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Master's Thesis

**Predictability of currency returns:  
The evidence from over-the-counter options market.**

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## Executive Summary

Can we make an accurate foreign exchange rate forecast if we know what is the market's best "guess" on future direction of that rate? The author attempts to answer this question by investigating the predictive ability of risk-reversals - market traded derivative contracts that measure the expected skewness of exchange rate distribution.

In order to find evidence in favor or against the use of risk reversals based forecasts the paper presents analysis of recent research in selected subject. The author applies econometric methods based on previous empirical works, to quantify the relationship between EURUSD exchange rates and 1 week ahead market expectations embedded in current prices risk reversals for the period of 01/2006-04/2010.

The results obtained in the sample period show that variation in weekly changes of risk reversals can explain up to 55% in variation of the same period currency returns pointing to significant positive relationship. But the outcome of out of sample predictability test, in selected specification, could not beat benchmark Random Walk model with RMSE ratio of 1.06.

Despite the low predictability, the evidence on risk reversals documented in this research paper contributes to existing literature by using weekly sampling and direct market quotes of risk reversals as explanatory variables to avoid "error in estimation" problem. Moreover the period before and after the events of fall 2008 is analyzed as well as robustness checked within several sampling methods.

The debate of using options market implied expectations for accuracy of forecasts is still open and it seems that there is more uncovered issues left for research.

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## 1. Introduction

Please have a look at chart in front of you, ignoring, for now, the abbreviation of EUR on left axis and RR on right axis. Do these two time series exhibit co-movement? Is move in one series “drags” the move in the other? And is relationship more pronounced in recent past compared to earlier period? What if left axis represents EURUSD nominal exchange rate and right axis is measure how “skewed” the expected change in EURUSD is around 0. Can we form a qualified opinion looking at this chart?

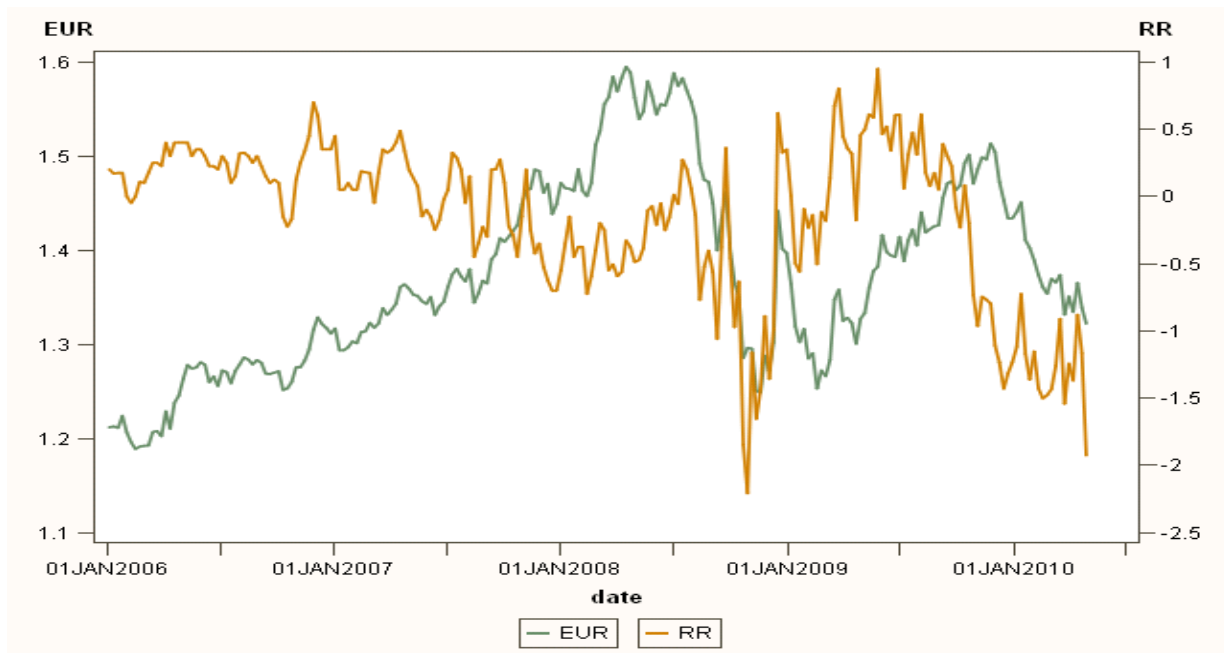


Figure i. EURUSD nominal exchange rate(left axis) and Risk reversals (right axis) for period 01.01.2006 – 01.03.2010. Source of data Bloomberg. Charting via SAS.

The answer most probably would be – No. For a person familiar economic theory and statistics, simple observation of the charts is not enough. But the time series behavior in Figure (i). could provide a reason to initiate an empirical investigation.

This thesis looks into EURUSD exchange rates and the information contained in the currency options market. The objective of the research is to use economic and statistical methods to quantify the relationship between two time series. The motivation for this thesis is from earlier works in this field. Malz (1997) suggested the way to extract information form options to use in

explaining currency returns, Dunis (2000) looked in to the risk reversals on daily frequencies, and Gabaix et.al(2009) related risk reversals to price of protecting against disasters and tested if Risk Reversals can explain the “forward premium puzzle”.

Regarding the relevance of the chosen subject, in the past years the information contained in options market has been used extensively not only by market participants but also by central banks. The Bank of England website contains section where the methodology is described to extract implied probability of changes in short term sterling rates from options. European Central Bank archive contains several working paper publications where option implied probability and risk neutral moments of exchange rates are used to assess the potential impact of interventions and policy changes in New member state currencies as well as EURUSD (Castren, 2004). And Federal Reserve Bank of New York, for example, publishes implied volatility rates on major currencies on their website. So the major central Banks do look into options market to get valuable insights on the expectations among market participants.

This work contributes to the existing literature by using EURUSD quoted risk reversals directly from the market similar to Dunis (2000) but use weekly frequency. Also compared to Gabaix (2009), the sample now contains the period after the crisis of fall 2008, which make this appealing to investigate from comparative point of view but pose potential problem with including the fourth quarter of 2008 due to credit crisis.

## **1.1 Problem statement**

The debate if exchange rate time series can be predicted is a long standing one. The most influential work in this field was introduced by Meese and Rogoff (1983) who found that most of the macroeconomic models of that time failed to outperform the simple random walk model of exchange rate. This finding was followed by extensive research, where naïve random walk was selected as benchmark for model selection on out sample forecast performance. But it turned out that properly selected variables and estimation techniques can beat random walk out of sample, this works include Kilian and Taylor (2001), McDonald (1997), McDonald and LaCour (2000) among others. The problem that author is facing is to accurately predict exchange rates in future provided the information available today.

In this thesis the information contained in options market related to expectations of exchange rate moves will be used to address the research question:

**RQ: Can information embedded in Risk Reversals predict the future currency returns?**

To answer the research question the following sub-questions are outlined:

- What is the role of Risk Reversals in currency derivatives market?
- What does previous research imply regarding the use of Risk Reversals in forecasts?
- Is there cointegrating relationship between currency returns and risk reversals?
- Can Uncovered Interest rate Parity prediction be improved if we use information from options market.

## **1.2 Methodology**

To address the research question the first step will be to investigate the nature of the options pricing the role of risk reversals. The theoretical literature will be reviewed as well as articles that describe the functionality of the foreign exchange market. The aim is collect evidence on theoretical and practical use of risk reversals and its relevance in options trading.

Once we have defined the subject of risk reversals, the empirical research from academic articles, working papers and economic surveys that uses risk reversals with respect to predicting exchange rates will be collected and analyzed. The most relevant works will be presented in more details to give understanding of the methodology used and results obtained. Namely the relation of risk reversals as well as the methodology used, in authors opinion, is well presented in Gabaix et al.(2009), so it might be interesting to apply researchers methodology.

Since the research question of this thesis requires an empirical investigation the econometric methods such as ordinary least squares (OLS) will be used from Applied Econometrics course of the AEF line. The SAS Enterprise software will be used for econometric tests.

The data is collected from Thomson-Reuters Datastream and Bloomberg and represent the time series of financial instruments prices. The author understands that such data is known to exhibit behavior that might not be well captured via OLS methods. In this case the validity of the hypothesis tested will be checked for statistical significance thoroughly and commented on to base a qualified conclusion. Also the results obtained will be compared to previous empirical

findings, so that similar results can be expected out of this thesis. However the period tested in this thesis takes the most recent year after financial crisis so that the results might show sensitivity to this period.

### **1.3 Note on Data mining**

As defined in Wooldridge (2009, p.837) Data mining is - *the practice of using the same data set to estimate numerous models in a search to find the “best fit”*. Unfortunately having a specific data set researchers may be induced in testing various variables on it in order to find statistical link were none actually exist. Such results even though can be OLS consistent but will be biased to specific data set used to find it. In this work the author faces the risk of data mining and will try to mitigate it in following ways:

- The existing theoretical framework and economic reasoning must be applied.
- Works of previous researchers in this field have to be accounted for.
- The model will be accepted only if OLS assumptions fulfilled and is in line with previous research.
- Will test performance on out of sample data.
- Will use different sampling techniques and other type of variables for robustness checks.

### **1.4 Delimitation**

- In this paper the primary focus is on EURUSD nominal exchange rates and its return series. Although other exchange rate is widely tradable on the market, the use of EURUSD is explained by its liquidity as the most heavily traded (by volume) compared to other currency pairs. Also this thesis use single exchange rate series rather than portfolio of currency pairs returns.
- EURUSD Risk reversals series, in empirical section, corresponds to 1 month maturity contract with 25Delta moneyness. Even though other maturity and moneyness contracts available the choice is explained by these series being most actively traded and liquid.
- Sample period is chosen from the beginning of the January 2006 and through the end of April 2010 due to availability and quality of Risk Reversals data before 2006. This limitation is



compensated by presence of existing empirical research that cover Risk Reversals before 2006 and discussed in this thesis.

## **1.5 Structure**

The structure of the thesis consist of 9 sections and is organized as follows. Section 1 outlines the introduction, the purpose and the problem statement of the thesis as well as methodology and limitations. Section 2 describes the exchange rate market. Section 3 presents the theory of derivatives pricing, overview of the foreign exchange market, the use implied volatility and risk reversals in practice. Section 4 describes the uncovered interest rate parity. Section 5 outlines the previous empirical research on derivatives market, exchange rate forecasts. Section 6 introduces the econometric methods used to address the research question. Section 7 describes the data characteristics used for empirical part. Section 8 presents empirical findings and analysis. Section 9 concludes.

## 2. Foreign exchange market

### 2.1 Overview of the market

The foreign exchange market is on the biggest in the financial world and trading here takes place 24 hours a day. The trading starts at 20:15 GMT on Sunday and finishes at 22:00 GMT on Friday, with no breaks in between, and the market is only closed on weekend. There is no physical location for the market and trading takes place over-the-counter between banks, interbroker dealers continuously. The market is divided into two key groups Price makers and Price takers. The former being large banks that quote two-way prices – willing to Buy and to Sell the currency on their own behalf and earn the difference between these prices. And the latter is the group who takes the price from Price makers on their behalf or on behalf of their clients in order to hedge, speculate or perform commercial activity.

According to the latest Bank of International Settlements (BIS) triennial survey (2007-2010) issued in April 2010 the average daily global foreign exchange turnover reached 4.0trln US dollars, this include trading in spot, forward outright, currency swaps, currency options and other FX instruments. The turnover increased 20% compared to April 2007 and was largely due to increase in activity of *other financial institutions* such as non-reporting banks, mutual and hedge funds, insurance companies, pension funds and central banks. Their share in global FX turnover increased from 1.3trln to 1.9trln USD during April 2007 - 2010. This segment of market participants showed the growth in spot, forward outright and swaps transactions of 92%, 60% and 11% respectively. Please see table below for breakdown of FX turnover by instruments

Table 1. Global Foreign Exchange market turnover by instrument, in bln US dollars

Instrument	2007	2010	%Change
Foreign Exchange Instruments	3,324	3,981	19,7
Spot Transactions	1,005	1,490	48,2
Outright Forwards	362	475	31,2
Foreign Exchange swaps	1,714	1,765	3,0
Currency swaps	31	43	38,7
Options and other products	212	207	-2,4
<b>Total</b>	<b>3,324</b>	<b>3,981</b>	

Table1. Foreign exchange rate average daily trading volume (billion, in US dollars). Source: BIS triennial survey April 2010

The survey also shows the contrast between OTC FX market and FX trades organized on exchanges. The OTC FX daily market turnover (excluding spot) reached 2.5 trln. USD compared to 166bln. USD traded on organized exchanges.

Still as in previous years, United Kingdom accounts for majority of the daily turnover 36.7% followed by USA (17.9%), Japan (6.0%), Switzerland (5.2%) and Singapore (5.3%). The most traded currency pair is USDEUR (EURUSD) which accounts for 28% (out of 3,981trln) of all the volume and is equal to 1,101 trln. USD in daily turnover. This is followed by USDJPY (14%), USDGBP (GBPUSD) (9.0%) and others currency pairs.

## **2.2 General notations and conventions in FX markets**

We start by introducing nominal exchange rate. Nominal exchange rate –  $S_t$  - is defined as the price of 1 unit of foreign currency expressed in units of domestic currency. For example the market convention is to express the rate of 1 EURO against US dollars as EURUSD where EURO is assumed to be foreign currency and USD the domestic currency. So if the EURUSD exchange rate is given as 1.2650/1.2652 it means that 1 EURO sells for 1.2650 (bid price) US dollars and to Buy 1 EURO the price will be 1.2652 (ask price) US dollars. The difference between the sell and purchase price is called bid/ask spread and is expressed in points called “pips” and represents the transaction cost charged by the dealer in foreign exchange market. In the example with EURUSD, the spread equals 0.0002 US dollars, or 2 “pips”. In this thesis the increase in level of  $S_t$  is defined as the appreciation in the price of the foreign currency against depreciation of the domestic currency. Equivalently, decrease in level of  $S_t$  corresponds to decrease in value of foreign currency against increase in value of domestic currency.

In foreign exchange (FX) market the purchase of one currency against another currency is called going “long”, and sale of one currency against the other is referred to going “short”. Usually these terms refer to the first currency in the currency pair. In the exchange rate of EURUSD, going “long” means buying EUROS against US dollars, going “short” means selling EUROS against US dollars.

### 3. Currency options in theory and practice

#### 3.1 Foreign exchange rate derivatives

Foreign exchange (FX henceforth) rate derivative contract, as its name suggests represents the financial contract the value of which is derived from the underlying exchange rate. There are several types of FX derivatives, forwards, swaps and options are the most common. In this thesis we will cover *European style plain vanilla options* on FX. This type of options expires on maturity date negotiated when the option is traded and cannot be exercised before that date.

European vanilla option has distinct features embedded in the contract:

Expiration date – is the calendar date on which the option will either be exercised or expired.

Strike – is the price at which the delivery of the underlying asset (currency) will take place at expiry date or the option will be exercised.

As described in textbook of Hull “Fundamentals of Futures and Options Markets” there are 2 types of European FX option contracts: Calls and Puts.

Call – option gives holder the right but not the obligation to buy the base currency and sell the quoted currency on expiration date of this contract at pre-defined price – strike - if at expiration the current FX rate  $S_t$  is trading above the strike price. In this thesis the Call option is referred to as a right to Buy EUROS against USD. The Call option price is positively correlated with  $S_t$ .

Put - option gives holder the right to sell the base currency against the quoted currency at pre-defined price - strike - on expiration date if the current  $S_t$  on the time of expiration is trading below the strike. Equivalently we refer to Put option as the right to sell EUROS against USD. The Put option price is negatively correlated with  $S_t$ .

It will cost the buyer of the option to enter an option contract – this cost is commonly referred to as option premium.

FX options are used by commercial hedgers, investors and speculators in the FX market. One of the main ideas of the option contract is to use it as a protection to existing position in the underlying asset (currency in this case). For example, if the fund manager based in US, has assets denominated in EUR in the portfolio and expects the depreciation of EUR against USD in

coming 3 months to the rate of 1.2300 from 1.2600 today, then the manager can purchase the Put option with right to sell EUR and buy USD at price 1.2500 in 3 months time. If depreciation on EURUSD actually happens as expected, the loss on EUR assets will be compensated by the gain in the value of Put options and exercising the right to sell EUR at 1.2500 when market is actually trading at 1.2300. If EUR does not depreciate as expected and, in contrast, appreciates, then the maximum loss for the manager is the option price paid at the beginning. The price of this is known with certainty from the start and removes much of the uncertainty of the future. The question arises of course: How much is the right price to buy such protection? The answer is presented later in the section.

FX options are mainly traded on over-the-counter (OTC) markets. OTC market advantage compared to traditional exchange is that specific features of options contract like strike, maturity can be negotiated between counterparties whereas on the exchanges traders have only fixed options contracts. Also OTC market is more liquid than exchange traded market so large trade sizes are possible which makes this market attractive to large institutions.

### **3.1.1 Black and Scholes pricing in foreign exchange market**

Since pioneering work of Black – Scholes – Merton (referred to as BS model) in 1973 the pricing of options became widely accessible to the financial world. The original work of BS was to price call and put options on non-dividend paying stocks. The BS extension to FX rates was presented by Garman and Kohlhagen in 1983. They calibrated the model to account for both interest rates in domestic and foreign currencies. General assumptions of the BS model and their adaption towards FX options are summarized below:

1. The differential representation of currency spot price is assumed to follow General Brownian Motion:

$$dS_t = \mu S_t dt + \sigma S_t dW_t,$$

where  $W_t$  is the standard Wiener process  $\in N(0,1)$ ,  $\mu$  is expected return and  $\sigma$  is the volatility parameter assumed to be constant. The currency price  $S_t$  is assumed to be lognormally distributed, and hence  $\ln(S_t)$  is normal.

2. Option prices are a function of only one stochastic variable,  $S_t$
3. Markets are frictionless
4. Interest rates, on domestic and foreign currencies are constant. Investors can borrow and lend at risk free interest rates.
5. There are no riskless arbitrage opportunities.

Given that assumptions outlined above hold the theoretical price of Call and Put options on currency exchange rate is given as:

$$\begin{aligned}
 c_t &= S_t e^{-r_f T} N(d_1) - K e^{-r_d T} N(d_2) \\
 p_t &= K e^{-r_d T} N(-d_2) - S_t e^{-r_f T} N(-d_1) \\
 d_1 &= \frac{\ln(S_t / K) + \left(r_d - r_f + \frac{\sigma^2}{2}\right) T}{\sigma \sqrt{T}} & d_2 &= d_1 - \sigma \sqrt{T}
 \end{aligned}$$

where:

$c_t$  = is the price of Call option at time  $t$

$p_t$  = is the price of Put option at time  $t$

$S_t$  = the current exchange rate at time  $t$  (domestic currency per unit of foreign currency)

$K$  = the Strike exchange rate

$r_d$  = the continuously compounded domestic risk free interest rate

$r_f$  = the continuously compounded foreign risk free interest rate

$T$  = the time in years until the expiration of the option

$\sigma$  = the implied volatility for the underlying exchange rate

$N(.)$  = the standard normal cumulative distribution function.

The pricing of derivatives is based on concept of «risk neutrality». This concept is very important in valuation of derivatives because it cancels out investors risk willingness effect on the price of an option Hull (2008, p.281) assuming that investors are risk neutral.

Below we present the outcome the world being risk-neutral suggested by Hull:

1. The expected return from all investment assets is risk free interest rate
2. The risk free interest rate is the appropriate rate to apply to any expected future cash flow.

The BS model represents a closed form solution to arrive at theoretical options price, given that assumptions outlined above holds. As we will see further the most important factor in the BS formula, unobservable at point in time  $t$ , is the expected volatility,  $E(\sigma)$ . Clearly the BS assumptions that  $\sigma$  is constant over time is too simplistic which makes the estimation of the option price more difficult than just plugging variables in the BS formula.

### 3.1.2. Implied volatility vs. Historical volatility

As its name suggests, implied volatility is the volatility that is embedded in the price of the option at the market (Hull 2008, p.283). Since the true volatility of underlying asset  $\sigma$  is not observable, it has become common practice to input the options price that is available at the market and all given parameters (current exchange rate, forward price or interest rates, strike, maturity) into the BS formula and solve it for volatility  $\sigma$ . The measure derived is commonly called «implied volatility» and is close (but not identical) to BS risk neutral standard deviation of logarithmic changes in the forward exchange rates (Malz, 1997, p.4). This volatility represents market “best guess” about future underlying volatility. We can often see that in the literature the realized historical volatility is referred to “backward looking” and implied volatility as “forward looking”.

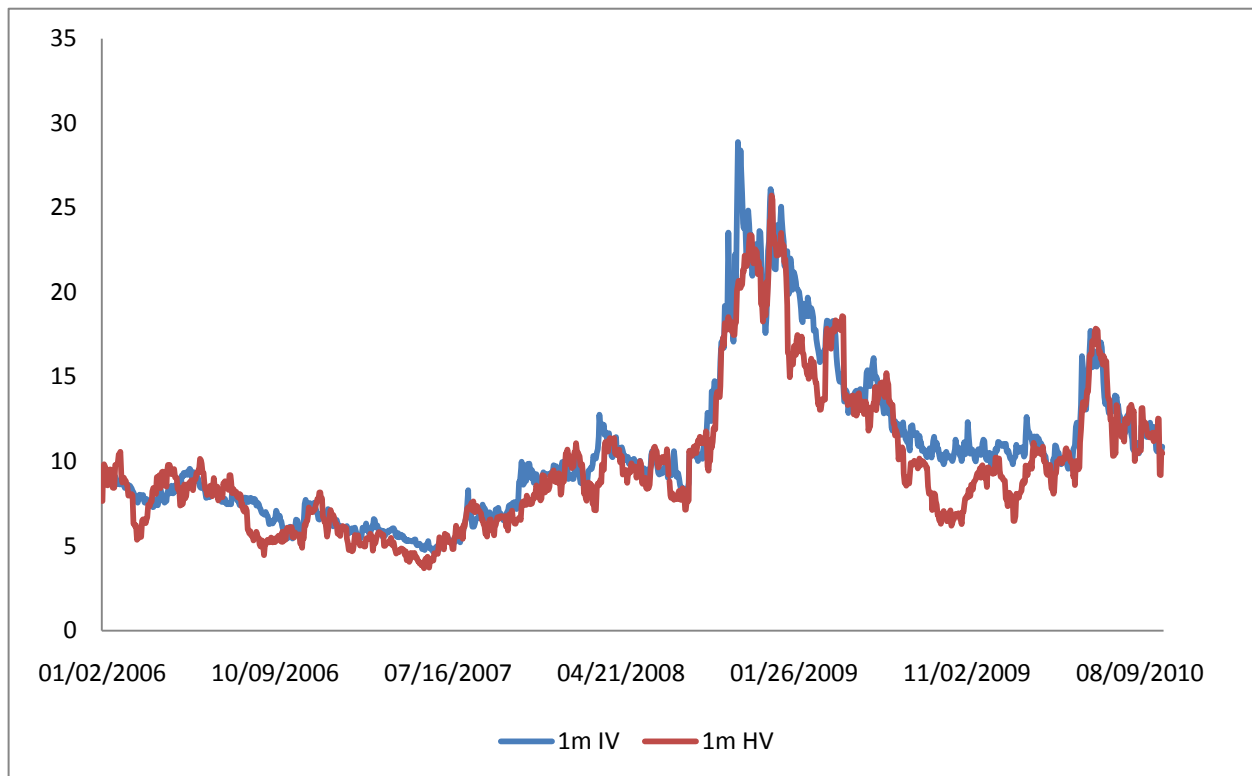


Figure1. Realized vs. Implied volatility on EURUSD. IV corresponds to 1m ATM vol.

The Figure 1 shows the time series of realized, historical volatility estimated using 1 month rolling window and 1 month ahead implied volatility derived for the prices of at-the-money currency options on EURUSD. Both series are closely tracking each other through time, but most of the time the markets «best guess» on future volatility exceeds that of the realized historical. Could it be that market overreacts to the assessment of future events and tend to express this by bidding up the volatility measure in the options market? Does implied volatility represent unbiased estimate of future realized volatility? There has been great deal of empirical research devoted to this, and it will not be covered in details, but major findings are outlined in Empirical section. Before describing how volatility is traded on OTC market some notation about the sensitivity of the option price is introduced.

### 3.1.3 The Greeks

The sensitivities of the option price to the changes in variables used to derive it: currency rate ( $S_t$ ), volatility ( $\sigma$ ), maturity ( $T$ ), interest rates ( $r_f$ ,  $r_d$ ) is referred to by Greek letters and commonly called as “the Greeks” Hull (2008). Knowing the Greeks of certain option the trader can quickly determine how sensitive is his option position to let’s say 1% change in volatility, or 1 day decay in option maturity and take necessary hedging to mitigate potential risk. The following Greek letters are:

Delta  $\Delta$  – is the partial derivative of option price on  $S_t$  and measures the sensitivity of option price to change in  $S_t$ . Delta of 0.4 means that for 1 point change in exchange rate the option price changes approximately 0.4 point (or 40% of that 1 point change). Delta of the put is 1- Delta Call. The market convention is to quote both option deltas in positive number and refer to whether its  $\Delta_{call}$  or  $\Delta_{put}$  (Malz 1997, p.10). If the underlying exchange rate equals the options strike ( $K$ ) the option is at-the-money (ATM) and has  $\Delta$  approximately equal to 0.5 (or 50 $\Delta$ ), for Call(Put) option, market quoted delta of less than 50 $\Delta$  indicates that option is out-of-the-money (OTM) and market deltas above 50 $\Delta$  indicate that option is in-the-money (ITM). So knowing the delta of the quoted option price one can imagine the relative «moneyness» of this option.



Gamma  $\Gamma$  – is the partial derivative of Delta on  $S_t$  and shows how Delta changes when  $S_t$  moves. Gamma is useful measure since the Delta is only accurate to approximate the change in option premium for small changes in  $S_t$ . As  $S_t$  moves for bigger values  $\Delta_{\text{call/put}}$  also changes and this captured  $\Gamma$ .

Theta  $\theta$  – is the sensitivity of option price on passage of time to maturity. As time to expiration of the option approaches, all else equal, the option will be less valuable. More often the theta is referred to as measure of option's time decay.

Vega  $v$  – is the sensitivity of option premium to changes in volatility ( $\sigma$ ). Changes in volatility have direct effect on option premium/price. The more volatile is the underlying currency the more expensive the price for that option will be all else equal.

Rho  $\rho$  – is the sensitivity of the option premium to changes in underlying interest rates all else equal.

### **3.1.4 FX options market**

According to BIS survey the average daily turnover of OTC currency options market is 212 bln. USD. This figure somewhat decreased for the period surveyed compared to previous years (Table 1) and in general represents the smallest segment of OTC currency market.

As stated earlier, on the over-the-counter (OTC) options market the exercise price ( $K$ ) of the options contract is set in terms of BS Delta  $\Delta$  «moneyness» by convention. For example the EURUSD 1 month Call option with the strike price which is equal to current spot ( $K=S_0$ ) will be quoted “50 delta” call *11.0 at 11.50* meaning that the dealer is ready to buy this contract at 11.00 and sell at 11.50 volatility units (annualized % vols). If the deal is struck between counterparties, dealers on both sides (buyer and seller) agree on vols, current spot and maturity, these parameters are entered in BS formula and the trade ticket with currency units representing agreed price is issued for settlement (Malz 1997, p7). This is also convenient because when spot and forward rate fluctuate the currency unit price can change even if implied volatility didn't change much. By using fixed deltas connected to IV quote the dealers don't have to recalculate the option prices each time the spot or forward changes since the single parameter they are interested in is

volatility. Hence the burden of recalculation is vastly reduced (Campa et al. 1997, p.7). Both Malz (1997) and Campa (1997) et al. note that traders do not necessarily think of BS model as the correct one to explain the volatility process, it's simply convenient to arrive at the price in currency units to finalize the trade when the vol term has been agreed upon between buyer and seller.

Also the dealer on OTC markets, when trade with each other often exchange the delta notional amount of underlying currency, this reduces the spot risk at the time of trade and results in them trading pure volatility. This is possible because the delta of the option, which is the element of the quote, is directly showing the amount of underlying currency need to be bought/sold to hedge the position against exchange rate move. Unlike in exchange traded options where the strike is fixed part the option contract and delta can vary considerably. As Carr and Wu (2007, p.5) argues, these features of the OTC market allows for greater liquidity and depth compared to exchange traded options and hence represents the advantage of OTC options.

In the options market dealers use Implied volatility as the quote of the option price and these quotes for standard maturities (1 week, 1 -3 -6 months) and deltas (ATM  $\Delta$ , 25 $\Delta$ , 10 $\Delta$ ) are readily available. The Table2 shows that mid-quotes on EURUSD implied volatilities are readily available in the market for standard maturities and deltas, whereas maturities outside of standard range are quoted after interpolating. It is clearly evident that figures differ across maturities and across the moneyness which contrast with assumptions of BS no.1 and no.2.

	10DP	25DP	ATM	25DC	10DC
1D	13.59	12.40	11.70	11.91	12.68
1W	11.19	10.28	9.89	10.00	10.46
1M	12.65	11.50	10.66	10.40	10.65
3M	14.74	12.88	11.57	11.17	11.57
6M	16.05	13.74	12.21	11.74	12.26
1Y	17.06	14.42	12.72	12.29	12.94
18M	16.65	14.16	12.57	12.20	12.82

Table2. EURUSD implied volatility (annualized). DP and DC refers to delta put and call respectively. First column represents the maturity of the contract. Data on 13/09/2010 Source Saxo Bank A/S.

The most common pattern that arises in FX options volatility, U-shaped curve referred to as “smile” is covered next.

## 3.2 Properties of options implied volatility

### 3.2.1 Volatility smile

Hull (2008, p.379) defines volatility smile as: *a plot of the implied volatility of an option as a function of its strike price*. In the world of BS the similar plot of implied volatility against strikes would result in a horizontal line, as described in 2.1. because single historical volatility is used to calculate prices of different maturities and strikes to arrive at theoretical price. In reality the plot takes a curve shape of a smile with implied volatility around ATM strikes usually at its lows and increasing further moving to the far strikes. Put another way the implied volatilities for Call and Put options with the same maturity but different strikes is not the same. By such shape the market is reflecting, in option price, the probability of extreme moves or jumps likely to occur in one direction rather than in the other (Hull, 2008, p.382).

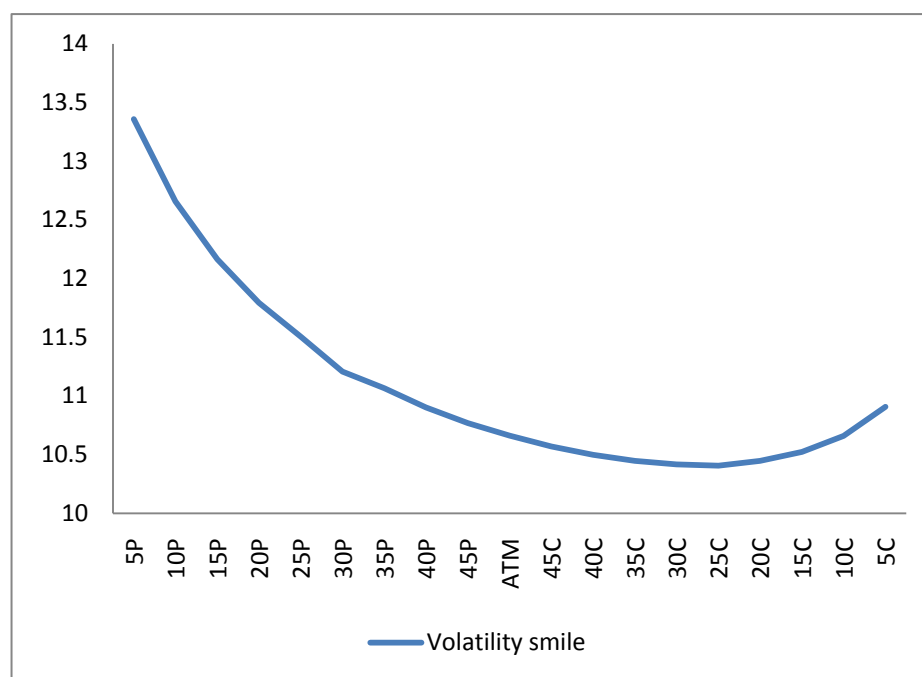


Figure2. Volatility Smile for EURUSD implied volatilities. X axis represents Delta strikes. Y axis corresponds to implied volatility level (% annualized).

As you can see in the Figure 2 above, the ATM volatility is located in the center where X axis represents different delta-strikes. The further we go to the left into put strikes (below ATM) and to the right into call strikes the implied volatility levels increase. Bates (1991) explained this

feature of implied vols as the indication by the market participants that the *distribution of future exchange rates to be skewed or a willingness to pay more for protection against sharp currency moves in one direction than in other. Such patterns are generated if the exchange rate follows an asymmetric jump-diffusion (Bates 1991, and Bates 1996a).*

Figure 2 also shows that, in volatility terms, Put options or a price of protection in depreciation of  $S_t$  are more expensive than equally distanced Call options volatilities.

### **3.2.2 Term Structure of Implied volatility**

It can also be shown that implied volatility is different across maturities giving rise to term structure. This has been studied by in the context of expectation theory set up by Chang and Chang (1995): *Options with same exercise price and different maturities have different implied volatilities which forms a term structure of implied volatility.*

A rising term structure indicates that market participants expect short-term implied volatility to rise or a willingness to pay more to protect against longer term exchange volatility (*Campa and Chang 1995*).

Please see the graph of implied EURUSD implied vols against standard maturities derived on 13/09/10.

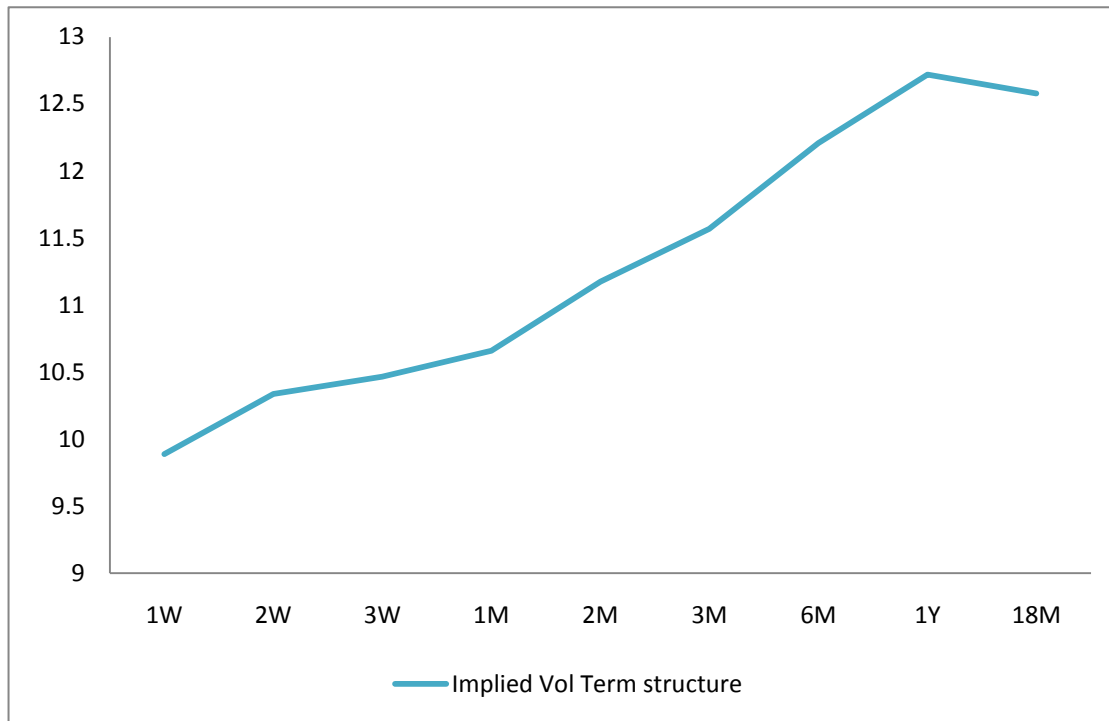


Figure3. The term structure of implied volatility. Maturity of options contracts on x axis and implied vols on y axis. data corresponds to 13/09/2010. Source Saxo Bank A/S.

As is consistent with empirical findings, the term structure of EURUSD Implied volatility is rising up to 18 month maturity. Hull(2008, p.379) writes: the volatility can be increasing with maturity when short term vols are low and vice versa, long run volatilities can be decreasing when short run vols are high. This can be related market participants expectations about future implied volatility.

If we combine the volatility smiles on different maturities with volatility term structure we arrive at volatility surface which is 3 dimensional space with volatility level, maturity and strike being on each of the axis's in Figure 3. Such surface is used by option dealers to be able to locate the implied volatility for given strike and maturity and price the option on the surface, put in other way the surface enables to look in to implied volatility as a function time and strike. Implied vols that are in between standard strikes or maturities for example 35 delta 9 days to expiration will be interpolated using 25 and 50 delta strike and 1 week to 1 month etc. Judging by the shape of the surface it is once again clear that market participants do not necessarily agree on lognormality of underlying exchange rate distribution.

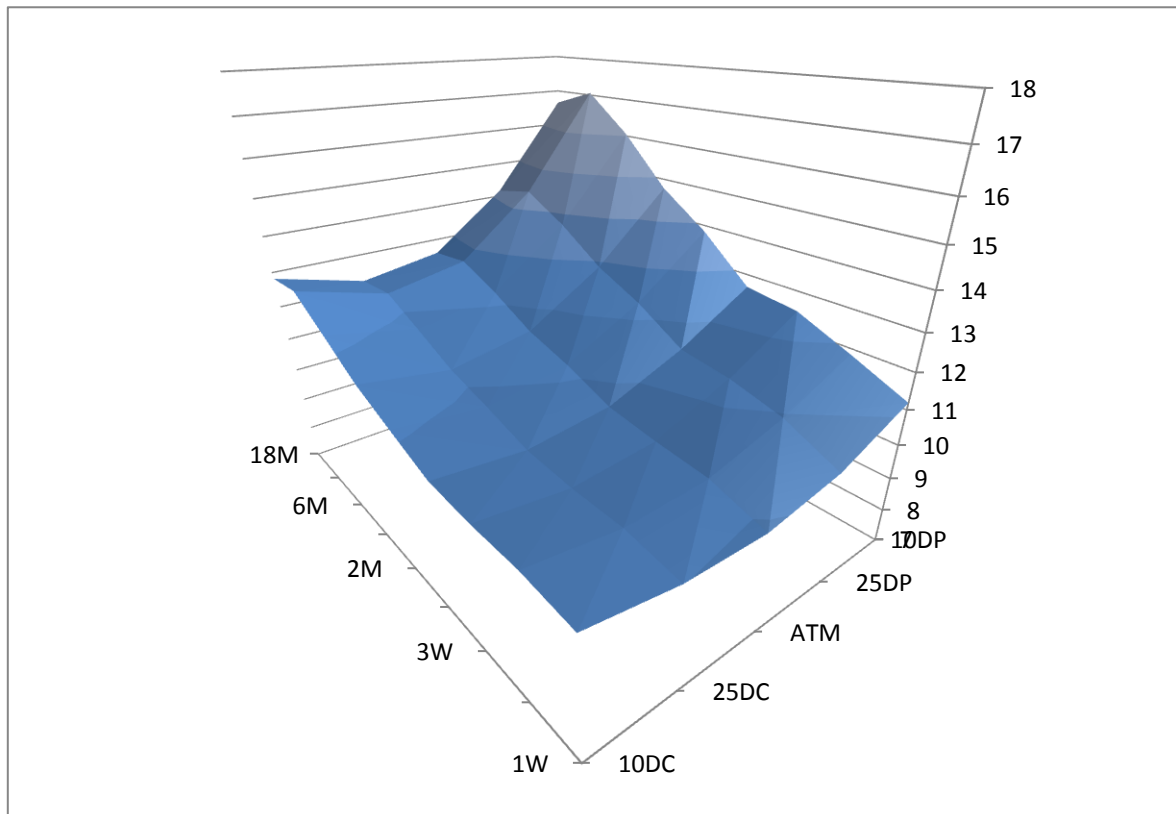


Figure4. Implied volatility surface for EURUSD. Source Saxo Bank.

Both features discussed above i.e. the term structure and the smile pattern can be also seen on the 3D surface in Figure 3. Highest vols are on the longer maturity (18 month) area on the 10 Delta EURUSD puts as in figure 2. The volatility smile tends to persist the longer we go onto maturity from 1 week to 1 year. Carr and Wu (2007), relates such property of the volatility surface to non-normality of the implied risk-neutral distribution of currency rates.

The graphical inspection of the properties above, support the well known conclusion that BS model cannot fully incorporate time variation and asymmetry of volatility across strikes. Moreover the distribution of expected currency returns derived from options prices can exhibit time varying positive or negative skewness and excess kurtosis. These model biases of BS have been empirically found by several authors Bakshi Chen (1997), Chang and Lim (1998), Carr and Wu (2007), Christofersen and Mazzota(2005) and Camara (2009) among others. Rebonato (1999, p82) wrote that several models are more keen in accounting for smiles compared to BS:

1. Fully stochastic volatility models
2. Complete-markets jump-diffusion models

3. Random-amplitude jump-diffusion models
4. Stochastic volatility functionally dependent on the underlying.
5. GARCH volatility models

We will not discuss further the properties of these models in this thesis.

### 3.2.3 Risk Reversal – the slope of volatility smile

**Risk reversal (RR)** is a combination of buying of equally out of the money Call option and selling equally out of the money put for the same maturity. The moneyness in this case is defined by delta of the option. So combination of 25Δ RR will contain long position in the 25Δ call and short position in 25Δ put. The similar intuition is for establishing 10D RR.

To arrive at the mid-price of 25Δ RR:

$$25\Delta \text{ RR} = 25\Delta \text{ Call volatility} - 25\Delta \text{ Put volatility}$$

From the Table 2 we can see that 1M 25D RR = 10.40 – 11.50 = - 1.10

Which means that 25Δ Puts on EURUSD with 1 month maturity are on average 1.10 vols more expensive than 25Δ Calls on 13.09.2010.

In BS risk-neutral world such combination should equal zero since the BS model has the same volatility for both puts and calls. In real world if this combination yield positive result it means that call options are more expensive than same moneyness put options and negative result means that put options are more expensive than same moneyness calls.

*By representing the volatility differential for the equally out of the money options (25 delta) RR represents the slope of the volatility smile curve and contain information regarding the skewness of option implied exchange rate moves (Campa, 1994, p.17).*

Trading RRs the speculator can directly place bet on the skewness of the exchange rate move. Moreover since the quotes of RR are directly traded and observable at any point in time in the market, the time series of RR may contain information how this expected “skewness” change

over time. It is the main subject of this thesis to examine the relation between this option implied skewness, RR, and changes in exchange rates.

### 3.2.4 Butterfly – as curvature of the volatility smile

If we subtract ATM volatility from average of two OTM options vols we'll get the Butterfly combination that represents the degree of curvature in volatility smile (Rebonato 1999, p.87) and contains information on implied Kurtosis of expected exchange rate changes. A positive quote for Butterfly means that OTM options are relatively more expensive than ATM options. As summarized in Taylor et.al (1994) the higher implied vols of OTM options compared to that of ATM reflects the market perception of the underlying distribution being leptokurtotic (fat tails) with respect to possible large moves. Such features could be generated if implied vols are stochastic or exchange rates follow a jump-diffusion process. (Taylor and Xu 1994). Using available volatility quotes on the options market the Butterfly combination can be computed as follows:

$$25\Delta \text{ Butterfly} = (25\Delta \text{ Call volatility} + 25\Delta \text{ Put volatility})/2 - \text{ATM volatility}$$

Form the table 2. we derive the mid quote of 25D 1 month butterfly =  $(10.40 + 11.50)/2 - 10.66 = 0.29$

On the OTC market there are readily observable quotes for 50 delta ATM implied volatility, 25 and 10 delta risk reversal and 25 and 10 delta butterfly. The standard maturities for these range from 1day, 1 week, 1 month, 3 month, 6 month and 1 year.

Below table shows the mid quotes of implied volatility for standard delta and maturity for EURUSD on 13/09/2010:

	ATM	25D RR	25D BF	10D RR	10D BF
1D	11.70	-0.49	0.45	-0.91	1.44
1W	9.89	-0.27	0.26	-0.73	0.94
1M	10.66	-1.10	0.30	-2.00	1.00
3M	11.57	-1.71	0.46	-3.17	1.59
6M	12.21	-2.00	0.54	-3.79	1.95
1Y	12.72	-2.13	0.64	-4.12	2.28

Table 3. market quotes of Implied volatility for 3 standard combinations RR, Butterfly, ATM straddle.

Source Saxo Bank A/S.



Having these three quotes of 25Δ RR, 25Δ Butterfly and ATM volatility, for certain maturity, the dealer can derive the volatility quote of 25Δ Call and 25Δ Put respectively:

$$25\Delta \text{ Call vol} = \text{ATM vol} + 25\Delta \text{ Butterfly} + 0,5*25\Delta \text{ RR}$$

$$25\Delta \text{ Put vol} = \text{ATM vol} + 25\Delta \text{ Butterfly} - 0,5*25\Delta \text{ RR}$$

For example it can be shown that 10D Put implied volatility with 1 week maturity in Table 2. can be derived from Table 3. :

$$10\Delta \text{ put IV} = 9.89 + 0.943 - 0.5*(-0.728) = 11.19$$

Next the dealer would insert this vol and other BS-GK parameters to calculate the option price in currency units. The technique described above is straightforward when we use standard maturities and deltas, for the contract values of non standard maturity and/or delta the dealer will use interpolation.

Looking at Table 3. the 25Δ RRs are increasing further into maturity indicating that puts become more expensive. 10D RRs also increasing across maturities and their values are bigger compared to 25Δ RRs. One can say that market expectations for 10Δ, deeper-out-of-the money, options are more skewed. In other words it's more expensive to buy 10Δ put compared to 25Δ put in volatility units. So the «skewness» (favor of puts over calls) is increasing with maturity and how far the strike is away from ATM for EURUSD exchange rate given the data on 13.09.2010.

### **3.2.5 Risk neutral moments derived from FX options**

Since the information in the options market is forward looking, the market expectations with respect to future risk, price movements are inherent in options prices. Moreover if the higher moments of market expectations (skewness, kurtosis of price distribution) can be on hand, this can provide invaluable source of information for market participants, including central banks to assess the market expectations at a given point in time. In general four moments of implied probability density function can be observable for particular currency at a given date. The obtained estimates PDF can then be visualized to judge the implied probabilities of the currency move. In particular these estimates are variance of PDF measures the degree of uncertainty

among participants. The third moment of PDF is implied skewness and represents the weighing by how much the move in one direction is more likely than in the other. The fourth moment is implied kurtosis measures tails of the PDF and too high kurtosis at given date can indicate that market assigns the increased likelihood of the exchange rate change to happen on unusual scale.

There are numerous techniques suggested in the literature to extract such expectations. Shimko (1993) used smoothed volatility method on stocks, Malz (1997) followed this technique on currencies, Campa et al. (1997) uses smoothing spline techniques on currencies. Carr and Wu (2005) suggested fixed coefficients that can relate market RR and butterflies into risk neutral skewness and kurtosis of underlying currency's Probability Distribution Function (PDF). We briefly discuss the Malz (1997) technique below because this has been used by several central Banks (please see Christensen and Mazzota 2005, p.584) to make assessments about future exchange rates. And also Carr and Wu (2005) methodology because it is very straight forward and the respective time series higher moments are directly available on Bloomberg.

### **3.2.6 Malz's method**

Malz suggested the simple technique to extract risk-neutral probability density function (PDF) of future exchange rates implied by the currency option market.

The steps suggested in Malz estimation method are as follows:

1. Obtain the market quotes for ATM vol, RR, Butterfly with respect to standard delta.
2. Use the interpolation form to estimate continuous volatility smile on delta space  

$$\sigma\Delta = \text{ATM vol} - 2 * \text{RR} (\Delta - 0.5) + 16 * \text{Butterfly}(\Delta - 0.5)^2$$
3. Convert options exercise strikes from delta space  $\Delta$  to currency units K (this requires solving BS formula with respect to K -strike).
4. Estimate the risk neutral PDF by twice differencing BS formula with respect to strike K.

The major point being here is that this method uses the inputs observed directly in the market, in such sense the choice of Risk Reversals for this thesis is not an arbitrary decision but is common relevant in practice.

### 3.2.7 Carr and Wu method

Petter Carr and Liuren Wu (2005) suggested to use the following relationship to convert the observable ATM, RR and Butterfly into the risk-neutral higher moments of currency's Probability Density Function.

For 25 Delta options:

$$\sigma_{t,n} \approx ATM\ vol$$

$$SQ_{t,n} \approx 4,4478RR_{t,n} (10\Delta)/ATM\ vol_{t,n}$$

$$KS \approx 52.7546*BF_{t,n}(25\Delta)/ATM\ vol_{t,n}$$

Where *ATM vol* is ATM volatility, approximated as a measure of location, the SQ as the measure of skewness approximated by risk reversal and KS as a measure of kurtosis approximated by Butterfly quotes. The exact derivation of the relationship is beyond this thesis. But the main objective is to examine the methods available for extracting risk neutral higher moments of probability distribution using market data.

### 3.2.8 The use of risk-neutral moments in practice

In general there are two approaches to make use of implied PDFs (Galati 2002). The first looks at the higher moments at particular time to asses, for example, how expected intervention by the Central Bank is assessed by market participants. The second approach looks at time series of higher moments, applying econometric knowledge to quantify the general tendencies for example. In this thesis we are mostly interested in the second approach. For example Malz (1997) extracted risk-neutral skewness and kurtosis and used these as explanatory variables along with ATM volatility in the CAPM setting and found that investors can earn excess returns on currencies that have positive skewness implied by options. Similar intuition was tested on Uncovered Interest rate model but for the sample of 6 currency pairs during 1992-1996 period, but the measure of risk neutral skewness was not found to have significant explanatory power.

The Malz method has found application among policy makers, including central banks, to assess the possible impact of FX intervention, key rate policy changes etc. Below is the chart with example on Brazilian real implied probabilities calculated Michael Gapen, US Federal Reserve.

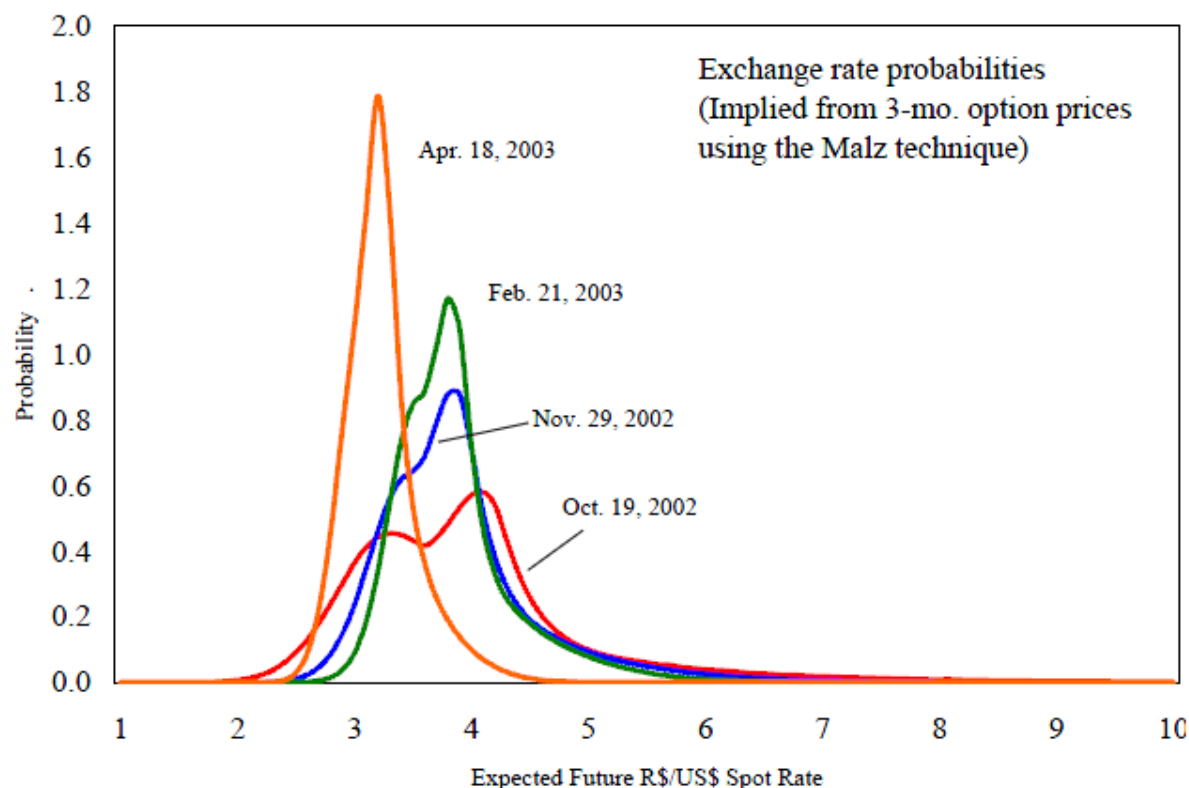


Figure5. Exchange rate probabilities implied from 3 month option prices using Malz technique. Source [www.michaelgapen.com](http://www.michaelgapen.com)

The chart shows estimated probability density functions at different point in time and its evident that market perception of uncertainty and direction of the change in spot rates differ at 4 different point in time.

The applicability of the Malz technique is not only limited to currency options, it can also be implied to short term interest rates. Bank of England, for example, assesses the implied volatilities of shortsterling futures contracts on short term interest rates.

The European Central Bank has numerous publications (Olli Castren 2004), that use techniques to extract higher moment from currency options market. the usefulness of the described methods in making qualified decisions about the market expectations cannot be underestimated. The end-users of this information along with policymakers can be investment managers, pension funds, hedge funds etc. in what follows this theses looks into the empirical works in this field.

### 3.3. Section summary

The Section 3 has introduced the type of currency derivative contract – European option. We looked at pricing of the derivative by Black and Scholes formula based on strict assumptions. But it seems like the market has its own view on how prices evolve. Hence the unobservable component – the volatility is allowed to change over time. This section further examined the properties of volatility derived from market prices with respect to its components – risk reversals and butterfly – that express how “non-normal” the distribution of expected exchange rates is. By being market traded contracts, at any given point in time the trader can place a bet against the expected skewness or kurtosis of this distribution. We showed that such information from the options market can be used in quantitative way to assess markets perception on expected changes in exchange rates. Moreover the fact that that major Central Banks look in to this area provides the evidence in favor of importance of market implied volatility, skewness and kurtosis. This in turns supports the choice of the subject for this thesis as the one that have certain relevance to real world.

Next the section 4 will cover the so called uncovered interest rate parity, as in the recent literature on risk reversals the relation between future currency returns, the interest rate differentials and the skewness in expectations of the rate move has taken the central part of empirical research. So it is important to introduce the concept of UIP in order to proceed further.

## 4. Uncovered Interest rate parity

### 4.1 Covered interest rate parity

It is well known that currency exchange rates, interest exchange rates and forward exchange rates are linked together by covered interest rate parity (CIP):

$$F_t/S_t = \frac{(1+r_d)}{(1+r_f)}$$

Or in percentage terms is expressed as  $f - s \approx r_d - r_f$

Where  $F$  - forward and  $S$  – spot exchange rates are quoted as amount of domestic currency required to buy 1 unit of foreign currency,  $f$  and  $s$  are logs of forward and spot rate at time  $t$ .  $r_d$  and  $r_f$  are domestic and foreign exchange rates.

Covered interest rate parity relation states that the percentage difference between the forward and the spot exchange rate is equal to the interest rate differential. If the  $r_f > r_d$  then investing in foreign currency asset and covering the future proceeds, expected at time  $t+1$ , back to domestic currency via forward rate today should offset this foreign interest return. This parity holds by arbitrage condition and forms the basis for pricing currency forward contracts. If this is not so the arbitrage opportunity exist which will be spotted on the market that eventually will drive the CIP to hold so that interest rate differential is equal to difference between forward and spot price.

## 4.2 Assumptions of UIP and “forward premium puzzle”

Uncovered interest rate parity - is an economic concept that, under assumptions of investors being risk-neutral, and having rational expectations asserts that the expected change in value of exchange rate at time  $t+n$  equals the forward exchange rate price today for delivery at time  $t+n$ :

$$(F_t - S_t) / S_t = E((S_{t+n} - S_t) / S_t)$$

and if UIP holds the forward price today represents an unbiased estimate of future nominal exchange rate:

$$F_t = E(S_{t+1})$$

So the investor is assumed to be indifferent to invest in foreign interest bearing asset and then convert the proceeds in future at  $E(S_{t+1})$  rate because this rate is expected to depreciate to reflect the interest rate differential.

UIP is not an arbitrage condition so whether it holds in practice can be tested empirically by regressing currency return on forward differential as in Fama (1984):

$$s_{t+1} - s_t = a_0 + a_1 * (f_t - s_t) + u_{t+1} \quad H_0: a_0 = 0 \quad a_1 = 1 \quad (4.1)$$

where spot and forward rates are in natural logs and  $u_{t+1}$  is random error. Since we assume that CIP holds by arbitrage then  $(f_t - s_t)$  and  $(r_d - r_f)$  can be used interchangeably.

The null of UIP regression is that currency return is expected to equal forward differential.

The most known results of Fama (1984) revealed the broad rejection of UIP. With slope coefficient  $\alpha_1$  found to be negative for the currencies investigated. The negative sign of  $\alpha_1$  was interpreted as the so called “forward premium puzzle” that high interest currencies tend to appreciate (against expectations of UIP) and that there is time varying risk premium ( $P_t$ ) that accounts for difference in actual exchange rates in future and forward rates:

$$f_t = E(s_{t+1}) + P_t$$

if we follow Fama (1984) and subtract  $s_t$  from both sides the result takes form:

$$f_t - s_t = P_t + E(s_{t+1} - s_t)$$

which implies that forward premium (interest rate differential) consists of component of risk premium and expected exchange rate change. If rational expectations assumption holds then the  $\alpha_1$  coefficient in (4.1) is equal to:

$$\alpha_1 = \frac{\text{cov}(E(s_{t+1} - s_t), f_t - s_t)}{\sigma^2(f_t - s_t)}$$

and the negative sign of  $\alpha_1$  Fama(1984) attributed to

(1) variance of risk premium exceeding that of expected exchange rate change -  $\sigma^2(P_t) > \sigma^2 E(s_{t+1} - s_t)$  and

(2) covariance of  $P_t$  and  $E(s_{t+1} - s_t)$  is negative that is the relation between expected depreciation and risk premium is negative.

This implication can help to explain the recent behavior in carry trades, when periods of slow appreciation of high interest rate currencies are followed by sharp depreciation (Brunnermeier 2009).

That is very informative summary of expected sign of  $\alpha_1$  from UIP regression is given by Bhansal et al. (1999):

Case	$a_1$	Var P and Var E( $s_{t+1}-s_t$ )	cov(P, E( $s_{t+1}-s_t$ ))
I UIP holds	=1	Var(p)>Var(s)=0	cov(p,s)=0
II Forward Premium puzzle	<0	Var(p)> cov(p,s) >Var(s)	cov(p,s)<0
III Time varying risk premium	>1	Var(s)> cov(p,s) >Var(p)	cov(p,s)<0
IV Time varying risk premium	=0.5	Var(p)=Var(s)	Undetermined

Table 4.1. Implication of UIP regression. p - is risk premium, (s) denotes expected change in  $s_t$ .  
Source Bhansal and Dahlquist (1999).

the table above provides sort of a key to explain the result that can be obtained when running (4.1). It also shows an interesting point, that even though the puzzle was found often in previous research, the negative coefficient  $a_1$  is not a “must”, so researcher should be ready interpret the sign and the magnitude of the coefficient.

Bhansal et.al (1999) also found that most of the UIP rejections occur when  $f_t - s_t > 0$ , whereas when  $f_t - s_t \leq 0$  UIP holds and especially in the case of USD. When US interest rates exceed other foreign interest rate the negative sign of the coefficient was found. Engel (1996) also warns that interest differential can change sign during the sample estimated. Overall the presence of risk premium

### 4.3 Carry trades as a strategy to exploit UIP violation

Carry trade – is a trading technique designed to exploit the “forward premium puzzle” anomaly, namely the well documented paradigm that high interest rate currencies tend to appreciate over time. In order to establish a carry trade strategy, one could borrow funds from low yielding currency, convert these funds into high yielding currency and invest in bonds, or other interest bearing asset to receive the yield. The profit from such trading activity is mainly comprised of two sources: the appreciation of the high interest rate currency (against prediction of UIP), and interest rate differential. It might seem almost riskless at first glance, but such a strategy poses a potential downfall, as time passes the risk of sudden depreciation of the high interest currency to comply with equilibrium, can take place thus wiping out profit form appreciation as well as earned interest rate differential.

Galati (2007) writes that this strategy works well during the times of low exchange rate volatility and stable interest rate policies. If this requirements are fulfilled the carry trade can work as a self fulfilling prophecy, as more market participants will be looking into this strategy for source of



return, the inflow of capital into high yielding country will lead to its currency appreciation, this in fact will attract more participants participate bidding the value of this high interest currency even higher until the macro economic shock, or unexpected event such as liquidity crisis we have witnessed in 2008 (Brunnermeier et al. 2009) will not force these investors to out of their accumulated positions. Which in fact can turn into liquidity spiral, as more participants exit the strategy in a short period of time, the high yielding currency depreciate rapidly forcing margin accounts to be forced to liquidate their position again leading to further depreciation. In such case the market participant facing the risk of invested currency to depreciate can opt to purchase a protection in form of an option. Depending on the situation on the market, whether the risks of sudden exchange rate moves are more likely than not, the price of the option (protection) should include these risks. Risk Reversals can is exactly the measure how much it's more expensive to buy protection against exchange rate move in one direction can contain important information.

The recent example for such activity was in 2008 when major high yielding currencies depreciated sharply after long period of gradual appreciation against Japanese Yen, US dollar and Swiss Franc. Among severely depreciated currencies where South African rand, Australian and New Zealand dollar. The role of risk reversal in this period in time was evident. As Galati wrote (2007) Risk reversal represented a certain directional indicator at the time when depreciation was about to happen. The empirical section will look in to more details regarding evidence of link between carry trades and risk reversals.

#### **4.4 Section summary**

This section has covered the notion of covered and uncovered interest rate parity as well as general assumptions of the latter. Further the strategy that is aimed at exploiting the UIP anomaly – carry trades - has been briefly touched upon. Based on the empirical evidence, violations of UIP, namely the appreciation of the high interest currencies instead of it depreciation has been found in the past. The next objective is to look in to existing empirical research that examined risk reversals and their relation to currency rates.

## 5. Empirical Literature review

### 5.1 Empirical evidence on FX implied volatility

We will start our review of literature from discussing recent works on implied volatility.

The unbiasedness of implied volatility had been tested by several researchers in the past by using equation (Chernov 2001, p.3):

$$RV_t = \alpha + \beta \sigma_{t,T} + \varphi HV_{t-T,t} + u_{t+T}$$

where RV is realized volatility,  $\sigma$  is implied volatility from Black and Scholes, HV is the historical volatility over preceding period. 3 Hypotheses are tested:

*Informativeness*: beta should be significantly different from 0

*Unbiasedness*:  $\alpha = 0$   $\beta = 1$

*Informational efficiency*:  $\varphi = 0$

According to Chernov (2001) most of the tests find evidence against unbiasedness and in favor of informativeness where the results for informational efficiency are mixed. Chernov (2001) explains the bias of implied volatility accepting that the volatility implied from the option price includes market risk premium on the underlying asset as well as the volatility risk of this asset. Taking this volatility risk premium into account tests on equity indices and 3 exchange rates show that unbiasedness hypotheses cannot be rejected.

Beckers (1981) shows that option prices do not incorporate all available information. Canina and Figlewski (1993) find little evidence that implied volatility is able to forecast realized volatility of the stock market. Jorion (1995) finds that implied volatility can outperform the past realized volatility when predicting future realized volatility, the evidence of bias is also found. Fleming (1998) finds that implied vols are biased predictors of future vols and suggest correcting for those using linear models. Christensen and Prabhala (1998 and 2001) use longer and non-overlapping time series also finds that implied vols can outperform realized vol in forecasting future volatility, and argue that OTC options are of better quality compared to exchange traded options to use in forecasting. Neely (2003) looks into inefficiency of implied volatility and explains it by autocorrelation and measurement error in estimating it.

Busch, Christensen and Nielsen (2007) use implied vol from FX market (as well as bonds and stocks) and find additional information that can help in forecasting continuous and jump components of realized volatility.

Also Covrig and Low(2003) find that market quoted implied vol is more accurate than historical vol on shorter time frames and but less so on longer time frames. Taylor and Xu et al. (2004) compare implied vol and AR(FI)MA models and find that on one day and one week implied vols forecasts are not better. Bollerslev and Zhou(2005), discuss biases in implied vols when used to forecast historical vols and general conclude that due to pricing of risk in options market the implied vols will be biased upward compared to historical. This result is also evident from Figure1. Christofersen and Mazzota (2005) find that implied vols from FX OTC market represent unbiased forecast of one month and 3 month realized volatility (using Mincer Zarnowitz regression).

Dunis, Sarantis and Kellard (2007) use implied volatility data confirm that realized and implied volatilities in the exchange rates are fractionally cointegrated series with slope of 1 (accepting unbiasedness hypotheses).

Empirical findings above, as expected, do not provide one clear statement whether implied volatility unbiasedness holds or not. Therefore this paper proceeds to use the implied volatility based data namely risk-reversals for empirical research.

## **5.2. Risk Reversals and crashes in currency markets**

This paper was in large inspired by the study of several researchers currency crash risks and risk reversals - Brunnermeier, Nagel and Pedersen (2009); Farhi, Gabaix, Verdelhan, Rancier and Freiberger (2009) and Jurek (2009) henceforth (Brunnermeier, Gabaix, Jurek).

### **5.2.1 Brunnermeier, Nagel and Pedersen (2008) – *Carry trades and Currency crashes***

In their work researchers investigate the carry trade strategies i.e. borrowing in low interest rate currency and investing in high interest yielding currency and find the evidence that while profitable for some time this strategy has negative skewness in returns and is exposed to risk of

sudden crashes associated with macro shocks. They relate event of such crashes to times when liquidity constraints are increased as well as low risk appetite among investors.

Methodology. Researchers address the Uncovered Interest rate Parity (UIP), specifically the “forward premium puzzle”. By referring to excess returns as a compensation required by investors to hold on risky assets which are subject to crash, they look into pooled cross section and time series data of interest rate differentials and physical as well as risk neutral (implied from options) skewness. They refer to the latter as “price of crash risk”. Also the measures of market risk such as VIX index and the measure of market liquidity – the TED spread is used to explain the relation with carry trades.

Data. Researchers use daily time series data for 8 nominal exchange rates all relative to USD from 1986-2006 period and sample these quarterly (options data starts from 1996). For risk reversal they use quotes of 25 $\Delta$  RR from OTC market. interest rates data represent 3-month interbank rates. They look into individual currencies as well as equally weighted portfolios of high-low interest rate currencies.

Results. The main conclusion of there is the linkage of currency crashes to liquidity constraints of speculators. These constraints lead speculators to unwind their positions in high interest rate currencies that lead to further depreciation of the these currencies. Hence the linkage of high interest rate differential lead to high speculator position which increase the crash risk. This risk is also amplified by the finding that currencies with similar interest rate levels co-move with each other. When it comes to implied skewness (risk reversals) the cross section with interest rate differentials shows negative relationship. High differential is reflected in high price of protection against the crash risk. However the interesting result is found in time series between future physical skewness (dependent variable) and current level risk reversal (independent variable 1 period lagged), controlling for other variables, the relation between these two is negative. Authors propose that that at the midst of the crash the price of the protection (risk reversals) is high, but since the major unwinding has already taken place the future crash risk goes down due to less speculators positions and that is reflected in future appreciation. Further they find that the relationship of physical and option implied skewness differs when currency returns are as dependent variable. High currency return at period  $t$  explains high risk reversal at period  $t$  (positive relationship), whereas opposite is true when physical skewness. They suggest that

option implied skewness is created is driven endogenously by speculators activity, when crashes occur and speculators decrease their positions, part of this option implied skewness is increased by buying protection against further depreciation of the currency. Also they found that currency portfolio skewness is not easily diversified away by adding more currencies because carry trade return risk is correlated among countries and have common factor risk factor such as liquidity.

### **5.2.2 Farhi, Gabaix, Verdelhan, Rancier and Fraiburger (2009) – Crash Risk in currency markets**

Authors also looked at the crash risk in carry trade returns, however they approached the concept of excess returns as the sum of 2 risk premia attributed to random shocks and rare disasters. The model suggested by Gabaix et.al assumed this separation and showed that disaster risk premia explained 25% of carry returns. They also tested the linkages to interest differentials, risk reversals (implied skewness) and futures exchange rate changes.

Methodology. Apart from the model assumptions, researchers use two concepts “forward premium puzzle” of UIP and the option pricing model with jumps to derive their results. The carry trade returns in their work is formed into unhedged and hedged via options portfolios against possible disaster. When it comes to risk reversal, Gabaix argue that it’s more theoretically sound to convert the volatility format into currency units via the option pricing model. Among others they put forward 2 hypotheses related to risk reversals 1) increase in risk reversals lead to depreciation of exchange rates, 2) high level of risk reversals predict future exchange rate returns. Gabaix calculates risk reversals as put options price less call options price which is opposite to market convention.

Data. Daily observations of nominal spot exchange rates (32 currencies), 1 month maturity options and currency forwards are used for the period of 1/1996-8/2008. The last 4 months of 2008 are excluded from the sample as authors claim this period represented example of a disaster and that their model assumes normal distribution of exchange rates within the sample.

Results. To test the first hypotheses they regress monthly nominal log changes of exchange rates on monthly changes in RR and found significant contemporaneous negative relationship, they also claim that RR have economic significance. To test second hypotheses they use UIP model

and use RR lag as additional explanatory variable to interest differential. As a result the RR do not improve the exchange rates forecasts one month ahead and appear with negative sign in specification with log difference of EUR rate as dependent variable, risk reversal appear to be not significant statistically. As in Brunnermeier (2008), they found positive link between risk reversals and interest differentials meaning that the price against crash risk is higher for high interest rate currencies. Their finding stressed the importance of accounting for time varying risk premia in explaining carry excess returns. Also, they argued, the investor can still earn positive return even if the disaster risk is fully hedged, they explain it by the fact that investors require compensation for remaining non-disaster risk. One of the explanations they proposed why the carry strategy is still profitable, even after hedging is that their sample didn't include disaster event during which the cost of protecting the carry portfolios can be very expensive.

### **5.2.3 Jurek (2009) – Crash Neutral Currency Carry trade**

In his work Jurek looks in to carry excess returns that had Sharpe ratio twice as much as US stock markets in the period of 1990-2007 against UIP prediction. Author investigates whether the source of this excess returns is actually the compensation for currency crashes. The currency options are used to create hedged portfolios of carry trades and the result show that in period of investigation portfolios, fully hedged against crash, delivered returns not significantly different from zero supporting the linkage between excess returns and crash risk. Meaning that the source of unhedged carry returns came from compensation for crash risk.

Methodology. Jurek uses two approaches, the first approach examines the time series of risk neutral properties of exchange rates, and the second approach looks at hedged portfolio returns and their performance in order to investigate the currency risk premia in carry trades. In order to construct hedged portfolios of currency returns Jurek defines the currency crash as a movement in nominal exchange rate of certain multiple of underlying volatility (certain distance from forward rate). Jurek also looks into the carry trade performance during credit crisis period of 2008. Hence Jurek defined protected via options carry trades as crash-neutral carry trades.

Data. the author uses daily data set of LIBOR rates on G10 currencies as well as nominal exchange rates versus USD (X/USD) spanning from January 1990 to December 2008. The monthly sampling. Also daily implied volatility quotes on five different strikes and four standard

maturities obtained and sampled monthly. To derive risk neutral moments of exchange rates implied volatility, implied skewness, implied kurtosis Jurek uses technique of Bakshi, Kapadia and Madan (2003).

Results. Within data sample of 1999-2007 Jurek used option implied skewness as dependent variable and finds positive relation with currency excess returns, past realized skewness and lag of option implied skewness, but insignificant negative relationship with interest rate differential. However, the latter relationship is positive and significant in univariate regression. Jurek relates his findings to that of Brunnermeier (2008), price of hedging the crash risk is lowest when risk of the crash is high and vice versa (negative sign between option implied and realized skewness). Next, Jurek tested the crash risk hypotheses where price of the crash proxied by option implied skewness expected to predict excess returns with negative sign. The coefficient of implied skewness was not significant however appeared with surprisingly positive sign.

When it comes to crash neutral portfolios, Jurek finds that quarterly hedging compared to monthly hedging during the for the period of 1999-2008 would have been cheaper in terms of buying protection against the crash. Also he finds that crash neutral portfolios' excess returns are significantly lower than unhedged portfolio returns and that the difference in two is attributed to the exposure to currency crashes and net US dollar exposure.

### **5.3. Section summary**

This section looked into empirical research undertaken in the field of options implied volatility. The evidence is mixed whether the implied volatility provides unbiased estimated of future realized volatility.

The product of option implied volatility is analyzed from the perspective crash hypotheses and uncovered interest rate parity. The research papers analyzed risk reversals and their approximation, namely the option implied skewness, to explain the currency returns and predictability. The main common finding can be summarized as the price of risk do not offer high level of predictability of currency returns. But in terms of contemporaneous relation between returns and risk reversals the research support one common finding – the price of protection against crash (sudden depreciation of investment currency) is highest when the crash has already occurred, that is quite puzzling, as one would expect the opposite to be true if risk reversals

predictive ability were a priori expectation. Brunnermeier related this to speculators demand to buy protection against further depreciation right when the crises has occurred and due to liquidity constraints the leverage is forced to be reduced.

Another explanation can be offered from the prospective of Behavioral Finance. Buying protection against further losses instead of exiting the losing position is in line with Disposition effect (Shefrin et.al 1985). It states that investors are prone to sell off securities that recently increased in value and tend to hold to securities that had negative loss instead of realizing this loss. So could it be that for speculator, whose positions are currently in loss after severe depreciation in value, realizing the loss is not the best option. Instead he/she accepts the high price of protecting this position by buying an option against further depreciation and hope for subsequent rebound in value.

## **6. Econometric Models and Estimation methods**

This section presents the econometric approaches that will be used to address the research question and consists of two parts, the first part will introduce the econometric concepts and notes residual analysis used. The second part will present models and put forward hypotheses for testing.

Basically the general method used in this thesis is ordinary least squares (OLS). The Asymptotic Gauss-Markov assumptions for time series is given in Wooldridge (2009, P.401)

1. The stochastic process follows the linear model.
2. No independent variable is constant nor linear combination of the others.
3. The errors are homoscedastic.
4. The errors are not serially correlated.
5. Errors have zero conditional mean.

If the assumptions above hold then OLS estimator is known as Best Linear Unbiased Estimator of the coefficients derived from linear regression model. The assumption of classical OLS that



errors being normally distributed is somewhat relaxed for large sample based on asymptotic theory in Gauss-Markov.

If assumptions 3 and 4 are violated the OLS can still be unbiased but will no longer be Best and the inferences based on t- and F-tests will be inconsistent. Therefore it very important to look after potential problems with heteroscedasticity and serial correlation when dealing with time series.

Test of serial correlation in the residuals will be conducted by running the Breusch-Godfrey LM test using maximum likelihood estimation via SAS. This test is used to test for higher order serial correlation AR(q) and is considered more general than Durbin Watson test. In case of massive positive serial correlation the model estimated should probably revisited for potential omitting explanatory variables or the nature of the series used in estimation should be thoroughly investigated.

Test for Heteroscedasticity will be performed using Q and LM test for absence of ARCH effects. These tests are computed from OLS residuals assuming “white noise” (SAS user guide).

To account for potential violation of assumptions 3 and 4 the Newey-West method for heteroscedasticity and autocorrelation consistent (HAC) standard errors will be calculated. This technique is often used to correct the standard errors of the coefficients to overcome the effect of Heteroscedasticity and Autocorrelation in residuals of time series data. Some cautionary note however must be said about Newey-West HAC, the correction can behave poorly when time series exhibit substantial serial correlation (Wooldridge 2009, p.430) and sample is relatively small.

Also the lag has to be chosen manually for this test and represents the assumed order of serial correlation. The larger the g the more terms are included to correct for serial correlation. Some suggest to use integer part of  $4 \cdot n / 100^{2/9}$  for selection g (where n is number of observations).

As part of residual diagnostic check, the Jarque-Bera normality test will also be performed and reported.

Stationary vs. nonstationary stochastic process.

When analyzing the financial time series data we need to know that the stochastic process  $\{x_t: t = 1, 2, 3\}$  that generated the series has stable distribution over time  $t$  and that this distribution is the same for the for  $t=2, 3$  (Wooldridge, 2009, p.378). If so this also implies that the variable  $x_t$  has constant mean and finite variance the same for all values of  $t$ :

$$E(x_1=x_2=x_t)=\mu$$

$$\text{Var}(x_t)=\sigma^2$$

And covariance between  $x_1$  and  $x_{1+k}$  depends only on  $k$  and not  $t$ . This is also known as weak stationary process. These conditions ensure stability over time and help to understand the underlying processes and make proper inference when used in regression. Most financial series however are non-stationary and have so called unit root (Koop 2009, p.184). a well known example of non-stationary process is Random Walk model:

$$Y_t = \rho Y_{t-1} + e_t \quad \text{RW without drift} \quad \text{and}$$

$$Y_t = \alpha + \rho Y_{t-1} + e_t \quad \text{is RW with drift}$$

Where  $\alpha$  is drift parameter the presence of which allows for the time series to grow at certain rate, on average. If  $\rho = 1$  then  $Y_t$  has unit root and non-stationary, if  $|\rho| < 1$  then  $Y_t$  is stationary.

As Koop states (2009, p.), the implications if  $Y$  has unit root its values will be highly autocorrelated, the mean and the variance will increase over time (especially if drift term non zero) and will create problems since the OLS assumptions will not hold.

If  $Y$  has unit root we cannot explain its behavior by regressing on stationary process. We must check for presence of unit root first. This will be done USING Dickey-Fuller test in SAS by regressing the first difference of RW with drift equation

$$\Delta Y_t = \alpha + \phi Y_{t-1} + e_t$$

$H_0 \phi=0$  series have unit root, equal to  $\rho=1$

$H1 \phi<0$  series do not have unit root

The critical value of DF tau statistic for 5% and 10% significance levels is -2.86 and -2.57 respectively (Wooldridge, 2009, p.632). If the error terms of (3) are correlated we will use Augmented DF test that includes lagged values of  $Y_t$  so that error term becomes uncorrelated. The selection of lag order can be performed with Akaike's Information Criteria (choosing the order with lowest AIC) and its importance has been stressed by Bernier et.al (2008) who found that ADF results are very sensitive to choice of lags order. Also Koop (2009, p.195) warns that DF test exhibits so called "low power" tending to find the unit root in the series when none is present and vice versa, especially this is the case if the time series has had structural break. There are also other test for unit root but we opt for the ADF choice and will not discuss other tests here.

### Spurious regression.

As described in Koop(2009, p.217) when both dependent and independent variables Y and X have unit roots explaining their relationship via OLS may lead to wrong results.

$$Y_t = \alpha + \beta X_t + e_t$$

The statistical tests may indicate that slope coefficient of the estimated regression is different from zero where in fact the true coefficient is not, or the regression results in high  $R^2$ . Such regression is spurious and should never be performed if X and Y have unit roots. In order to avoid this problem and be able to explain relation between Y and X the two variables have to be cointegrated, if no cointegration is found the first differencing the time series may be used to transform it into stationary.

### Cointegration.

According to Koop(2009, p.218) "*if Y and X have unit roots, but some linear combination of them is stationary, then we can say that Y and X are cointegrated*". Two stochastic processes may have long-run relationship like common trend and exhibit some sort of equilibrium relationship. Over time the difference between Y and X can increase but it tends to return to some equilibrium. This is because the error term will not get too large over time and leading Y and X to be in a common trend. If this is so there is we can use the cointegration test to explore the properties of these stochastic processes and not worry about non-stationarity of the individual Y and X.

To test for cointegration we use Engle-Granger test which is in fact similar to DF test described earlier but use critical values computed by Engle-Granger. Provided that both Y and X have unit roots we perform the test Koop(2009, p.170):

1. Running regression of  $Y_t = \alpha + \beta X_t + e_t$  and saving the residuals
2. Perform DF unit root test on the residuals (without deterministic trend)
3. If null of unit root is rejected (3) we conclude that Y and X are cointegrated.

Engle-Granger Critical values for Cointegration test (Woolbridge, 2009, p.639)

1% -3.90      5% -3.34      10% -3.04

If we cannot reject the null (calculated t statistic is not larger than critical values) then there is no cointegration between Y and X and spurious regression risk present. We cannot work with Y and X via OLS and will have to rethink our model and work with first differences instead (Koop 2009, p.227). In this way we will be working with difference stationary series but our interpretation of the results will also change:

$$\Delta Y_t = \alpha + \beta \Delta X_{t-1} + e_t$$

Small change in  $X_t$  will be explaining small change in  $Y_t$ .

If we find cointegration we next look into the long run equilibrium relation between Y and X. Cointegration concept however can also be used to examine the short run dynamics of the process by applying Error Correction Model (ECM). (Koop 2009, p.224)

$$\Delta Y_t = \alpha + \gamma \varepsilon_{t-1} + \omega_0 \Delta X_t + e_t$$

where  $\varepsilon_{t-1}$  is lagged error term from cointegrating regression ( $\varepsilon_{t-1} = Y_{t-1} - \alpha - \beta X_{t-1}$ ).

Structural break. We are going to use the Chow test for presence of structural break in our data. for this the data will be split in two sub samples. One before and one sample after the crisis started. The Chow test represents the F-test for equality of coefficients from the two sub samples. Chow test, is only valid under assumptions of homoscedasticity of error terms, in other words the variance of error terms of two samples must be equal. to save space the actual test will be presented along with results in Section 7.

After describing the econometric methods above the next part of this section will introduce the models that we want to test and a priori expectations.

Contemporaneous relationship. If RR represents the amount in implied volatility units by how much it is more expensive to trade one option (call) over the other (put) and hence the markets ex-ante perception of likely exchange rate move (negative sign – foreign currency is expected to depreciate; positive sign – the foreign currency is expected to appreciate) I want to test how much the change in this price premium can explain the currency return measured as log difference in spot rate. To do that the first difference of RR is used as independent variable and log changes in currency rates as dependent variable over one week horizon in OLS regression:

$$\text{Ln}S_t/S_{t-1} = \beta_0 + \beta_1 \Delta\text{RR}_t + u_t \quad H_0: \beta_0=0, \quad H_a: \beta_0 \neq 0 \quad (1)$$

$$H_0: \beta_1=0 \quad H_a: \beta_1 \neq 0$$

where  $u_t$  is disturbance term.

The expectation of relationship in (1) formulated in Gabaix et.al (2009, p.37): “*Increases in risk reversals are associated with contemporaneous exchange rate depreciation*”. I follow similar expectation but with one difference, for this expectation to be found the sign of slope coefficient should be negative. The reason is in RR definition, Gabaix defines RR as Put – Call, so when RR increase puts are becoming more expensive. In data set used here the RR is defined as Call – Put, for puts to increase the RR should change negatively.

I expect the decrease in Risk Reversals (more negative RR) to be associated with foreign currency depreciation. Currency depreciation in the variable of  $\text{Ln}S_t/S_{t-1}$  is a negative sign, hence I expect the sign of  $\beta_1$  to be positive and significant from zero, so that decrease in RR will be tested to explain explain the negative return of  $\text{Ln}S_t/S_{t-1}$  . The intercept is expected to be insignificant.

The notion of currency exchange rate is the same in Gabaix, units of domestic currency per 1 unit of foreign currency. There is also difference in units of measurement, I use the direct quote that represent volatility units, Gabaix converted these into currency units. While it might be intuitive to work with currency units, my argument is in ease of interpretation. Since the RR quotes are

directly observable in the market at any given point in time the estimated coefficient will have direct link to observed value at the market.

The intuition of Gabaix model with respect to RR is that when high interest rate currency appreciates against UIP prediction, this is partly due to disaster risk premium that investors require for holding currencies that are most likely candidates to crash (after period of appreciation). So when foreign currency appreciates, disaster risk increases, put options on foreign currency become expensive, this is captured by RR that turn positive (in favor of put) reflecting cost of insurance against the crash. I expect to see if in model (1) similar reasoning can be applied to EURUSD for the sample period tested and its respective 25Δ Risk Reversals (but with opposite sign, since increase in puts for us is negative sign of RR).

Predictive ability of RR on EURUSD. Next I want to look into the more dynamic relationship to describe between  $\ln S_t/S_{t-1}$  and  $\Delta RR_t$  and use lagged values of changes in RR as independent variables:

$$\ln S_t/S_{t-1} = \beta_0 + \beta_k \Delta RR_{t-k} + u_t \quad (2)$$

$$H_0: \beta_0=0 \quad H_a: \beta_0 \neq 0$$

$$H_0: \beta_k=0 \quad H_a: \beta_k \neq 0$$

The lag length  $k$  of  $\Delta RR_t$  will be determined by using Akaike's and Schwarz's information criterion (AIC and SBC respectively). The lagged model with lowest value of AIC and SBC will be selected for OLS regression. The results of (2) will be tested for sample before and after the crisis. To my knowledge neither Brunermeier, Jurek or Gabaix used past values of  $\Delta RR$ .

As in (1) the expected sign of  $\beta_k$  is positive, so that increase in  $\Delta RR$  in  $(t-k)$  is expected to explain positive change in currency return at time  $t$ .

The UIP and RR as proxy for risk premium. Next I want to examine whether RR as a proxy of "price of a crash" can help predict the currency returns. Consistent with previous research violation of UIP has been attributed to time-varying risk premium (Fama 1984) due to which investors require compensation for holding high interest yielding foreign assets and as a result the currency returns weren't found equal to interest rate differential. If RR represents the price of protection against sudden move of an exchange rate, and was found to be highly time varying

(Carr and Wu 2007), I would expect RR to have explanatory power in explaining future currency returns as proxy for crash risk and augment the UIP regression to include RR:

$$\ln S_t / S_{t-1} = \beta_0 + \beta_1(i_d - i_f)_{t-1} + \beta_2 RR_{t-1} + u_t \quad H_0: \beta_0=0, \beta_1=1, \quad (3)$$

$$H_0: \beta_2=0 \quad H_a: \beta_2 \neq 0$$

$$xS_t = \beta_0 + \beta_1(i_d - i_f)_{t-1} + \beta_{23} RR_{t-1} + u_t \quad H_0: \beta_0=0, \beta_1=0, \quad (4)$$

$$H_0: \beta_{23}=0 \quad H_a: \beta_{23} \neq 0$$

where  $(i_d - i_f)_{t-1}$  is interest differential between weekly domestic and foreign interest rates for period t-1.  $RR_{t-1}$  is lagged risk reversal (in levels, not differenced).

(3) is specification of UIP where null for  $\beta_1$  equals 1 and state that currency returns are equal to interest differential i.e. UIP holds if null is not rejected;

(4) uses null  $\beta_1=0$  and predicts that, if UIP holds, expected currency excess returns, after accounted for interest differential, are equal to 0 and adding.

Gabaix et.al(2008, p.34) expected to find the evidence that: “*high levels of RR predict future currency returns*” however the expectation of sign in  $\beta_2$  coefficient was not clear. I turn to Jurek (2009, p.22), who expected risk neutral skewness to predict currency excess returns with negative sign if it represents a proxy of the markets expectation of a crash. Hence I will use RR variable and expect its negative relation to currency excess return in UIP regressions.

In section 3, the technique for approximation of risk neutral skewness and from risk reversals was illustrated. I expect that this approximation does not change the sign of the variable when converting RR into risk neutral skewness, because this linear approximation does not contain algebraic transformation that can alter the sign of the variable. So RR in (3) and (4) will be used as a proxy for expected skewness.

Finally the intercept in both models is expected to be insignificant.

Since models (3) and (4) test the UIP prediction the results will only be reported to (3). For comparison, one of the outputs from (4) will be presented in Appendix.

Risk reversals against Random Walk. As an example of predictability exercise the model that is suspected to provide good explanatory power and fulfill the assumptions of OLS will be tested

against naïve Random Walk without intercept. The criteria for beating the random walk is the ratio between Root Mean Squared Error (RMSE) of the models performance out of sample on RMSE from random walk. For this purpose I reserved 17 observations, from 05/05/2010 to 25/08/2010. The methodology is from Wooldridge (2009, p.651). I have chosen to perform 1 step ahead forecast. Once the new observation is taken into account, the observation will be added to existing data set and reestimated for new coefficients. The procedure continues until no more observations left to predict one period ahead.

## **7. Data**

### **7.1 Description of the data**

This thesis use daily nominal exchange rate time series for EURUSD spanning for period 02 January 2006 – 28 April July 2010. These series include daily 1128 observations of spot and 1 month forward exchange rates from DataStream. The spot rates represent the mid rate on the close of that date on 17.00 New York time. The spot and forward exchange rates at time  $t$  are denoted as  $S_t$  and  $F_t$  respectively, and represent the amount of domestic currency(USD) needed to buy 1 unit of foreign currency (EUR). An increase in value of  $S_t$  means appreciation of the foreign currency and depreciation of the domestic currency.

On the FX options data I obtained daily time series of mid quotes (mid rate between bid and ask) for EURUSD 1 month Risk Reversals and 1 month Butterfly for 10 and 25 Delta strikes, 1 moth implied ATM volatility from Bloomberg for the same period (Bloomberg command - VOLC). Volatility quotes are annualized. Additionally as discussed in section 2, I obtained risk neutral moments of RR implied 1 month skewness and Butterfly implied 1 month kurtosis of EURUSD exchange rates from Bloomberg. These data series are calculated by methodology of linear interpolation proposed by Carr and Wu (2005) and is readily available. The choice of 1 month options maturity is explained by these contracts being the most actively traded and hence are more liquid compared to longer or shorter maturities. Also in empirical literature 1 month option contacts for 25 $\Delta$  Delta and 10 $\Delta$  Delta are most actively analyzed. (Please see Malz (1997), Carr and Wu (2007), Jurek (2009) for example).



Chernov (2001, p.3) claims that using directly quoted IV instead of estimating it via backwardation from BS model will drop the problems with errors in computing, and varying moneyness. The last term corresponds to the fact that quotes of IV are related to fixed deltas not spot values. Hence the choice in variables was to take directly the quotes available at the market.

The interest rate series for EUR and USD represent the British Bankers Association daily Libor fixings for 1 month maturity rates and are provided by Thomson-Reuters Datastream. All Libor quotations are annualized on a 360-day basis. Series are updated at approximately 12.00 each day with the values for the current day's data. Libor fixings represent the benchmark rate at which banks are willing to lending and borrow funds to each other. Libor rate is effectively the rate at which currency forward contracts are priced and hence represent the borrowing and lending cost for typical currency trader/investor/speculator.

Sampling of the data is done on weekly frequency. Taking each Wednesday observations (as in Campa et al.1996) I obtain 226 observations of nominal exchange rates. The first observation is for 4<sup>th</sup> January 2006, the last is for 28<sup>th</sup> April 2010. First this gives more number of observations compared to monthly or quarterly data, and second to my knowledge, this frequency has not been used on OTC market quotes of risk reversals in previous empirical research. However the cost to this choice can come in data containing more “noise” when dealing with returns.

## 7.2 Derivation of variables

As widely accepted in empirical literature the log return at time t is calculated as

$$s_t = \ln(S_t/S_{t-1}),$$

again positive return means appreciation of foreign currency between Wednesday t and t-1. This procedure produces 225 weekly return observations for EURUSD.

The foreign interest rate is denoted as  $r_f$  and domestic interest rate as  $r_d$ . Interest rate differential is calculated as the difference between weekly domestic and foreign interest rates.

$$(r_d - r_f)$$

Since we have monthly compounded annualized interest rate we convert these into weekly compound interest rate by dividing the rate by 52 corresponding to number of weeks in 1 year.

We calculate the excess return  $xs_t$  at time  $t$  as:

$$xs_t = \ln(S_t/S_{t-1}) - (r_d - r_f)_{t-1}$$

as in Jurek (2009). Where first term represents the nominal spot return and second term represent the interest rate differential for period  $t-1$  (interest rates are converted into weekly units). According to UIP the  $xs_t$  is expected to be zero. Hence the  $xs_t$  represents the measure of return in excess of predicted by UIP.

The FX options data represents 1 month maturity European vanilla options and is in annualized volatility units. For example ATM vol of 12.0 represents 12% implied standard deviation of exchange rate. The products of ATM vol, namely risk reversals and butterflies are converted from annualized into weekly by dividing on  $\sqrt{52}$ . The data is collected daily and represents the mid quote on 10.00am on New York time.

The Table 7.1. contains summary statistics for selected period sample period 04/01/2006-28/04/2010.

Table 7.1. Summary Statistics

	EURUSD	$s_t^*$	$xs_t^*$	<i>id-if</i>	ATMvol	RR	Butterfly	$\Delta RR$
Mean	1.3741	0.020	0.018	0.002	10.330	-0.160	0.252	-0.009
std.dev	0.1	0.108	0.108	0.014	4.500	0.589	0.161	0.290
skewness	0.33	0.900	0.940	-0.090	1.500	-0.998	1.920	0.480
kurtosis	-0.688	8.410	8.570	-1.250	2.200	0.530	3.280	5.530
Max	1.1889	0.102	0.102	0.023	26.250	0.950	0.800	1.600
Min	1.5831	-0.048	-0.048	-0.024	4.725	-2.200	0.100	-1.200
SW test	0.97	0.97	0.91	0.93	0.84	0.92	0.75	0.93

Table 7.1. Descriptive statistics for EURUSD weekly data from 01/2006-04/2010.  $n=226$  (225 for return and RR diff). \* - means and st.dev are annualized for  $s_t$ ,  $xs_t$ . Min/max values represent weekly data. Id-if is difference between annualized  $rd$  and  $rf$ .  $\Delta RR$  is differenced RR. SW test – ShapiroWilk test for normality, all t-stats in table are significant at 1% significance level. Mean, skewness, kurtosis, st.dev are calculated via SAS. Source Bloomberg and DataStream.

Based on the table statistics it can be seen that annualized weekly mean Spot return and excess return is about 2% and 1.8% respectively and have standard deviation of 10.8% per annum. Compared to that is a significant value of 1 weekly return of 10.2% in week ended December 17<sup>th</sup> 2008. Within that week the EURUSD spot rate moved from 1.3023 (10<sup>th</sup> December) to 1.4419 on (actually the rate high of 1.47 was recorded during on 17<sup>th</sup> December). Clearly the market during the fall 2008 up to beginning of 2009 was experiencing unusual times. It is also not surprising to see that the biggest change of RR (max value of RR column), the move from -0.985 (in favor of puts) to +0.62 (in favor of calls) happened during the same week. So this spot move was not left unnoticed by the options market. Please see the scatter plot of  $s_t$  against  $\Delta RR$  in Figure A1 of Appendix. In order to test if this observation is an outlier I will set the dummy variable of 1 corresponding to week ended 17 December and 0 for the rest dates. The result of analysis will be presented with and without this dummy. If the Dummy coefficient proves to be statistically significant it will be included to offset the influence of this observation. As Wooldridge (2009, p.327) states “the significant coefficient of the outlier in the model can be used to see how far off is this observation from the regression line obtained without using that observation”.

Interest rate differential for the sample period is positive, meaning on average the US interest rate exceeded that of EURO. This can be seen on the comparative interest rate time series chart in Figure 7.1. Even if one can argue that EURO rates were above US rates for longer period (137 weekly observations out of 243), the differential itself, when turned negative (in favor of EURO), decreased in absolute terms. In other words USD rates dominated the sample period by higher margin which makes mean differential positive for this sample.

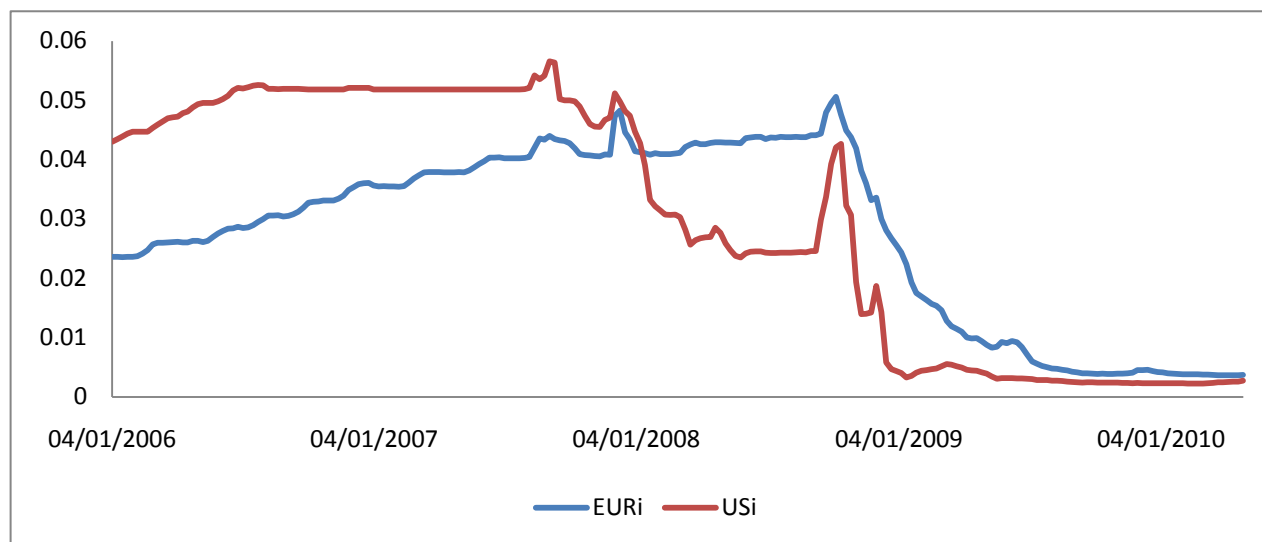


Figure 7.1. EURO and USD Libor 1 month interest rates. Period January 2006 – April 2010. Source DataStream.

ATM 1 month maturity vols have mean of 10.33% for the sample and the highest value of 26.25% on 29th October. Its second highest value of 25.25% was during the week discussed above. Please see Figure 1. for the graph of ATM and historical volatility of EURUSD.

The graphical inspection of the 1 month ATM volatility chart clearly indicates the period of the dramatic increase during the fall of 2008. If we take only 2008, for example, the lowest volatility observation of 8.035% was recorded on 1<sup>st</sup> of August and the highest value reached the level of 28.85% on 27<sup>th</sup> of October (both values are from 10.00 NY time) which corresponds to 2.5 times increase in the market's perception of the 1 month ahead EURUSD volatility.

When we turn to option data, namely RR, representing the slope of the volatility smile, and butterfly, accounting for its curvature, these two show quite different behavior. The standard deviation of RR is 3.65 times larger than that of butterfly. This finding on EURUSD is consistent with conclusions of Carr and Wu (2007) that the major variation of implied volatilities comes from the risk reversals, whereas the variation of the curvature is not that big. The plot of RR and Butterflies confirm this in figure 7.2. We can see that Butterflies were relatively stable over time, whereas RR exhibited strong variation that is directly linked to the dynamics of market expectations on exchange rate directional moves.

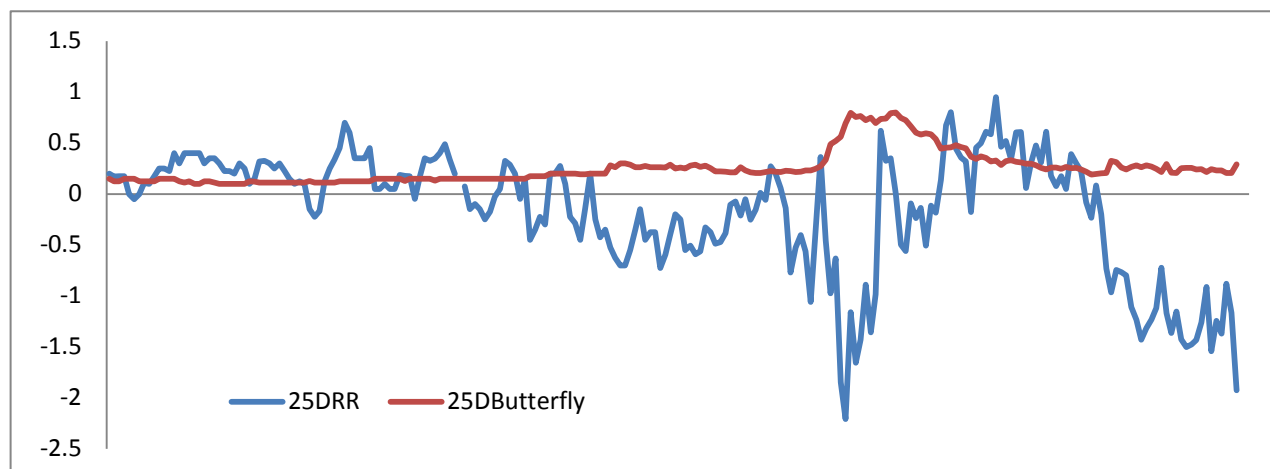


Figure 7.2. 25D Risk Reversals and 25D Butterfly quotes time series. Period 01/2006-04/2010. Source Bloomberg.

In my opinion it is informative to study the data before events of fall 2008 and after. In Appendix I divide the sample in two sub samples and present the summary statistics for both of the samples. Namely 04 January 2006 - 28th August 2008 and 03 Sept 2008 – 28 April 2010 ( $s_t$  return for second sample starts on 10<sup>th</sup> September). The choice of this specific period sub-sampling is explained by the period of unusual market instability that started in the fall of 2008 and deepened with collapse of Lehman Brothers on 15<sup>th</sup> September 2008. The magnitude of the change is also apparent if we look at the mean of ATM vols for two sub periods before and after the market crash that corresponds to 7.835% and 14.44% per annum respectively. Market's best guess of average future volatility is also close the realized standard deviation of weekly spot returns 15.3% compared to 7.2% per annum for the second and first sub samples respectively. It should also be noted that ATM vol in our example corresponds to 1 month ahead market's expectation, whereas historical standard deviation of returns is calculated from weekly sampling so the interpretation here should be for general information purposes.

### 7.3 Statistical tests

**Correlation.** In the Table 7.2 we present the cross correlation of Spot returns, risk reversals and weekly changes in risk reversals for full sub period as well as for two sub periods. I find that RR and its changes are positively correlated with spot returns. In fact the relationship of returns with weekly changes in RR is more positive than that of RR levels. For the sample period until fall 2008 the correlation coefficient is larger compared to subsequent period (the sample size should also be taken into account). Carr and Wu (2003) found similar results, namely the stronger

correlation of RR changes to spot returns rather than RRs for GBPUSD and JPYUSD and their work. Dunis (2001) looked into leads and lags correlations as well for several currency rates. The implication of the results for EURUSD is rather straightforward there is positive relationship, when the currency appreciates, the spot return is positive, and the risk reversals also rises that may lead to positive skewness of risk-neutral distribution (Carr and Wu, 2007).

	01/2006-05/2010			01/2006-08/2010			09/2008-04/2010		
	LnS <sub>t</sub> /S <sub>t-1</sub>	RR	ΔRR	LnS <sub>t</sub> /S <sub>t-1</sub>	RR	ΔRR	LnS <sub>t</sub> /S <sub>t-1</sub>	RR	ΔRR
LnS <sub>t</sub> /S <sub>t-1</sub>	1			1			1		
RR	0.32	1		0.4	1		0.18	1	
ΔRR	0.66	0.24	1	0.74	0.29	1	0.61	0.2	1
	n=225			n=137			n=86		

Table 7.2. Correlation analysis. Spearman correlation coefficients. All coefficients different from zero at 5% confidence level.

Next a closer analysis into statistical properties of our time series is performed. I have conducted standard test for unit root, serial correlation and heteroscedasticity. The results are presented in the table 7.3 for the full sample. Appendix has similar table for 2 separate sub samples.

Table 7.3. Diagnostics test

01/2006-4/2010	EURUSD	$s_t$	$xs_t$	id-if	ATMvol	RR	Butterfly	ΔRR
<b>Unit root Test</b>								
ADF tau (single mean)	-1.94	-15.01	-15.06	-1.22	-1.83	-3.23	-1.41	-16.86
p value	(0.3148)	(0.0001)	(0.0001)	(0.6687)	(0.3647)	(0.0199)	(0.5794)	(0.0001)
<b>Serial correlation</b>								
Godfrey LM test	213.01	0.0191	0.0329	222.21	212.512	171.94	218.42	4.15
p value	(0.0001)	(0.89)	(0.8561)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0413)
<b>ARCH effects</b>								
ARCH-LM	201.68	1.647	1.59	207.64	171.58	103.55	212.26	3.85
p value	(0.0001)	(0.1994)	(0.20)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0495)

Table 7.3. Augmented Dickey Fuller test, null of unit root. Godfrey LM test null of no serial correlation. ARCH-LM test for ARCH effects, null of no ARCH. n=225 Authors calculation via SAS. Sample 01/2006-04/2010. Source of input data DataStream, Bloomberg, estimated in SAS.

The table 7.3 confirms the well known fact that exchange rate series and interest rate differentials have unit root (non stationary time series) and the first difference of these series is (weakly, covariance) stationary. The augmented Dickey-Fuller (ADF) critical values for unit root test with

single mean and no deterministic trend are  $-2.86$  and  $-2.57$  for 5% and 10% level of significance for relatively “large sample”(Wooldridge, 2009, p.632). The ADF test of unit root rejects the null for EURUSD return series. Similar test for RR and  $\Delta RR$  series are also stationary based on the test results. The same cannot be concluded for the rest series in the table with their respective ADF test statistics not exceeding the critical values. However when I look into ADF test results on each of the sub sample results are the same except for RR series, that has ADF statistic  $-2.17$  (p-value 0.2177) for the period of 2008-2010 and thus exhibits non-stationarity for that sample only.

Next in the table test for serial correlation in the residuals - Breusch-Godfrey Lagrange Multiplier(LM) test. This test is considered to be more powerful than Durbin-Watson test statistic, as it can be applied in case of stochastic regressors and to detect higher order serial correlation. From table 7.3 it can be seen that the null of LM test of no serial correlation can be rejected for all (hence higher order serial correlation concluded) series except currency returns  $s_t$  and  $xs_t$ . for  $\Delta RR$  the null can be rejected at 5% confidence level.

The last test is LM test for absence of ARCH effect proposed by Engle (1982). It is the test that shows if the variance of the error term, given past information, is linearly dependent on the past squared errors. The null hypothesis is no ARCH errors. The alternative hypothesis is the presence of ARCH components in residuals. The results of the test presented in table 7.3 show that the null of no ARCH effect cannot be rejected for return series only. The first difference of RR can reject the null in favor of ARCH effects in residuals at 5% significance level.

It is also worth noting that the tests above were performed on 2 sub samples, the results are the same except for  $\Delta RR$ . For both of the periods RR difference time series could not reject the null of no serial correlation and the null of no ARCH effects at 1% confidence level (tables A1-A4 in Appendix).

To summarize, the results of the tests presented here shows that series of interest exhibit non-normality, the result is consistent with Dunis (2000, p.6). Further tests show that unit roots present in some of the series data, which implies the risk of spurious regression results if non-stationary series are used in the regression. This can be accounted for if cointegration is found between two non-stationary series. In addition the risk of error terms being autocorellated with

their past values and/or being dependent is also present. This is not surprising as we are working with financial time series. Using data with such properties in OLS regression requires caution. Diagnostics tests on residuals used in regressions will be conducted to check if OLS assumptions are not violated when working with testing hypotheses of the models chosen.

## 8. Results

### 8.1 Cointegration test

As discussed in Section 6, and part of the research question of this paper, the test if cointegration is conducted between EURUSD nominal exchange rates and RR levels. The EURUSD exchange rate series has unit root within the full sample period of 01/2006-04/2010. RR time series have Dickey Fuller tau statistic of -3.23 enough to reject the null of unit root at 5% significance level (critical value is -2.86) for the full sample period. However when we look at the second sub period 09/2008-04/2010 the DF tau-statistic estimated as -2.17 and the we fail to reject null of unit root at 1%, 5%, and 10% significance levels (DF critical values of -3.43; -2.86; and -2.57 respectively). As such we can proceed to test for cointegration of EURUSD and RR for this sample. The Engle-Granger test for cointegration:

1. I obtain the fitted regression  $\widehat{EURUSD}_t = 1.3889 + 0.113RR_t$   $n=87$  and save the residuals.
2. We run  $\Delta\hat{\varepsilon}_t = \varphi\hat{\varepsilon}_{t-1} + \gamma_{p-1}\Delta\hat{\varepsilon}_{t-p+1} + u_t$   $H_0: \varphi = 0$  (null of no cointegration).

<b>ADF/Engle-Granger</b>			
<b>test</b>	<b>Lags</b>	<b>tau-statistic</b>	<b>Pvalue</b>
Single Mean	0	-1.77	0.3934
	1	-1.57	0.4914
	2	-1.74	0.4102
	3	-2.13	0.2325

Table 8.1. ADF/Engle-Granger test for cointegration.  $n=87$ .

3. We compare the tau-statistic -1.77 to critical values of Engle-Granger: 1% - 3.90; 5% - 3.34%; 10% - 3.04; and fail to reject the null of no cointegration at 1% significance level.



The result is robust to augmenting the regression on residuals up to 3 lags. Based on the output I fail to reject the null of no cointegration and cannot use nominal exchange rates and RR values directly (without differencing). (Koop, 2009. p.222).

## 8.2 Currency returns and changes in risk reversals

### 8.2.1 Contemporaneous relationship

Before performing the regression of (1) I look at the scatter plot dependent and independent variables in Figure A1. Though the relationship between the two seems to be positive there is one observation that lies away from the rest. This has been discussed Data section. To check if this is outlier the Dummy variable is used for that observation and report the results of the regression separately.

The results of (1) of full sample is presented below.

$$S_t = \beta_0 + \beta_1 \Delta RR_t + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$
$s_t$	0.00076	0.2847	0.00052	0.2578	0.04391
s.e.	(.00068)	(.0168)***	(.0006)	(.0175)**	(.0106)***
NW	(.00068)	(.0365)***	{.0006}	{.026}***	{.006}***
adj.R <sup>2</sup>	0.56		0.59		
N=225					

Table 8.2.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>.  $\widehat{\beta}_2$  coeff.for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in { } represent heteroscedasticity robust standard errors. 01/2006-04/2010

Based on the results I can see that the estimated coefficient of  $\Delta RR_t$  is positive and statistically significant from zero at 1% significance level against two sided alternative with 223 df, thus rejecting the null of  $\beta_1=0$ . A 1 point positive change in volatility unit of  $\Delta RR$  price can account for 28.47% in weekly return on average all else equal. that might seem a bit unrealistic for RR to change 1 vol unit, so we are more comfortable in saying 0.01 point change in RR is associated with 0.2847% change in weekly exchange rate. Based on the size of the slope coefficient it is also economically significant. The intercept is insignificant as expected. Overall variation of  $\Delta RR_t$  can explain 56% of variation in currency returns for sample period. The relation in the model is

contemporaneous and the relationship holds for within the same point in time. Before testing the hypothesis outlined in Model section we want to perform the residual diagnostics, if they fulfill the OLS assumptions.

Residual diagnostics. Serial correlation. Since we are working with time series data we want to check if there is no serial correlation in the error terms. The Godfrey LM test is performed on the residuals and the results indicate the higher order serial correlation on 2<sup>nd</sup>, 3<sup>d</sup> and 4<sup>th</sup> lags:

Godfrey's Serial Correlation test	
Alternative	Pr > LM
AR(1)	0.7203
AR(2)	0.0116
AR(3)	0.0059
AR(4)	0.0064

In the presence of serial correlation our inference on the estimates and the significance of the estimates are not reliable. To correct for serial correlation and possible heteroscedasticity we perform the method suggested by Newey and West. Using this method and selecting 4 lags we rerun the regression and obtain heteroscedasticity and autocorrelation consistent (HAC) standard errors. The s.e. for intercept does not change, whereas s.e. for  $\Delta RR_t$  estimate changes from 0.0168 to 0.0365 as a result of the correction the standard error of the  $\widehat{\beta}_1$  increased twofold. This however does not change the significance of the coefficient from zero.

Next the regression is estimated with Dummy variable that takes value of 1 for observation no.156 and 0 for the rest observations. The estimates of the regression model are presented in the second part of the table 8.1, where the estimate  $\widehat{\beta}_2$  corresponds to the Dummy coefficient. The coefficient of the Dummy is significant from zero at 1% level indicating that this observation should be accounted for in the regression. The interpretation of  $\widehat{\beta}_2$  is that controlling for  $\Delta RR_t$ , the observation no.156 accounted for 4,3% average weekly return in the sample. The sign and significance of  $\Delta RR_t$  doesn't change however. The adj.R<sup>2</sup> has improved. The F-test for joint significance of  $\Delta RR_t$  and the Dummy coefficient rejects the null at 1% confidence level showing that that these two variables are simultaneously statistically different from zero.

Residual diagnostics. Serial correlation. The Godfrey's LM test on the regression with Dummy also shows presence of serial correlation on 2<sup>nd</sup>, 3d, and 4<sup>th</sup> lags.

Heteroscedasticity. Q and LM show presence of Heteroscedasticity. H consistent standard errors are presented in brackets { } calculated by SAS.

Normality of residuals. The Jarque-Bera test with null of residuals being normally distributed is rejected at 1% significance level for the regression with and without the Dummy.

To see if the relationship differs across subsamples the regression is run separately on each of sub-samples:

$$s_t = \beta_0 + \beta_1 \Delta RR_t + u_t$$

	01/2006-08/2008		09/2008-04/2010	
	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_0$	$\widehat{\beta}_1$
$s_t$	0.0015	0.2608	-0.00044	0.289
s.e.	(.0006)**	(.0286)***	(.0014)**	(.0242)***
NW	(.0006)**	(.0320)*	(.0014)**	(.0251)***
adj.R <sup>2</sup>	0.37		0.625	
N	138		86	

Table 8.3.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively.

The coefficients of  $\Delta RR_t$  are positive and significant at 1% significance level in both samples and take the value of 0.2608 and 0.2897 for the pre- and post-crisis period respectively. The intercept estimate  $\widehat{\beta}_0$  appear with positive sign for the first sample and takes negative sign for the second sample, moreover for both samples  $\widehat{\beta}_0$  is significant at 5% significance level.

The adj.R<sup>2</sup> for the first sample is 37.58% and increases to 62.50% for the second period. The use of Dummy in the second period sample is significant at 1% confidence level and equals 0.0465, this improves the adj.R<sup>2</sup> to 66.71%. To save space the output with Dummy is not tabulated.

The test for positive sign  $\beta_1$  with null hypothesis that  $\beta_1 \leq 0$  in both sub-samples is rejected against alternative  $\beta_1 > 0$  at 1% significance level.

Residual diagnostics. Serial correlation. Godfrey's LM test failed to reject the null of no serial autocorrelation up to AR(4) in the residuals for both samples indicating that serial correlation in the residuals of the model is not a problem. The HAC standard errors reported in the table do not differ much from OLS standard errors.

*Heteroscedasticity.* Q and LM test is cannot reject the null of no heteroscedasticity (no ARCH effect) for both of the sub samples. Once dummy is included in second sub-sample it doesn't change the result Q and LM test.

*Normality of residuals.* The JB test for the first sub-sample cannot reject the null of normal distribution in residuals at 10% significance level (p-value 0,87) indicating normality is fulfilled. The JB for the second sub sample however rejects the null of normality at 1% significance level. Including the Dummy in the second sub-sample improves the JB statistic (p value from 0,0002 to 0,0192).

Based on the test output in table 8.2 and 8.3 the initial result is that the sign of slope coefficient is positive and appears to be significant. The contemporaneous relationship between currency returns and changes in risk reversals is positive. This finding is consistent with correlation diagnostics performed in Data section, as well as finding of Jurek, Brunnermeier, Gabaix (but with opposite sign).

### 8.2.2 Predictability test

To test the predictive ability of RR on weekly  $s_t$  I estimate the distributed lag model. The lag length  $k$ . was selected following the AIC and SBC selection criteria. I started with max number of lags 8 and have found the lowest AIC and SBC (-1.219 and -1.212) using only 4th lag in the regression. Next the model is estimated and results with and without the Dummy ( $\widehat{\beta}_2$ ) for the full sample are reported below:

$$s_t = \beta_0 + \beta_1 \Delta RR_{t-4} + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$
$s_t$	0.00035	-0.064	-	-0.074	0.1043
s.e.	(.0010)	(.0259)**	(.0009)	(.0231)**	(.0137)***
NW	(.0011)	(.0286)*	{.0009}	{.0291}**	{.0012}***
adj.R <sup>2</sup>	0.023		0.23		
N=221					

Table 8.4.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>.  $\widehat{\beta}_2$  coeff.for Dummy variable. \*,\*\*,\*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in { } represent heteroscedasticity robust standard errors. 01/2006-04/2010

As expected the intercept estimate is not significant. However the  $\widehat{\beta}_1$  appears with negative sign and is significant from zero at 5% significance level on a two sided alternative. This result contrasts with estimate when examined contemporaneous regression (Table 8.2) where it was positive estimate of  $\widehat{\beta}_1$ . It should also be noted that when considered the order of lags to be estimated all weekly lags of  $\Delta RR_t$  appeared with negative sign. The overall significance of the results measured by  $\text{adj.}R^2$  is only 2.3%. meaning that the variation in  $\Delta RR_{t-4}$  can explain less than 3% of variation in  $s_t$ . The interpretation of the coefficient 0.01 increase in  $\Delta RR$  can explain 0.064% depreciation EURUSD 4 periods later. The economic significance of the coefficient estimate is also reduced. But the fact that weekly appreciation of EURUSD is associated with puts getting more expensive 4 periods later (as if markets expecting a depreciation and thus bidding up put prices) is more relevant in the context of research questions posed by Brunnermeier, Jurek and Gabaix, that as currencies appreciate that could be due to increased risk premia required by investors.

When the dummy variable is used for the observation in December 17th the estimate the regression the intercept appears non significant albeit negative, the  $\widehat{\beta}_1$  is reduced but still is negative and significant at 5% level. The dummy coefficient takes on value 0.1043 and is significantly different from zero at 1% level. can interpret the estimate of  $\widehat{\beta}_3$  similarly, holding the  $\Delta RR_{t-4}$  constant, the observation week with Dummy accounted for weekly return in st of 10.4%.

The model with first two lags was also been analyzed, but had to be dropped due to insignificance of the both slope coefficient from zero based on joint F-test.

Residual diagnostics. *Serial correlation.* Godfrey's LM test did not show presence of serial correlation in residuals on all 4 lags for both models (including and excluding the dummy).

*Heteroscedasticity.* The LM test for ARCH disturbances cannot reject null of homoscedasticity in the residuals for model without the Dummy. But when Dummy is included the LM test for ARCH disturbances rejects the null of homoscedasticity at 10% significance level with p-value of 0.073:

Q and LM Tests for ARCH Disturbances				
Order	Q	Pr > Q	LM	Pr > LM
1	32,088	0.0732	32,097	0.0732
2	111,745	0.0037	101,717	0.0062

The Heteroscedasticity standard errors are thus reported in the Table 8.4.

*Normality of residuals.* The JB test rejects normality of residuals at 1% significance level for regression with and without Dummy.

### 8.2.3 Robustness check

It is interesting to get the negative coefficient for the lag of  $\Delta RR_{t-4}$ . I would like to check if this result is robust to the estimation of the RR variable and/or sampling of the data. In the Data section we used 1 month maturity RR contract and scale it to weekly values by dividing the RR by square root of 52. One way to test if the results differ when different maturity of RR is used, is to take 1 week maturity Risk Reversal contract, which is available daily, sample it into weekly frequency and perform the same regression. The number of observations remain the same.

$$s_t = \beta_0 + \beta_1 \Delta RR_{t-4} + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$
$s_t$	0.00038	-0.0395	0.000	-0.0489	0.104
s.e.	(.0010)	(.0203)*	(.0009)	(0.018)***	(.0137)***
NW	(.0011)	(.0189)*	{.0009}	{.0204}**	{.00137}
adj.R <sup>2</sup>	0.017		0.215		
N=221					

Table 8.5. Robustness check on RR using 1 week maturity.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>.  $\widehat{\beta}_2$  coeff.for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in {} represent heteroscedasticity robust standard errors. 01/2006-04/2010

The intercept and its s.e. is roughly the same. The value of the slope coefficient is less which might be the result of scaling but its sign is negative, the s.e. is not far different from the previous regression. The sum of squared errors for monthly and weekly maturity contract is equal to 0.051 and 0.05166 respectively. More importantly the behavior of the residuals judging by the results of the Godfrey's serial correlation test is similar to the first regression (no serial correlation. Also similar results for ARCH LM test and Jarque-Bera test). Lastly the data is sampled monthly and I obtain 50 monthly observations of currency returns and 1 lagged changes in RR with first

month (so first observation month March and the last is April 2010 included). The result of the OLS regression recovered the negative sign of the slope estimate but it turned out to be not significant from zero. I do not report the results here to save space.

#### 8.2.4 The Chow test for structural break

I would like to test if the relationship between the weekly currency return  $s_t$  and fourth lag of  $\Delta RR_t$  has changed and is different between two sub-samples namely 04/01/2006 – 27/08/2008 and 03/09/2008 – 28/04/2010:

$$s_t = \beta_0 + \beta_1 \Delta RR_{t-4} + u_t$$

	04/01/2006-27/08/2008		03/09/2008-28/04/2010	
	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_0$	$\widehat{\beta}_1$
$s_t$	-0.0014	-0.0607	-0.000808	-0.088
s.e.	(.00086)*	(.0387)	(.0022)	(.0386)**
NW	(.00095)	(.0392)	(.0023)	(.0250)***
adj.R <sup>2</sup>	0.01		0.05	
N	134		82	

Table 8.6.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively.

Residual diagnostics. *Serial correlation.* Godfrey's LM test do not show signs of serial correlation in the residuals up to AR(4) on both sub-periods.

*Heteroscedasticity.* The Q and LM test for ARCH disturbances doesn't indicate the heteroscedasticity on both samples.

*Normality of residuals.* The JB test of normality in residuals doesn't reject the null of normality on first and second sub-samples (JB p-values 0.12 and 0.90 respectively).

Next we perform the Chow test for structural break:

1. 3 Sum of Squared Errors, one on each of the sub samples avoiding overlapping and one on the full sample period are collected:

$$- \text{SSE}_1 = 0.0132; \text{SSE}_2 = 0.0323; \text{SSE}_{\text{full}} = 0.0511;$$

2. The Chow statistic is calculated using the formula:  $F_{k,(n_1+n_2-2k)} = \frac{(\text{SSE}_{\text{full}} - \text{SSE}_1 - \text{SSE}_2)/k}{(\text{SSE}_1 + \text{SSE}_2)/(n_1 + n_2 - 2k)}$ ;

3. The null of no structural change in intercept and slope  $\beta_{01}=\beta_{02}$ ; and  $\beta_{11}=\beta_{12}$  has 2 restrictions (k) and  $n_1=134$   $n_2=82$  ;
4. The estimated Chow statistic is 11.73 and the corresponding  $F$  statistic with 2, 212 df at 5% critical value is far less than the estimated value thus we reject the null of no structural break in the period. In fact we can reject the null even at 1% critical level.

One important point to note, is that Chow test assumes that the variance within the sample is the same, i.e. homoscedastic (Woolridge, 2009, p.450). The Q and LM tests for ARCH disturbances performed on each of the sub samples as well as full sample showed that the null of no conditional heteroscedasticity cannot be rejected, thus supporting the use of Chow test.

The results obtained clearly indicate that in the model estimated both the intercept and the slope parameters shifted through time. This is not surprising result given the state of the world after fall 2008.

### 8.2.5 Risk Reversals against Random walk

The model  $s_t = \beta_0 + \beta_1 \Delta RR_{t-4} + u_t$  is chosen against random walk model  $Y_t = Y_{t-1} + u_t$ . The estimation of the model will be performed including the dummy to account for an outlier in the sample. The results are performed below:

RMSE_diff	0.024885
RMSE_randomwalk	0.023429
RMSE Ratio	1.062156

Based on 16 weekly out of sample observations used, forecasting EURUSD returns using model selected could not outperform the Random Walk model on one step ahead forecasts.

To summarize this part of test it can be said that on the sample period used the results of contemporaneous relationship test are consistent with previous research. The positive coefficient implies that as currency returns are getting positive the market expects positive implied skewness 1 week ahead (RR measure of expected skewness  $t+m$  ahead, with  $m$  being maturity of the contract). When used on 4<sup>th</sup> lag of  $\Delta RR$ , coefficient is negative meaning 4 periods after the appreciation the markets 1 period ahead expectation of skewness is negative. Does it take for market to realize that currency move is overdone only 4 period later? Not necessarily, since all



lags appeared with negative sign there is some sort of negative relationship. But the author doesn't have enough evidence to support this result.

### 8.3 Uncovered Interest rate parity and Risk Reversals

#### 8.3.1 UIP test

Following the discussion in Section 6, next UIP regression is preformed on weekly currency return:

$$s_t = \beta_0 + \beta_1(i_d - i_f)_{t-1} + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$
$s_t$	-0.000135	5.36	-		0.104
s.e.	(.0010)	(3.74)	(.00099)	(3.35)**	(0.01377)***
NW	(.0011)	(4.09)	{.0010}	{3,46}**	{.0018}***
adj.R <sup>2</sup>	0.0046		0.20		
N	225		225		

Table 8.7. UIP test.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>.  $\widehat{\beta}_2$  coeff.for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in { } represent heteroscedasticity robust standard errors. 01/2006-04/2010

UIP in  $s_t$  specification has the null  $H_0: \beta_0=0, \beta_1=1$ . the intercept is not significant from zero at 1% significance level. To test if  $\beta_1=1$  against alternative  $H_a: \beta_1 \neq 1$  we calculate the t statistic for  $\widehat{\beta}_1 = \frac{5.36-1}{4.09} = 1.165$ . with 225-2 degrees of freedom the two sided critical value at 5% significance level is 1.96 and larger than our test statistic thus we fail to reject the null and conclude that UIP holds for the sample period of 01/2006-04/2010 for the EURUSD. This is one of the most surprising result in this paper however the value of adj.R<sup>2</sup> is less than 0.5%.

Residual diagnostics. *Serial correlation.* Judging by Godfrey's LM the null of no serial correlation cannot be rejected on 1<sup>st</sup> and 2<sup>nd</sup> lags but can be rejected on 3<sup>d</sup> and 4<sup>th</sup> order lags with 10% confidence. The t-test is reestimated using NW standard errors. The conclusion of the test doesn't change.

*Heteroscedasticity.* Q and LM tests do not show presence of ARCH effects in the residuals.

Normality test. The JB test rejects the null of normality in residuals at 1% significance.

Similar regression but with Dummy variable included is reported in the right hand side of the table. The  $\beta_1$  and  $\beta_2$  coefficients are significantly different from zero at 5% and 1% levels respectively. The t-statistic for the null of UIP is calculated equal to 1.95, with 225-3 df, we cannot reject the null at 5% significance level (critical value is 1.96) but the null of UIP can be rejected at 10% significance level (critical value is 1.658).

The sign of  $\widehat{\beta}_1$  in regression with Dummy is positive, which means that “forward premium puzzle” or contradictory appreciation of high interest rate currency against its low counterpart is not evident from the sample we are using. However it is not clear whether this sign is a result of sample period choice that takes on the August of 2008, when most probably the market’s perception of expected depreciation of high yielding currencies was very high.

Also note that the level of interest differential the sample is given in basis points (0.0001 = 1 bp), that is 1 bp. change in weekly interest differential, all else equal, is associated with 0.0536% weekly return.

### 8.3.2 Augmenting UIP with Risk Reversals

After performing standard UIP regression I proceed and include the lagged RR to the model (3). The OLS results for full sample period is presented in Table 8.8.

$$s_t = \beta_0 + \beta_1(i_d - i_f)_{t-1} + \beta_2 RR_{t-1} + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_4$
$s_t$	-0.00023	6.96	-0.01324	-0.00062	8.35	-0.0068	0.104
s.e.	(.0011)	(4.1)	(0.0140)	(.00099)	(3.67)**	(.0125)	(0.01382)***
NW	(.00124)	(4.38)	(0.0191)	{.0010}	{3.88}**	{.0137}	{.0020}***
adj.R <sup>2</sup>	0.0042			0.20			
N	225			225			

Table 8.8. UIP test with  $RR_{t-1}$  as additional explanatory variable.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>.  $\widehat{\beta}_4$  coeff. for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in {} represent heteroscedasticity robust standard errors. 01/2006-04/2010.

From the output above we can see that inclusion of the lagged RR into UIP do not improve the overall significance and predictability of currency returns judging by the adj.R<sup>2</sup> of less than 1%.

The intercept and the coefficient of lagged RR appears not different from zero at 1% significance level. Looking at the  $\widehat{\beta}_2$  one can also note that the OLS standard error is larger than the estimate of the slope itself, which points to its low statistical and economic significance. In output with Dummy  $\widehat{\beta}_2$  increases but the standard error do not change much.

The F test for joint significance with null that all slope coefficients are simultaneously equal to zero cannot be rejected (p value < 0,92) at conventional significance levels.

When the Dummy variable is included, the coefficient  $\widehat{\beta}_4$  in the second part of the table 8.8 takes on familiar value of 0.104 and is significant at 1% level. The coefficient for the lagged interest rate differential becomes significant at 5% level and is increased from 6.96 to 8.35. the adj.R<sup>2</sup> of the resulting regression has improved to 20%. We perform the UIP test for the null of

$H_0 \beta_1=1$  against  $H_a \beta_1 \neq 1$

$$t \text{ value } \widehat{\beta}_1 = \frac{8.35-1}{3.88} = 1.89$$

with 225-4 degrees of freedom the 5% significance level in the table corresponds to 1.96 and we cannot reject the null of UIP in favor of alternative hypothesis.

Residual diagnostics. Serial correlation. Godfrey's LM test results do not support the presence of serial correlation at 1<sup>st</sup> and 2<sup>nd</sup> lags (pr>LM is 0,89 and 0,86 respectively) and not significant at 10% significance level for 3<sup>d</sup> and 4<sup>th</sup> lags of residuals (pr>LM 0,06 and 0,09). For the robustness of the results we compute Newey-West HAC (at 4 lags) and report them in the table. Dummy doesn't change the conclusion on the presence of serial correlation supported by Godfrey's LM test.

*Heteroscedasticity.* Q and LM test for ARCH effects fail to reject the null of no ARCH.

*Multicollinearity.* Variance inflation factor is 1,2047 for both independent variables and is in line with accepted rules, usually VIF above 5 and 10 points to presence of severe multicollinearity issues.

*Normality of residuals.* The JB test rejects the null of normality at 1% significance level, even when the Dummy is included.

To see if the results change with the sample data I will perform the similar test on the period before the fall of 2008: 01/2006- 08/2008.

The results of the regression are presented in the table below

$$s_t = \beta_0 + \beta_1(i_d - i_f)_{t-1} + \beta_2 RR_{t-1} + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$
$s_t$	0.000137	8.09	-0.05068
s.e.	(.0010)	(3.97)**	(0.0245)**
NW	(.0012)	(4.62)*	(0.0249)**
adj.R <sup>2</sup>	0.021		
N	138		

Table 8.9. UIP test with  $RR_{t-1}$  as additional explanatory variable.  $s_t$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R<sup>2</sup> – adjusted R<sup>2</sup>.  $\widehat{\beta}_4$  coeff. for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. sample period 01/2006-08/2010.

The slope coefficient is still not significant as expected. The  $\widehat{\beta}_1$  coefficient is positive and different from zero at 10% significance level using Newey-West HAC standard errors with 4 lags.

The test of UIP cannot reject the null at 5% level supporting previous results. The  $RR_{t-1}$  coefficient appears to be significant in the sample. The size of the estimate is increased, even though the sign has not changed.

The F test for joint significance of the slope coefficients rejects the null at 10% significance level (p value 0.08), so we can say with 90% confidence that the slope coefficients are jointly significant from zero. Overall the variation in interest differential and RR lags explained around 2.1% in variation of  $s_t$  judging by adj.R<sup>2</sup>.

Residual diagnostics. *Serial correlation.* Godfrey's LM test does not show presence of serial correlation on 4 lags. This has not been the case when full sample was used (with and without dummy).

*Heteroscedasticity.* Q and LM test are fail to reject the null of no ARCH effects in residuals.

*Multicollinearity.* Variance inflation is 1,68 and doesn't indicate presence of severe multicollinearity.

*Normality of residuals.* The Jarque-Bera test for normality of residuals cannot reject the null of normal distribution (p value 0.126) at 10% significance level.

Overall it seems that UIP test performed better in the first sample, supported by the residuals in line with OLS assumptions.

## **8.4 Analysis**

Briefly after concluding that cointegration might not be the one governing the relationship between risk reversals and EURUSD exchange rates the focus moved to using differenced time series. The results we have obtained are consistent with previous empirical works outlined in Section 5. that contemporaneous positive relationship between changes in RR and current returns exist. And for the period studied positive change in risk reversals could explain the appreciation of EUR against USD within the same period. This relationship has intensified after the crisis, based on increased slope coefficients for two separate sub-samples. Both the results from tests show increased slope coefficient and the increased power of the test. This can be related to the events of fall 2008 where the “safe haven” flows lead to unwinding of carry trades and market players where actively purchasing protection against further depreciation - the price of put options for example in EURUSD increased dramatically. And it can be assumed that in such tense environment, where periods of depreciation of EURUSD followed periods of further depreciation the change in RR could follow similar pattern.

Next the focus turned to using past information on RR changes in order to investigate the predictive ability on EURUSD. The first point that requires attention is the negative sign of past changes in RR on current currency returns (Table 8.4). If positive changes in RR was found to lead to EURUSD depreciation several periods later and vice versa, that could indicate that currencies that had most negative risk reversals were in fact first candidates for appreciation, this is consistent with Brunermeier et al. (2007) that found that after a crash in the market, the investors are willing to pay the high price for insurance against future crash where the probability of the crash happening again is very low. I would also like to add that not only there is willingness to Buy the insurance by participants, there is also reluctance of option dealers to

decrease the price because the “tail” event probability and uncertainty about future. Which is what reflected in RR time series for the period of fall 2008. Sharp drop in EURUSD RR and subsequent sharp increase along with EURUSD. To my knowledge the reason in better performance of the 4<sup>th</sup> lag in  $\Delta RR$  is not clear compared to other lags. The test has been done on monthly sampling and 1 month lag used to proxy for 4<sup>th</sup> lag on weekly sampling. Even though the negative sign was recovered, the significance of the monthly lag was not different from zero. The check has also been done on weekly sampled 1 week maturity RRs. There was no obvious difference compared to initial result (Table 8.5). To confirm statistically that two chosen samples differ in level of slope and intercept the Chow test has been performed. The interesting result is that intercept of the first sub sample appears significant and not so in the second sample period and opposite is true if slope coefficient. If the significance of 4<sup>th</sup> lag  $\Delta RR$  only showed up in the second sample, the significant coefficient of intercept in the first sample can be argued in favor of this explanatory variable having little economic significance should the events in 2008 never happened.

The next area of research was related to UIP tests. The most surprising was to obtain positive sign of the interest rate differential. In UIP literature it's the negative sign that is called “forward premium puzzle”. However the explanatory power of the results do not deserve much attention (Table 8.7). However empirical evidence exist (Bhansal and Dahlquist 1999) that found that the rejection of UIP is mostly for cases when US interest rates are higher than foreign interest rate differ from its counterpart for a wide margin rates. For the second sample of the data the interest differential was in favor of EUR. So our positive slope of UIP is consistent with authors. However the result for first sample also estimated positive slope of interest differential coefficient in UIP test. Contrary to that, Gabaix has negative slope for interest differential and negative for RR. This result could be attributed to the sample size where for example Gabaix uses period of 1996 and 2008, my sample is 01/2006 and 08/2008. Nevertheless I managed to recover the negative slope of UIP test only when excluded August 2008 in the first subsample. The overall result shows that the estimates of the regression are very sensitive to the period tested and do not provide consistent significant results. So the results of the test have to be interpreted with caution.

Assuming that UIP held, in the first sample (Table 8.9), based on the slope coefficient what can be said about the role lagged RR? According to our a priori expectations and as defined in Jurek

(2009) the RR is expected to predict currency return with a negative sign if RR represents the proxy for market “crash risk”. The result obtained supports the expectation, and it is checked against currency excess returns (Appendix. Table2) and the results do not differ in sign. However, as in the case with lagged differences, the past value of RR does not account for much of the variation in currency returns. Nevertheless it has been shown that as far as the first sample period is concerned the relationship between currency returns and past values of interest rate differentials, and risk reversals accounts for more compared to the whole sample tested (table 8.9 and table 8.9). The reason of this could be due to the state of the global financial markets in 2008. Kohler (2010) in the BIS Quarterly review reports that the events of the fall 2008 were characterized by global risk aversion and repatriation of capital in to *safe haven* currencies Japanese Yen, Swiss Franc and US dollar (Ranaldo et.al. 2007). The EURO on the other hand experienced depreciation also because of concerns of in its banking sector. So could it be that the model used in this thesis omitted other important variables? The answer is most likely – yes. Even though the UIP augmented with RR is expected to take into account the presence of time varying risk premium and the investors’ expectations about currency directional moves the model seems to be too simplistic based on the results of the fit for the full period. For example Brunnermeier (2009) used additionally the VIX index that traces risk aversion among investors in US equity market, and the futures positions of speculative investors in foreign currency futures on Chicago exchange. One cautionary note should be stated however, suggested by Ballie and Bollerslev (1997) and quoted from Jurek (2009, p5): *as interest rate differential is highly persistent, the standard asymptotic distribution of the slope coefficient in the UIP regression is a very poor approximation of its small sample counterpart. For this reason most of the research has been done on pooled data.* Not very positive comment for UIP regressions in this paper that use only single currency pair EURUSD is used.

## 9. Conclusion

The research question of this paper was aimed to investigate if currency returns, namely EURUSD, can be predicted using of information contained in options market.

For this purpose the markets best “guess” on future direction of the currency move, Risk reversal, has been chosen as explanatory variable. The choice of risk reversals was justified by the fact that it is commonly used by several central banks to assess the market’s expectations from practical perspective as well as it has been the subject of extensive empirical research in the recent past.

The results of the econometric tests have shown that that strong positive relationship exist between EURUSD currency returns and changes in EURUSD risk reversals on contemporaneous basis weekly basis. But when past values of risk reversals are used to explain future returns the explanatory power is very limited. This is also confirmed by out of sample forecast accuracy test where the changes in RR based forecasts of EURUSD could not beat simple Random Walk model.

Next the EURUSD Risk Reversals were used in the framework of uncovered interest rate parity to see if it account for as a proxy for time varying risk premium and help to explain the expected exchange rate changes conditional on interest rate differential. The result showed that for the full sample examined the inclusion of the RR appear with negative sign in the UIP consistent with Fama (1984), that covariance of time varying risk premium and expected exchange rate changes is negative, however the RR do not add explanatory power on UIP regression in the sample period to explain the EURUSD returns.

These findings are consistent with Dunis (2000) and Brunnermeier (2008), Gabaix (2009), Jurek (2009) who found similar results for daily and monthly and quarterly observations on other exchange rate currencies as well as in portfolios of currencies.

Possible explanation for the low predictability of Risk Reversals in chosen specifications can be attributed but not limited to several factors:

- RR is a poor measure to account for time varying risk premium.
- The sample chosen for test exhibits the event of severe crisis, and the short sample period chosen is affected by these events. RR could be impacted by risk aversion in 2008.



- The model is not completely specified with explanatory variables chosen (potentially omitted explanatory variables).
- The persistence in interest rate differentials, especially after the crisis in 2008 effects the slope coefficient in UIP regression.
- The linear model chosen does not take well into account the variance of exchange rate returns (Malz, 1997) compared to ARCH family models.

Like Dunis (2000) I found reasons to reject “informational content” in RR in explaining future EURUSD returns, but only based on methods, data set and sample period chosen in this paper.

Overall on the results obtained I find that risk reversals are still useful in obtaining information on market expectations at current point in time and will gain more attention in coming future. However caution is advised in investment decisions based solely on Risk Reversals.

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*BIS Quarterly review, June 2010*, This publication is available on the BIS website ([www.bis.org](http://www.bis.org)).

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*Triennial Central Bank survey, Foreign Exchange and Derivatives Market activity in April 2010*,

This publication is available on the BIS website ([www.bis.org](http://www.bis.org) ).

Data bases.

Thomson Reuters Datastream

Bloomberg L.P.

Online resources.

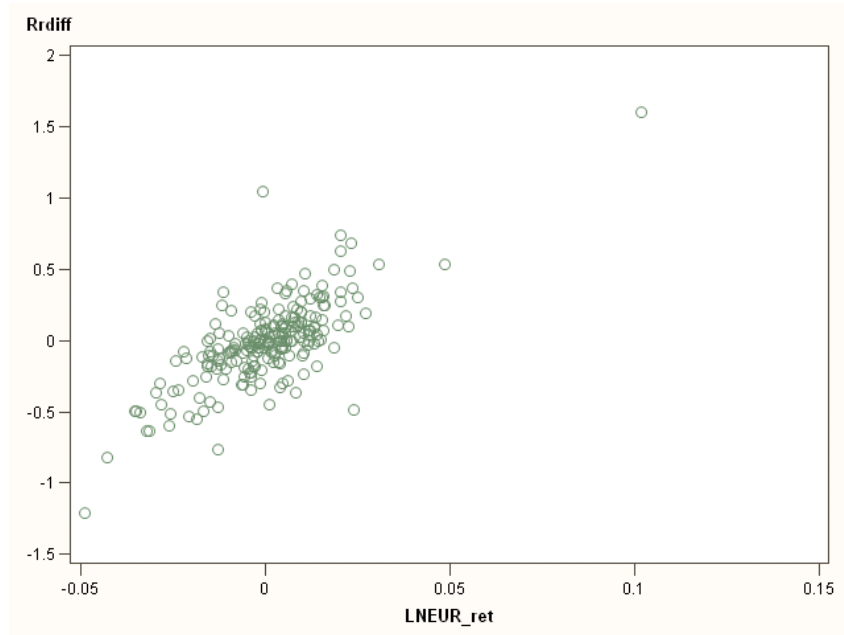
[www.saxobank.com](http://www.saxobank.com)

[www.wikipedia.org](http://www.wikipedia.org)

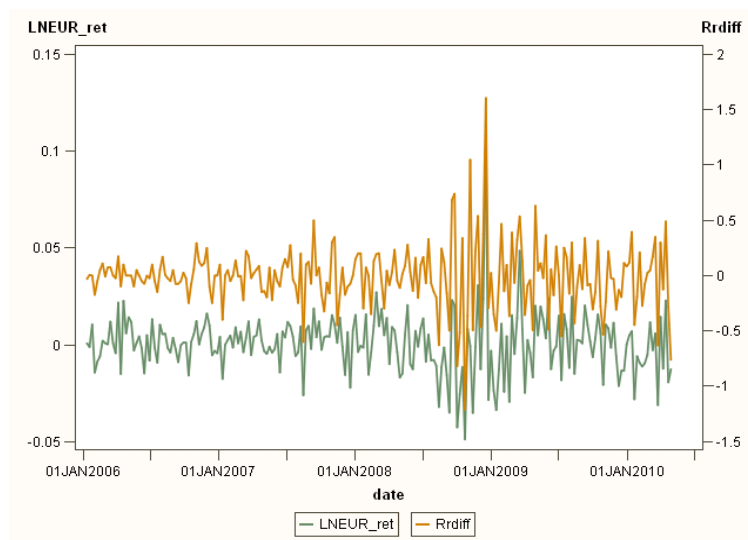
[www.ssrn.com](http://www.ssrn.com)

## APPENDIX

FigureA1. Plot of RR differenced series on Y axis and EURUSD log differences on X axis.



FigureA2. Time series of first difference in RR (right scale) and log difference in EURUSD (left scale).



1. Summary statistics for separate sub samples.

01/2006- 08/2008	EURUSD	$s_t^*$	$xs_t^*$	<i>id-if</i>	ATMvol	RR	Butterfly	$\Delta RR$
Mean	1.37	0.07	0.07	0.01	7.83	0.23	0.17	0.00
std.dev	0.12	0.07	0.07	0.01	1.70	0.17	0.06	0.04
skewness	0.44	-0.37	-0.34	-0.91	0.11	-0.19	0.70	0.49
kurtosis	-0.98	0.55	0.52	-0.65	-0.94	0.79	-0.69	5.56
Max	1.59	0.03	0.03	0.02	11.85	0.70	0.30	0.22
Min	1.19	-0.03	-0.03	-0.02	4.73	-0.23	0.10	-0.17
SW test	0.97	0.91	0.91	0.93	0.84	0.92	81.90	0.93

TableA1. Descriptive statistics for EURUSD weekly data from 01/2006-08/2008. n=139 (138 for  $s_t$ ,  $xs_t$  and RR diff). \* - means and st.dev are annualized for  $s_t$ ,  $xs_t$ . Min/max values represent weekly data. Id-if is difference between annualized rd and rf.  $\Delta RR$  is differenced RR. SW test – ShapiroWilk test for normality, all t-stats in table are significant at 1% significance level. Mean, skewness, kurtosis, st.dev are calculated via SAS. Source Bloomberg and DataStream.

09/2008- 04/2010	EURUSD	$s_t^*$	$xs_t^*$	<i>id-if</i>	ATMvol	RR	Butterfly	$\Delta RR$
Mean	1.38	-0.05	-0.05	-0.01	14.44	-0.43	0.38	-0.02
std.dev	0.07	0.15	0.15	0.01	4.62	0.78	0.18	0.42
skewness	-0.06	1.14	1.15	-1.16	0.94	-0.17	1.05	0.54
kurtosis	-0.90	5.34	5.52	0.05	-0.34	-1.19	-0.32	2.18
Max	1.51	0.10	0.10	0.00	26.25	0.95	0.80	1.61
Min	1.25	-0.05	-0.05	-0.02	9.05	-2.20	0.19	-1.21
SW test	0.98	0.92	0.92	0.79	0.86	0.95	0.81	0.08

TableA2. Descriptive statistics for EURUSD weekly data from 09/2008-04/2010. n=87 (86 for  $s_t$ ,  $xs_t$  and RR diff). \* - means and st.dev are annualized for  $s_t$ ,  $xs_t$ . Min/max values represent weekly data. Id-if is difference between annualized rd and rf.  $\Delta RR$  is differenced RR. SW test – ShapiroWilk test for normality, all t-stats in table are significant at 1% significance level. Mean, skewness, kurtosis, st.dev are calculated via SAS. Source Bloomberg and DataStream.



01/2006-08/2008	EURUSD	$s_t$	$xs_t$	id-if	ATMvol	RR	Butterfly	$\Delta RR$
<b>Unit root Test</b>								
ADF tau (single mean)	-1,07	-11,35	-11,39	1,44	-1,63	-3,04	-1,44	-12,1
p value	0,7274	0,0001	0,0001	0,99	0,4629	0,0344	0,56	0,0001
<b>Serial correlation</b>								
Godfrey LM test	135,17	0,0766	0,1644	137,7	124,97	54,736	129,47	0,252
p value	0,0001	0,782	0,6852	0,0001	0,0001	0,0001	0,0001	0,6157
<b>ARCH effects</b>								
ARCH-LM	126,03	0,0282	0,1132	137,21	95,02	102,02	94,81	0,495
p value	0,0001	0,8665	0,7365	0,0001	0,0001	0,0001	0,0001	0,4817

TableA3. Augmented Dickey Fuller test, null of unit root. Godfrey LM test null of no serial correlation. ARCH-LM test for ARCH effects, null of no ARCH. n=137 Authors calculation via SAS. Sample 01/2006-08/2008. Source of input data DataStream, Bloomberg.

09/2008-04/2010	EURUSD	$s_t$	$xs_t$	id-if	ATMvol	RR	Butterfly	$\Delta RR$
<b>Unit root Test</b>								
ADF tau (single mean)	-1,99	-9,65	-9,65	-1,86	-1,72	-2,17	-1,15	-10,68
p value	0,2891	0,0001	0,0001	0,3497	0,41	0,2177	0,6921	0,0001
<b>Serial correlation</b>								
Godfrey LM test	71,52	0,1629	0,1644	76,81	75,67	63,77	81,9	2,34
p value	0,0001	0,6865	0,6852	0,0001	0,0001	0,0002	0,0001	0,1254
<b>ARCH effects</b>								
ARCH-LM	53,28	0,1164	0,1132	57,041	41	13,76	74,5	0,1521
p value	0,0001	0,73	0,7365	0,0001	0,0001	0,0001	0,0001	0,6965

TableA4. Augmented Dickey Fuller test, null of unit root. Godfrey LM test null of no serial correlation. ARCH-LM test for ARCH effects, null of no ARCH. n=87 Authors calculation via SAS. Sample 09/2008-04/2010. Source of input data DataStream, Bloomberg.

2. UIP test augmented with  $RR_{t-1}$  using excess returns as dependent variable.

$$xs_t = \beta_0 + \beta_1(i_d - i_f)_{t-1} + \beta_2 RR_{t-1} + u_t$$

	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_4$
$xs_t$	-0.00023	5.96	-0.0133	-0.00061	7.35	-0.0068	0.104
s.e.	(.0011)	(4.10)	(0.01405)	(.00099)	(3.67)**	(.0125)	(0.01382)***
NW	(.00124)	(4.38)	(0.0191)	.00010	3.88	.0137	.0020
adj.R <sup>2</sup>	0.0042			0.20			
N	225			225			

TableA5. UIP test with  $RR_{t-1}$  as additional explanatory variable.  $xst$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R2 – adjusted R2.  $\widehat{\beta}_4$  coeff.for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in {} represent heteroscedasticity robust standard errors. 01/2006-04/2010

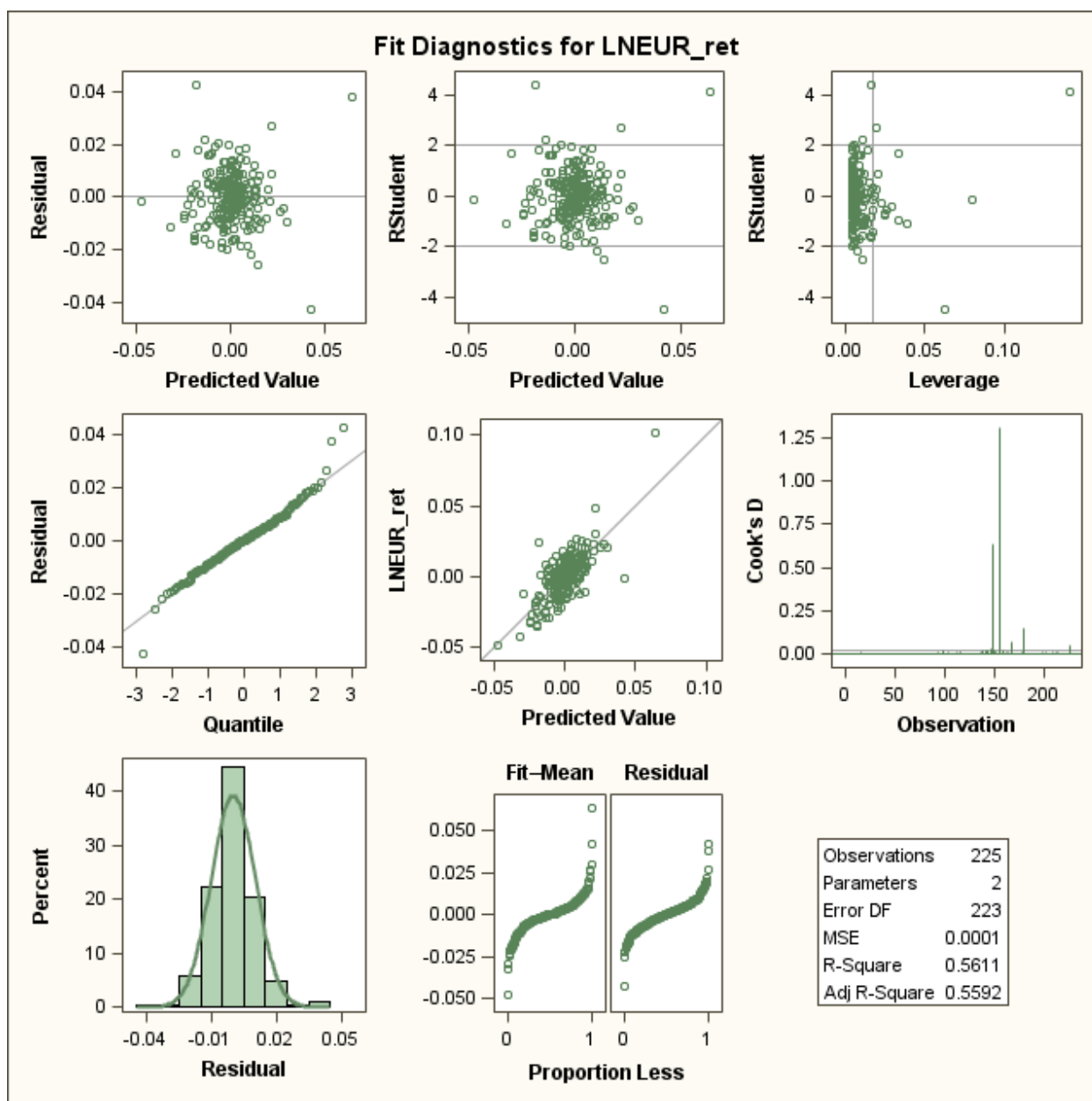
3. UIP test augmented with  $RR_{t-1}$  using EURSD log difference as dependent variable and RR from 1 week maturity contract.

$$s_t = \beta_0 + \beta_1(i_d - i_f)_{t-1} + \beta_2 RR_{t-1} + u_t$$

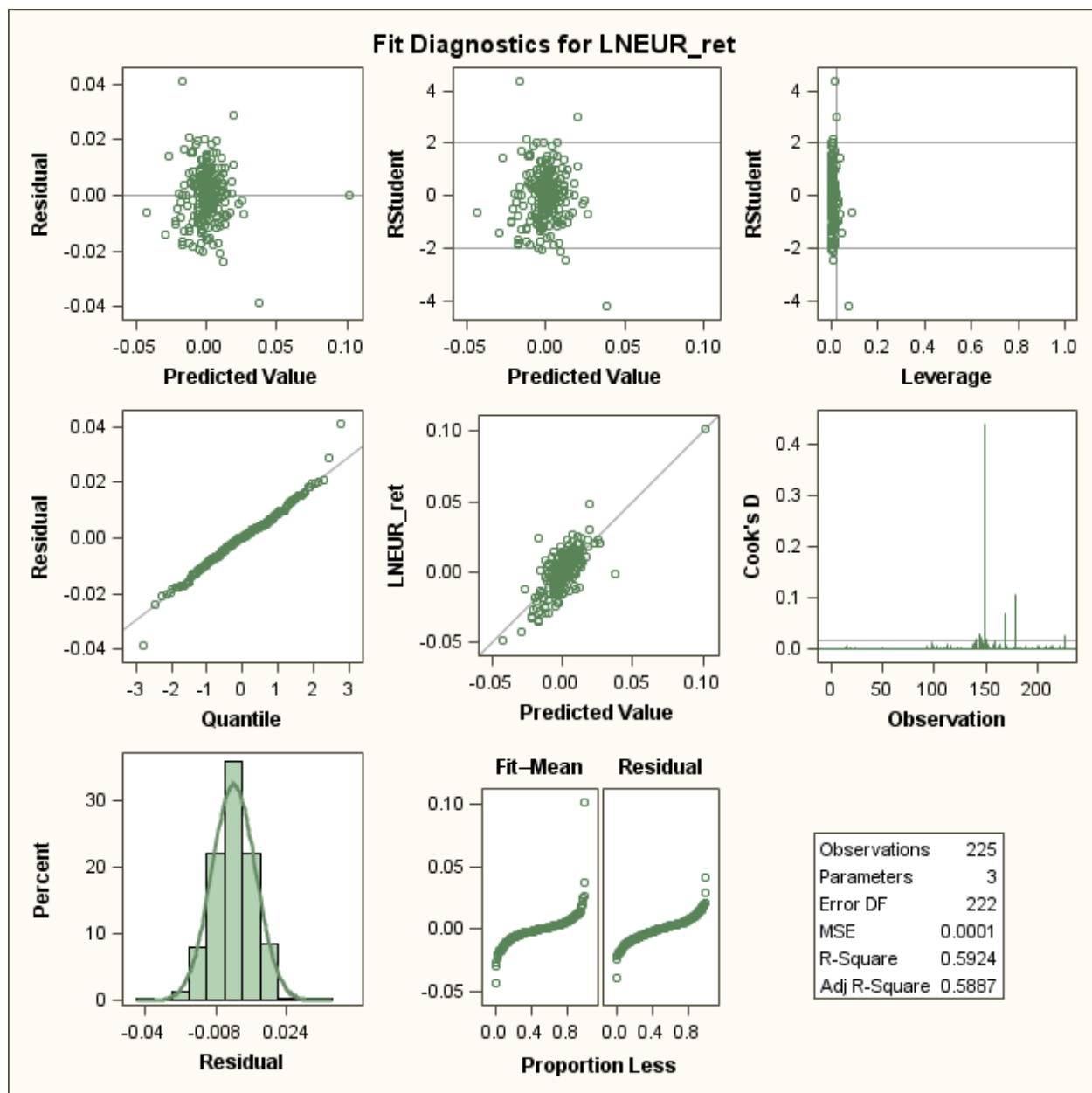
	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_4$
$s_t$	-0.00009	6.34	-0.0094	-0.00057	8.14	-0.0059	0.104
s.e.	(.0011)	(4.01)	(0.0140)	(.00097)	(3.59)**	(.0125)	(0.0138)***
NW	(.00124)	(4.38)	(0.0191)	{.0010}	{3.78}**	{.0137}	{.0019}***
adj.R <sup>2</sup>	0.0023			0.20			
N	225			225			

TableA6. UIP test with  $RR_{t-1}$  as additional explanatory variable.  $st$  – dependent variable. s.e. – OLS standard errors. NW – Newey-West HAC standard errors with 4 lags. adj.R2 – adjusted R2.  $\widehat{\beta}_4$  coeff.for Dummy variable. \*, \*\*, \*\*\* denotes statistical significance on 10%, 5%, 1% level respectively. figures in {} represent heteroscedasticity robust standard errors. 01/2006-04/2010

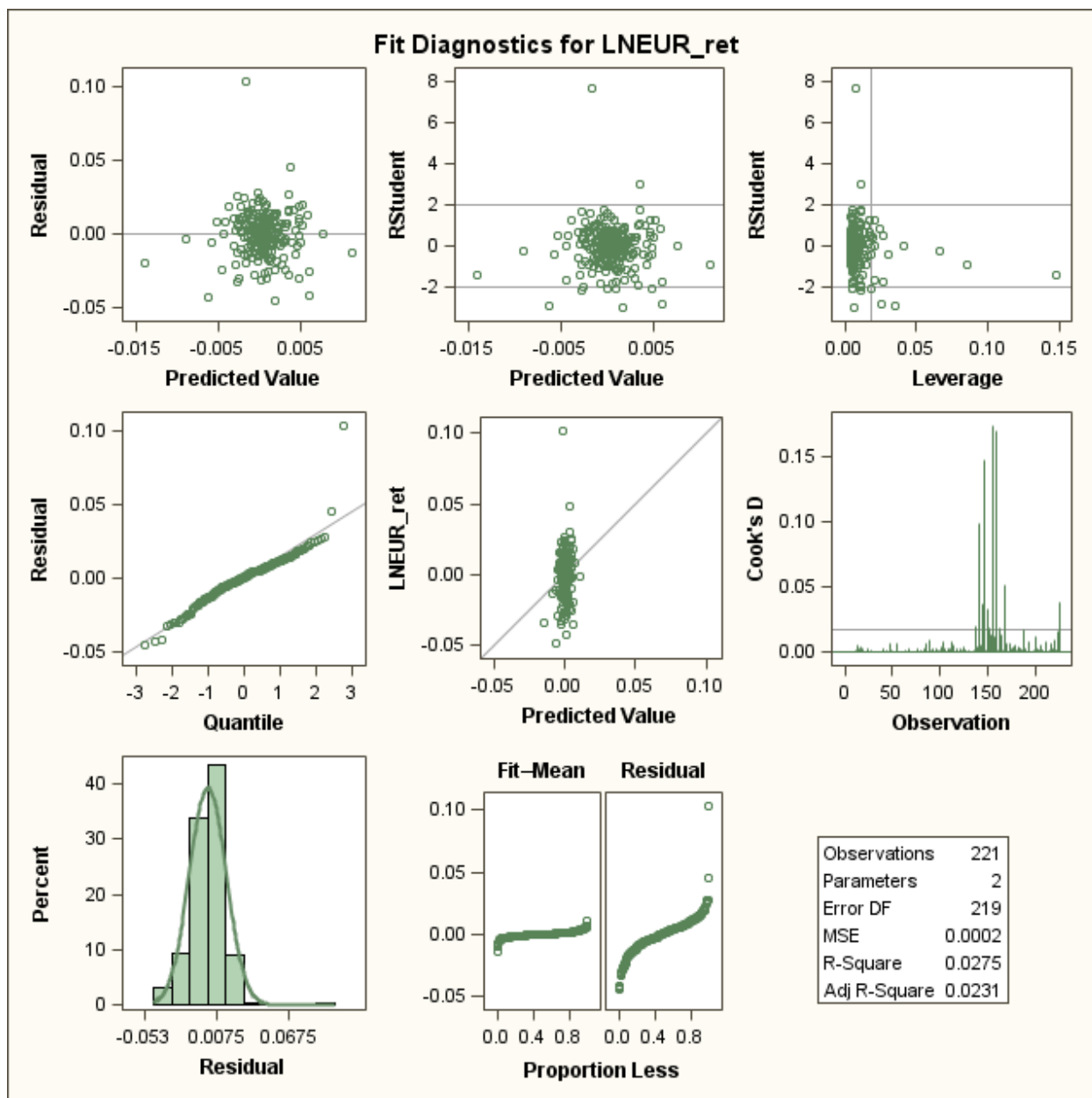
#### 4. Residual Fit diagnostics.



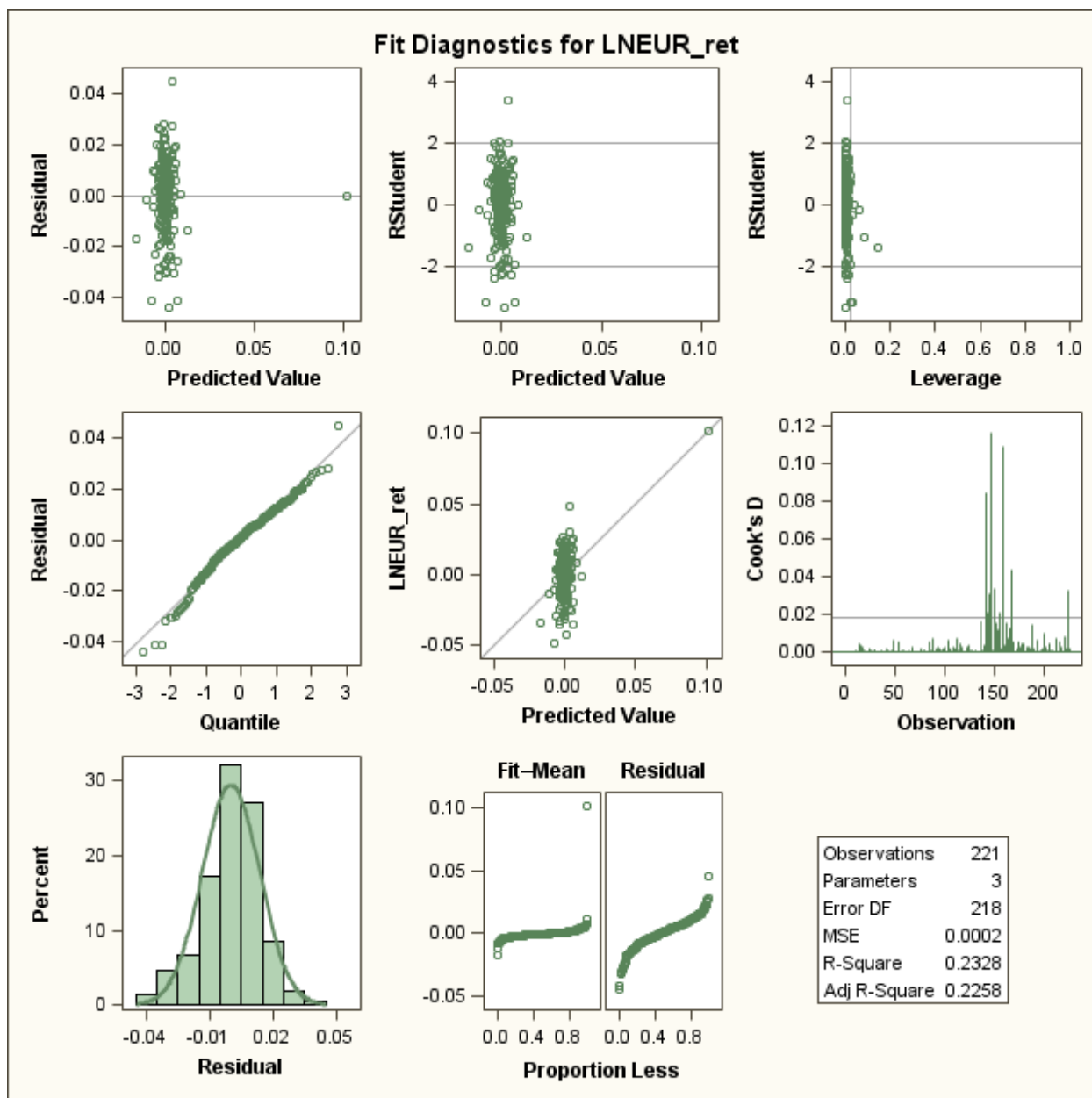
Output from estimated regression in Table 8.2 without Dummy.



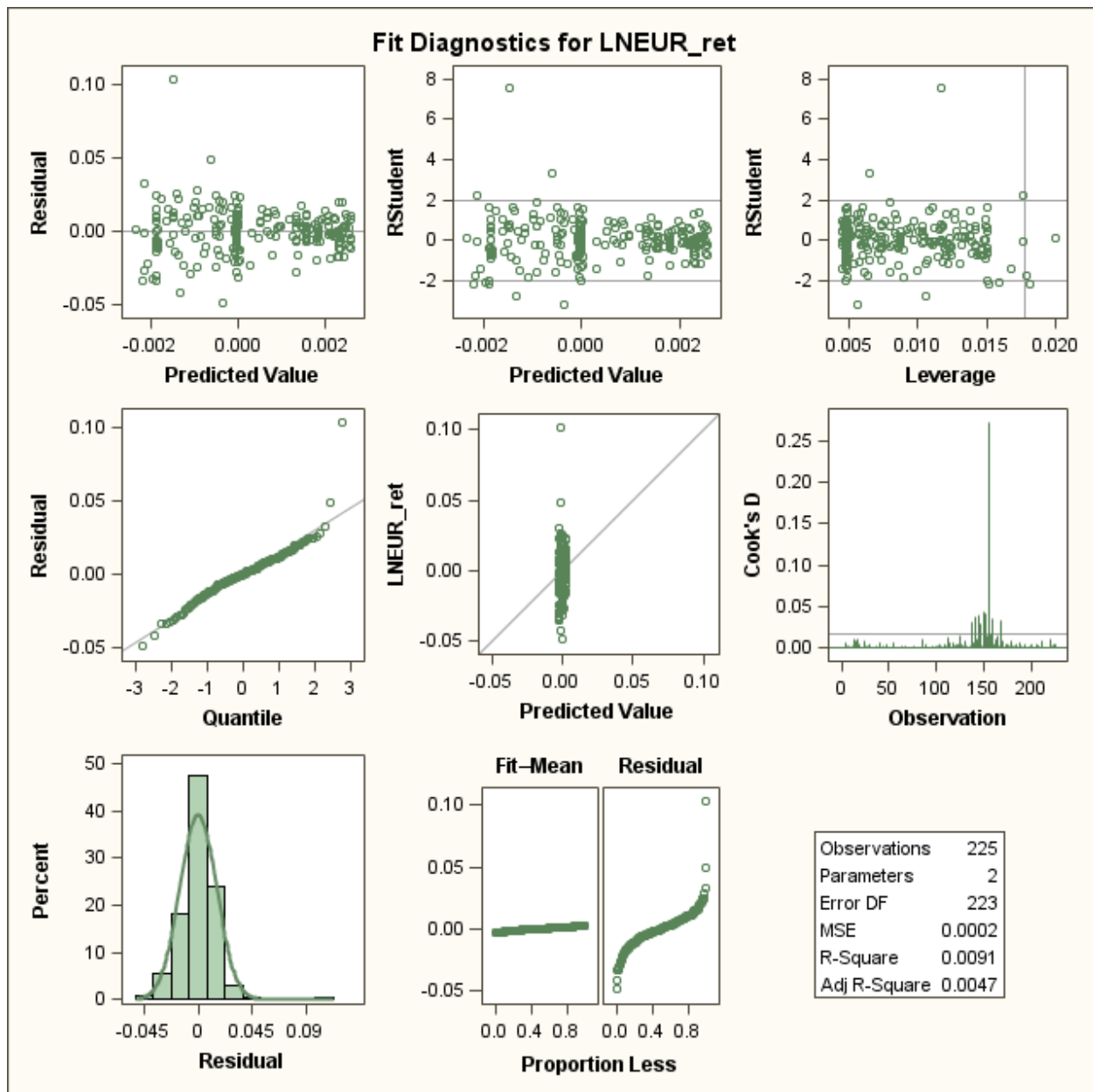
Output from estimated regression in Table 8.2 without Dummy.



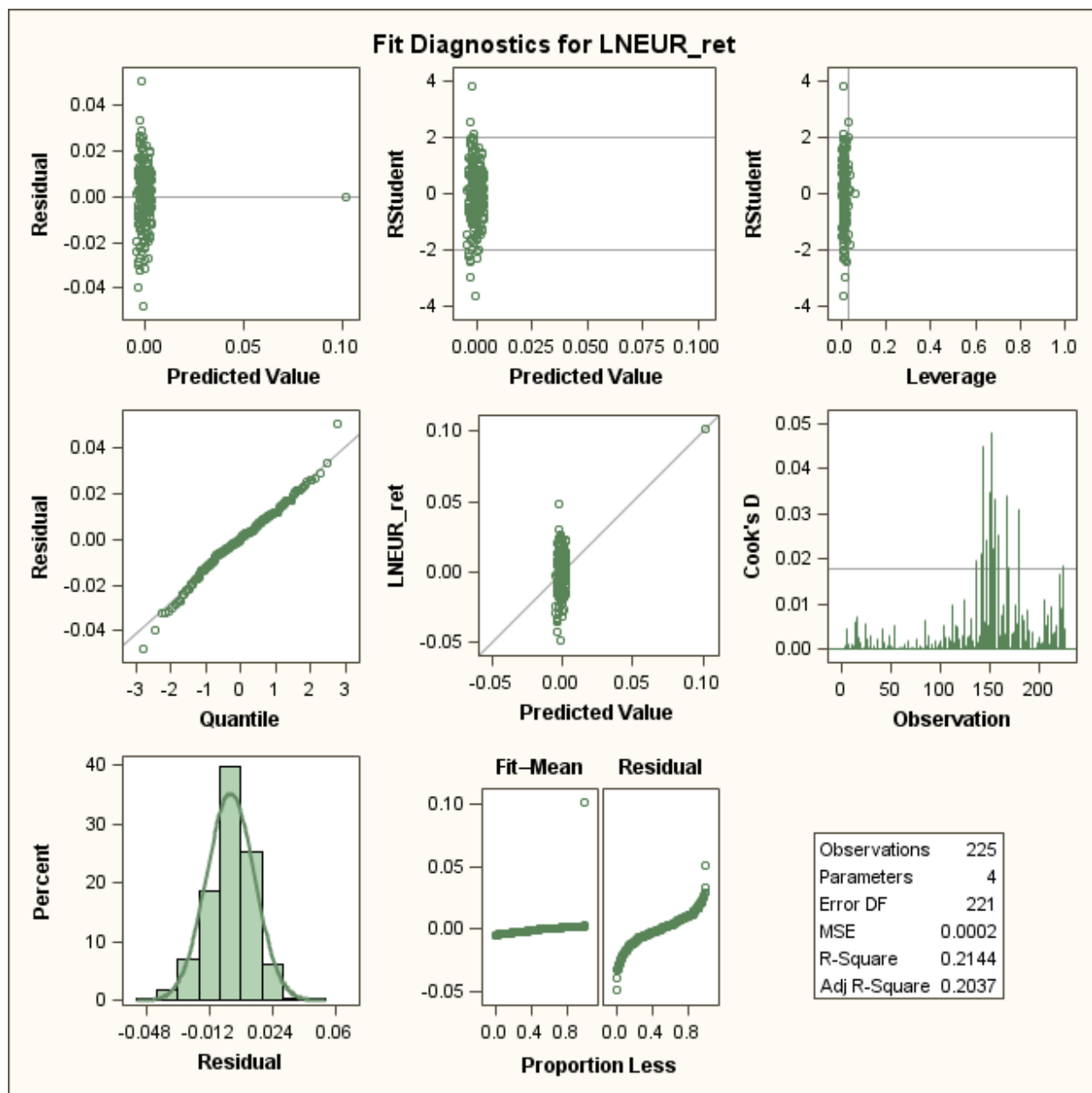
Output from estimated regression in Table 8.4 without Dummy.



Output from estimated regression in Table 8.4 with Dummy.

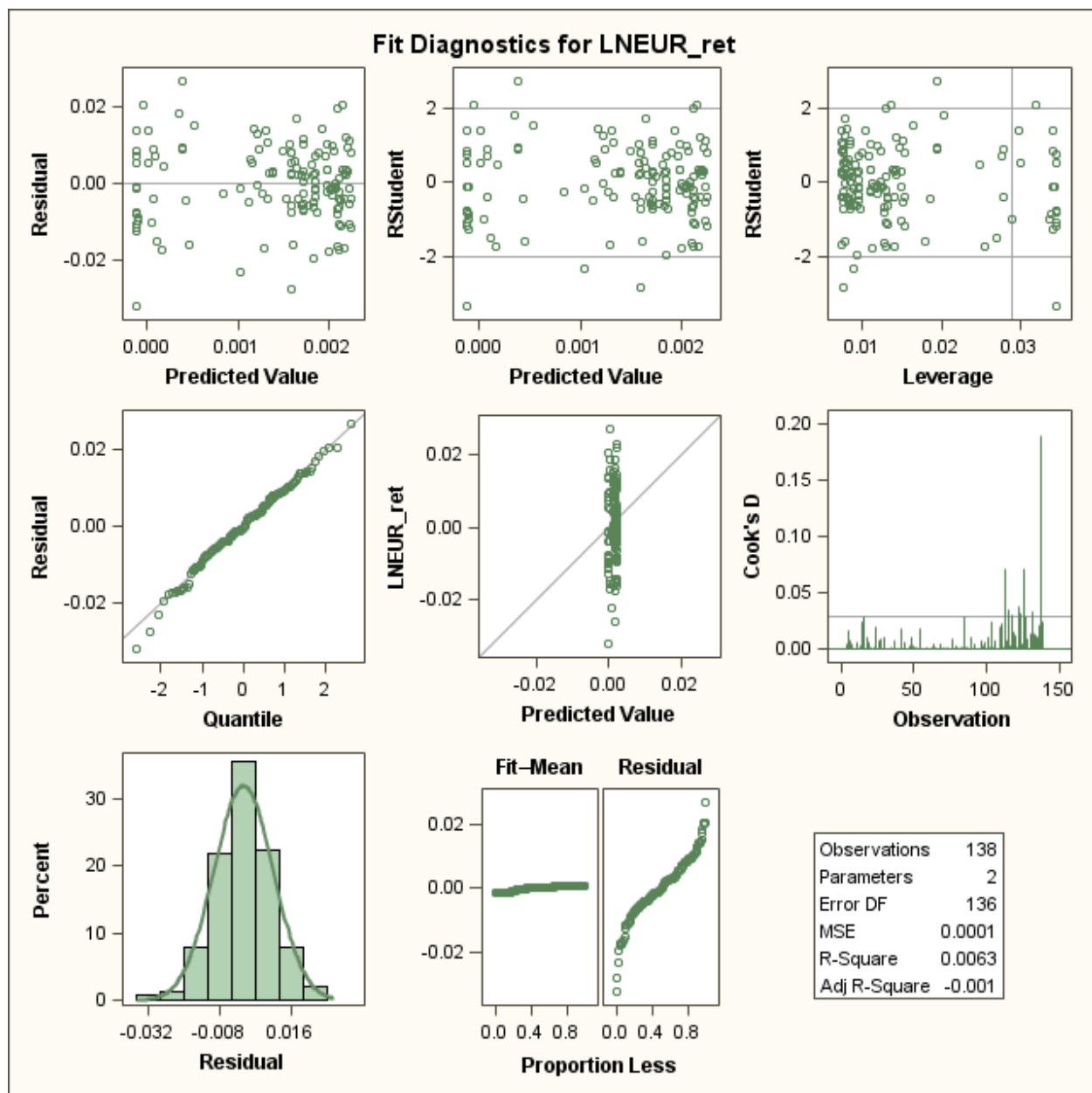


Output of regression in Table8.8 without Dummy.

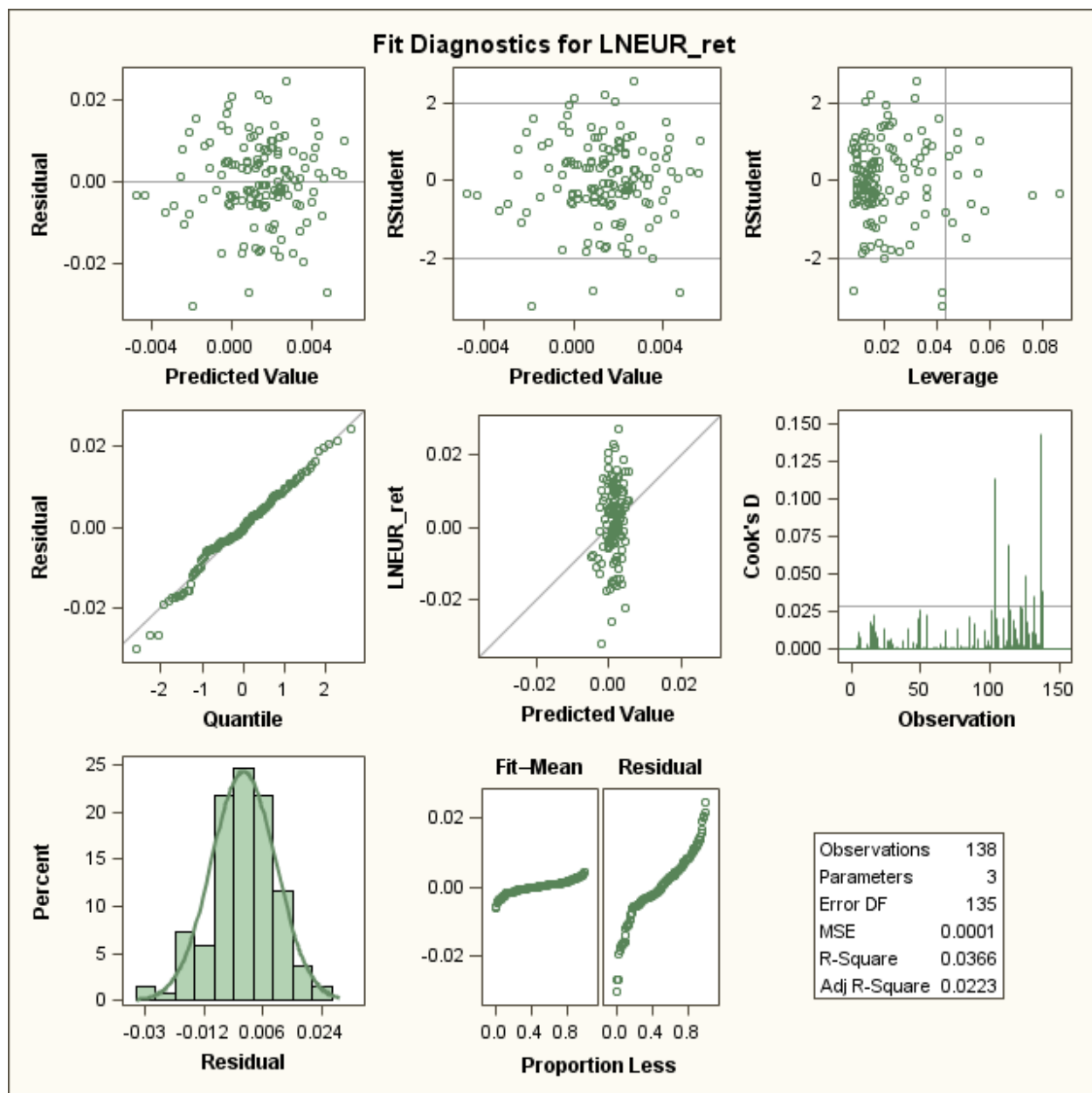


Output of regression in Table 8.8 with Dummy.





Output from UIP regression on first sample.



Output of the regression in Table8.9