fair- and dealpips (EURUSD: 3 months)



(a) Returns fx forward EURUSD 3 months

(b) Returns fx forward EURUSD 6 months

(c) Returns fx forward EURUSD 9 months

(d) Returns fx forward EURUSD 12 months

Fig. A2. Returns fx forward (EURUSD: all maturities)
Returns are calculated with a EUR long position and USD short position in the forward contract for the period July 2008 – August 2011 (827 observations for each maturity). The returns' histograms demonstrate that the expected return of the forward contracts is not zero and fx forwards are not a reliable estimator of future fx spot prices. This result is in accordance with existing studies, for example, Hansen and Hodrick (1980) or Engel (1996).