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**MODELLING AND EXPLAINING CARRY TRADE EXCESS RETURNS
IN THE FOREIGN EXCHANGE MARKET**

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1 INTRODUCTION TO FOREIGN EXCHANGE MARKET AND CURRENCY TRADING

The modern foreign exchange market started to form in the early 1970s when developed countries gradually switched from fixed exchange rates (also called the Bretton Woods system) to floating exchange rates. The foreign exchange market determines exchange rates for floating currencies. An exchange rate is a price of one currency in terms of another currency and, therefore, it transfers purchasing power from one currency to another. Each currency has a bilateral exchange rate against each other currency. In principle, trading a currency is only a partial investment decision since investors still need to decide which underlying asset to trade, e.g. cash, money-market instruments, or bonds. In practice, currency values can be speculated just like any other asset prices making the foreign exchange market really a market on its own and by far the biggest market in the world with its average daily turnover of \$4,0 trillion (\$ = U.S. dollars). In comparison, the average daily turnover of world stock exchanges (dark pools not included) was \$200 billion in the beginning of 2012 (World Federation of Exchanges 2012). The rise of currency trading has been fast from \$1,7 trillion in 1998 and \$1,0 trillion in 1992. Around \$1,5 trillion of the current total volume is traded in spot foreign exchange transactions and \$2,5 trillion in currency derivatives (mainly forward contracts and swaps). The turnover in the derivatives market is growing more rapidly, which means that its proportion is going to increase further. (Bank for International Settlements 2010.) Currencies are traded multiple times more than what is required for trade in goods and services. Around 90% is based on global investments and only 10% on imports and exports. (Pekkarinen & Sutela 2002: 144, 277.)

The foreign exchange market is geographically decentralized and works over-the-counter (OTC) via a worldwide dealer network. However, there are some more important trading centers where many of the biggest market players operate. London

is the most significant one with an approximate one third proportion of all currency trading. New York and Tokyo come next, Auckland, Sydney, Singapore, Hong Kong, Frankfurt, and San Francisco being the other important locations. (Sager & Taylor 2006.) Besides of the fact that there is no centralized exchange or regulatory authority, foreign exchange trading differs from the equity and bond markets since there are only limited number of currency pairs to choose from, whereas for instance the stock market has thousands of stocks. U.S. dollar is by far the most popular currency traded being involved in 84,9% of all currency transactions. Euro, Japanese yen, and British pound come next (see Table 1). The dominance of the dollar may seem overwhelming but actually its share has little bit decreased during the past ten years. (Bank for International Settlements 2010.) There are many reasons for that phenomenon, which could be a topic of an entire research. To name a few important ones, the emergence of the euro has diminished the usage of the dollar in international trade. Moreover, the economic difficulties and all the time worsening budget deficit that the United States has faced/is facing have eaten dollar's share. Globalization and the growing importance of emerging markets around the world have ensured that today there are more actively traded currency pairs than ever before. Some currency pairs are not traded with large volumes and their exchange rate is determined through their relationship to a widely used third currency, most often to the U.S. dollar. Because exchange rates are relative values between currencies, all of the exchange rates have to be in balance relative to each other in order to cancel out any arbitrage opportunity. This highlights the role of the dollar-denominated cross rates in determining other exchange rates.

Table 1. Shares of individual currencies in foreign exchange trading.

Currency	Share
USD	84.9%
EUR	39.1%
JPY	19.0%
GBP	12.9%
AUD	7.6%
CHF	6.4%
CAD	5.3%
HKD	2.4%
SEK	2.2%
NZD	1.6%
NOK	1.3%
Other	17.7%
Total	200.0%

Because there are two currencies involved in each transaction, the sum of percentages of individual currencies totals 200% instead of 100% (Bank for International Settlements 2010).

The foreign exchange market has some institutional features as its two-tier market structure affects how the currency values are determined. The two-tier structure means that trading is conducted via different channels depending on the participant. Dealers operate within the order-driven interdealer market, where over half of the total volume is traded mainly for purposes of speculation or inventory control (of dealers' positions) after an imbalance is created by a customer trade. The trading of customers with dealers is quote-driven and represents roughly the other half. (Sager & Taylor 2006.) Nowadays also individual investors are able to take part in the currency trading thanks to the emergence of internet based dealers, who accept also smaller trade sizes. Still in the 1990s foreign exchange trading was mostly conducted by big players such as financial institutions, multinational corporations, and others alike. (Sarno & Taylor 2001.) Dealers act often as market makers determining bid-ask spreads, facilitating trades, and providing liquidity. For each currency pair there

are many dealers, who post their quotes on one of the electronic interdealer limit order books, where buyers and sellers are matched automatically. The top two of the most traded currency pairs (euro-dollar and dollar-yen) are traded primarily on EBS, while the third (pound-dollar) is traded primarily on Reuters FXX. These two platforms, EBS and Reuters, are overwhelmingly the two largest trading avenues within the interdealer market. (Chaboud et al. 2007.) After incoming orders have been executed there is no regulatory obligation to publish the detailed information about the trades. This makes the foreign exchange market very different from the highly regulated stock market. Furthermore, customers' orders are held only by individual dealers, which means that there is neither public information about the current bid and ask prices nor volume for any particular currency pair. So, although its huge size and apparent liquidity, the foreign exchange market is rather opaque. (Cerrato et al. 2011.) This lack of transparency has important implications on the price formation of the currencies and it will be discussed later with more details.

The goal of this paper is to obtain a thorough comprehension of the foreign exchange market and the pricing process of exchange rates. The main focus is on the most popular currency trading strategy, carry trade, which is defined as borrowing low-yielding currencies and lending/investing in high-yielding currencies. At some future date the proceeds from lending to the high interest rate currency are used to cover the loan in the low interest rate currency. The balance, which consists of interest rate differential and exchange rate change, shows the gained profit/loss from the carry trade. If Uncovered Interest Rate Parity (UIP) held, carry trade should not be profitable as exchange rate change should eliminate any gain arising from interest rate differential. Hence, carry trade is speculating against UIP. If carry trade succeeds to provide returns, the exchange rate does not offset the interest rate differential between the two countries. Most empirical evidence, including my own initial analysis, agrees that most of the time the offset is not complete and sometimes the exchange rate even moves to the opposite way, i.e. carry trade target currency

appreciates against the funding currency that is just the opposite what UIP predicts. This suggests that in addition to the interest rate gain investors can earn also positive currency return. Furthermore, since interest rate changes are rarely large, carry trade portfolios have traditionally been quite stable. Therefore, the need to rebalance occurs only seldom keeping the transaction costs marginal. It is no wonder that carry trade, which aims to exploit the UIP failure, has become very popular among foreign exchange investors.

When one takes into account the foreign exchange market's high volume, free flow of capital over borders, and the speculative nature, it is difficult to understand why carry trade strategies deliver excess returns. Certainly this does not happen always because carry trade contains great risks. Investors want to avoid rapid appreciation/revaluation of the funding currency they have borrowed and depreciation/devaluation of the target currency they have invested in. It is also worthwhile to highlight that interest rate difference is not constant but varies over time. In this study, the effects of the difference fluctuations on carry trade returns are examined. Also the size for the UIP failure is disputable. Some researchers argue that the findings are statistically not very far from the UIP equilibrium state and can be accounted for transaction costs. For instance, Baldwin (1990) argues that even a relatively small transaction cost together with uncertainty about the future exchange rate produce a “hysteresis band” where expected carry trade returns are too low compared to the costs. Hence, exchange rate movements to the UIP equilibrium state happen only when interest rate differential is high enough compared to the transaction costs. Because of transaction costs, portfolio rebalancing inevitable becomes more infrequent accumulating the deviations. As the size of the deviations has been under heavy debate, it will be checked once more in this paper with the most current data of daily exchange rates and interest rates of G10 countries in 1997-2012.

As carry trade clearly turns out to be a profitable trading strategy, this paper aims to identify proper explanations for this so called forward premium puzzle. In order to do so different risk concepts and market anomalies need to be discussed extensively. The usual explanations that have been forwarded include: opportunity costs, central bank interventions, peso problems, other time-varying risk factors, and investors' irrationality. So far none of the explanations have succeeded to offer solid and all pleasing solution to the puzzle although majority of the academics seem to agree on the existence of time-varying risk premium. However, the modelling of it remains a challenge since many of the models fail out-of-sample. Ideally good time series modelling should describe both short-term dynamics and long-term equilibrium simultaneously. This paper is part of the recent literature, which emphasizes nonlinear dynamics in the UIP relationship and utilizes Smooth Transition Regression -model.

The paper is organized as follows. Section 2 describes, how exchange rates should be determined, if the pricing process was all about fundamentals. Section 3 explains the role and behaviour of central banks in the foreign exchange market. Section 4 describes the data and the portfolio construction as well as the initial results. Section 5 presents the theoretical background that is built around the role of risk-aversion in asset pricing. Section 6 takes a deep look on the risk based explanations for the documented excess returns. Section 7 considers behavioral biases and market frictions that can result in market inefficiencies and excess returns. Section 8 is all about modelling the carry trade returns by STR-model and testing whether the risk-aversion induced nonlinearities can be exploited and create economic value. Section 9 concludes.

2 EQUILIBRIUM MODELS

2.1 Uncovered Interest Rate Parity

When considering exchange rate formation, two famous cornerstone parity conditions stand out, Uncovered Interest Rate Parity (UIP) and Purchasing Power Parity (PPP). According to UIP, the difference in nominal interest rates between two countries determines the movement of the exchange rate between their respective currencies: the currency of the country with the lower interest rate appreciates and the currency with the higher interest rate depreciates until the equilibrium is achieved. Investors in either of the currencies would achieve the same average return, i.e. an investor with a lower interest rate would get a gain from the appreciation of the currency, whereas another investor with a higher interest rate would lose in the form of depreciation of the currency. Investors should be indifferent between holding risk-free securities in either of the currencies since excess returns on average should not be possible to earn. (Chinn 2007.)

Equation (1) describes the UIP mechanism:

$$(1 + r_t^*) = \frac{E(S_T)}{S_t} * (1 + r_t) \quad (1)$$

where r_t^* and r_t are the current foreign and domestic interest rates, respectively, for the period from t (when investment is made) to T (when investment matures), S_t is the current spot exchange rate expressed in terms of foreign currency per unit of domestic currency, and $E(S_T)$ is the expected spot exchange rate at time T . An investor executing carry trade is exposed to the uncertainty of the future exchange rate, $E(S_T)$, which is the only unknown variable in the equation (1). Thus, if the future exchange rate differs from the one predicted by UIP, it is both a profit-making

opportunity and a risk. The exposure to this exchange rate risk can be covered with the use of currency forward contract. Then, interest rate parity is called Covered Interest Rate Parity (CIP). It differs from UIP that it does not wait the exchange rate to adjust by itself but instead fixes it with the forward rate F_t , see equation (2).

$$(1+r_t^*) = \frac{F_t}{S_t} * (1+r_t) \quad (2)$$

F_t is derived from the current interest rate differential thereby fulfilling the no-arbitrage equilibrium condition, see equation (3). If UIP held, the expected future spot rate $E(S_T)$ should naturally match with F_t .

$$F_t = S_t * \frac{(1+r_t^*)}{(1+r_t)} \quad (3)$$

Forward premium/discount is defined as the difference between the prevailing forward F_t and spot S_t rates. When forward rate is higher/(lower) than spot rate, forward rate is said to be on premium/(discount). If UIP held, forward premium/(discount) should be equal to the coming appreciation/(depreciation) that is the current interest rate differential. In common language forward premium is used to indicate also forward discount (minus sign though). (Akram et al. 2008.) Interest rate differential is not the only variable to be looked at because there are also different compounding frequencies across different bonds, e.g. U.S. government bonds are compounded semi-annually and European bonds annually. Especially at longer maturities the compounding frequency is important. For simplicity, most authors calculate forward rates by using continuous compounding, which will also be the approach of this paper, see equation (4).

$$F_t = S_t e^{(r_t^* - r_t)T} \quad (4)$$

T is time to maturity of the forward contract and e is the number of Neper. Hence, the expected change in the spot exchange rate from time t to T can be calculated in either of the following ways, see equations (5) and (6).

$$E(\Delta S_{t \rightarrow T}) = e^{(r_t^* - r_t)T} - 1 \quad (5)$$

$$E(\Delta S_{t \rightarrow T}) = \ln\left(\frac{F_t}{S_t}\right) = \ln(F_t) - \ln(S_t) \quad (6)$$

Academics have acknowledged that for both UIP and CIP to hold, capital must be allowed to flow free across borders and the risk-free assets of the two countries must be perfect substitutes (e.g. Meredith & Chinn 1998, Twomey 2010). In general, the capital markets of developed countries are highly integrated but this is not the case with some less developed countries, which have fixed exchange rates, capital restrictions, and other regulations on their currency. Thus, UIP and CIP should be tested among freely floating currencies. Perfect substitutability is needed to distinguish asset risk from exchange rate risk. This is more complicated thing especially when interest rate parities are tested among lots of currencies because "risk-free" assets across different countries are not perfect substitutes but have different levels of risk, e.g. credit risk. In history some countries have defaulted bonds and may do so again that has become apparent in the times of euro crisis of 2011-2012. Neither is liquidity same for bonds across different countries. Big countries' bonds are much more liquid than small countries' counterparts and therefore also less risky. These facts should be taken into account when testing UIP and CIP.

In general, deviations from CIP are very small, which means that forward exchange rate covers well the interest rate differential between two countries. Hence, it does

not matter whether one uses equation (5) or (6) to predict the expected change in the exchange rate. Even though CIP holds well empirical evidence sees frequent violations of UIP. The failure of UIP, which was first documented by Hansen and Hodrick (1980), Bilson (1981), Meese and Rogoff (1983), and Fama (1984), is also called the forward premium puzzle/anomaly indicating the fact that currency forward prices are calculated by using current spot exchange rate and interest rate differential between the countries. Carry trade can be equally implemented by selling forward currencies that are at a forward premium and buying forward currencies that are at a forward discount. If UIP held, forward exchange rate should provide a close estimate of the future spot exchange rate. In reality, the interest rate differentials are often bad predictors of future spot exchange rates resulting in situations where spot exchange rate falls when the forward exchange rate would have predicted it to rise and vice versa.

The actual change in the spot exchange rate and thereby the validity of UIP is usually estimated by using the following time series regressions, see equations (7) and (8).

$$\Delta S_{t \rightarrow T} = S_T - S_t = \alpha + \beta (r_t^* - r_t) + \varepsilon_{t \rightarrow T} \quad (7)$$

$$\Delta S_{t \rightarrow T} = \alpha + \beta (F_t - S_t) + \varepsilon_{t \rightarrow T} \quad (8)$$

If UIP held perfectly, the regressions above should give an intercept (α) of zero and a slope coefficient (β) of one. Therefore, a small alpha and a beta close to one would indicate a good model. If beta is very low, UIP cannot explain the returns or the risk of carry trade and we would need a better model. The error terms (ε) should be random and have a mean of zero. The literature refers to “forward premium bias” when the estimated slope coefficient is less than one and “forward premium puzzle” when the coefficient is negative. Quite often the coefficient, indeed, is negative meaning that the currency with the higher/(lower) interest rate tends to appreciate/

(depreciate). (e.g. Chaboud & Wright 2005, Mark & Moh 2007.) This would be ideal outcome for investors implementing carry trade.

2.2 Purchasing Power Parity

Another widely used equilibrium model, Purchasing Power Parity (PPP), states that an exchange rate between two currencies is in equilibrium when their purchasing power is the same in each country. In other words, national price levels should be the same when expressed in a common currency. PPP is founded on the law of one price: if two countries produce an identical product, and there are no trade barriers or transportation costs, the prices of the identical products should have the same (one) price in different markets throughout the world. Instead of observing individual product prices, PPP concentrates on nationwide price levels. If price levels are different between two countries, according to PPP the exchange rate will adjust to the equilibrium where prices equal. For example, if price level is lower/(higher) in another country, its currency is undervalued/(overvalued) and its value is likely to rise/(decline) as long as the equilibrium is achieved. (Taylor et al. 2001.) If two countries have differing rates of inflation, then the relative price levels between the countries will change. Inflation makes purchasing power to fall and hence a country with a lower/(higher) inflation will have higher/(lower) purchasing power compared to the counterpart. According to PPP this cannot sustain in long-run and the exchange rate will adjust to the purchasing power difference like it was described above.

Purchasing power of a currency relative to another is called real exchange rate. If PPP held perfectly, the real exchange rate would be constant and equal to one. Thus, any variation in the real exchange rate would represent deviations from PPP. These deviations should not be persistent and therefore PPP predicts real exchange rates to be mean-reverting that becomes visible especially in long-term. (Begg et al. 2003: 402-403.) PPP is longer-term theory compared to UIP as short-term changes in

exchange rates cannot immediately affect the price levels of different countries. Indeed, Korhonen (2005) finds that exchange rate changes do not fully convert to consumer price changes, i.e. inflation is not as sensitive as exchange rate movements. One obvious reason is stiff competition, which makes companies willing to reduce their profit margins in order to maintain market shares.

In economics literature PPP is perhaps the most important of the macroeconomic fundamentals determining exchange rates but unfortunately it cannot be tested in perfect circumstances. Real exchange rates are not directly observable but need to be constructed via national price levels that themselves are just proxies. Moreover, because PPP is built upon unrealistic assumptions like the absence of trade barriers and transportation costs, it has not much predictive power for most products and services. The main exception is financial markets, where identical securities must have the same price no matter how they are created. If they did not have the same price, speculators would exploit these arbitrage opportunities very rapidly. In most other markets perfect competition does not exist but suppliers are able to charge different prices in different locations. Mishkin (2006: 435-437) argues that more realistic model of PPP is based on relative price levels, which does not consider strict equilibrium state, but simply states that a rise/(decline) in a country's price level relative to the foreign price level causes its currency to depreciate/(appreciate). Thus, it is in line with PPP with the exception that the likely exchange rate change does not need to achieve a certain equilibrium point.

2.3 Mean-reversion

The predictive power of PPP is stronger when the forecast horizon is extended. This is due to slow mean-reversion of exchange rates that only becomes visible over long horizon. Dumas (1992) finds that the relationship between real exchange rates and PPP is nonlinear and mean-reverting: the larger the deviation from the PPP condition,

the faster the reversion towards it. When deviations are not large, reversion may not happen at all because transaction costs are too big relative to potential gains. Also Cheung and Laib (1994) find support for mean-reversion in real exchange rates of nine different countries (Canada, France, Germany, Italy, Japan, Netherlands, Switzerland, the UK, and the U.S.) by utilizing nominal exchange rates as well as consumer and wholesale price indexes in 1900-1992. Taylor et al. (2001) agree that real exchange rates are mean-reverting. They construct real exchange rates for dollar, yen, pound, franc, and deutschemark in 1973-1996. The mean-reversion is nonlinear strengthening hand in hand with the size of the deviation from PPP equilibrium. In other words, the speed of adjustment is not constant. This can be due to arbitrage costs, which enable small deviations.

Since real and nominal exchange rates are highly correlated, it would be strange if mean-reversion is present with real exchange rates but absent with nominal exchange rates. Sweeney (2006) studies G10 nominal exchange rates in 1974-1996 and finds them to be mean-reverting. Mean-reversion is caused mainly by central banks and is therefore time- and country-specific. During the research period the major players were the U.S. and German central banks, which jointly targeted stable dollar-deutschemark exchange rate. Other G10 countries stabilized their exchange rates to either of these two major western currencies. So, on average all the G10 exchange rates stayed inside certain limits and bounced back if the limits were crossed. This naturally rises a question whether perfectly floating exchange rates would experience such mean-reversion. Surely nominal exchange rates vary more than real exchange rates but still the deviations cannot continue forever without affecting the overall economy and competitiveness of the country. Moreover, since all the central banks intervene the foreign exchange market, we do not have to answer to the question but instead it is enough that we accept some degree of long-term mean-reversion. The equilibrium does not have to be constant but it can develop over time and in practice the exchange rate changes can be huge. With quite similar inflation levels, the

exchange rate of the two world's biggest currencies, dollar and euro, has fluctuated heavily. For example, in 2002/04/01 the euro traded at \$0.88 and exactly six years later in 2008/04/01 at \$1.56, which means over 75% rise. Although today we are somewhere between these numbers, mean-reversion does not offer much help for predicting short-term exchange rate changes what is the ultimate goal of this paper.

2.4 The relationship between UIP and PPP

Inflation determines time value of money. The higher the expected inflation, the less appealing it is to receive money in the future compared to today. This has severe consequences for the economy and therefore too high inflation needs to be tackled. The main vehicle is to increase interest rates. Hence, interest rate changes mirror the expectations of future inflation. (Begg et al. 2003: 368-369.) Via this link UIP is connected to PPP. Most of the time they are reinforcing the effect of each other on exchange rates simply because high inflation (PPP predicts currency depreciation) is usually accompanied by high interest rates (UIP predicts depreciation) and vice versa. For example, Froot and Thaler (1990: 187) argue that UIP works better when higher/(lower) interest rate is accompanied by higher/(lower) inflation. Also Twomey (2010) points out that UIP fails particularly when PPP does not hold between the countries. Nevertheless, sometimes these forces can be in conflict highlighting the fact that PPP is derived from goods market and UIP from capital market. Brière and Drut (2009) compare the performance of carry trade and PPP strategies for 28 currency pairs in 1990-2008. The performance of carry trade strategy is significantly better than that of PPP strategy, but it fluctuates widely over time. PPP strategy performs better in crises that is no surprise since financial crises are periods of a sudden return back to fundamentals. The authors suggest that a portfolio, which is built around these two strategies, outperforms a pure carry trade strategy and would be robust to crises.

Furthermore, PPP and UIP have a crucial difference in the perception of time. In PPP context time is not important because exchange rate equilibrium is not time-specific but just a certain point where national price levels equal. On the contrary, new UIP conditions need to be constructed continuously if the interest rates do not equal across countries, i.e. UIP predicts that high interest rate currencies continue to depreciate against low interest rate currencies as long as there is a difference in the interest rates. If the predicted depreciation was limited only to the periods where interest rates changed, carry trade would get free lunches on the periods where interest rate difference was static. UIP's obvious drawback is that the exchange rate would one day approach to zero if the interest rate difference continues to be positive for the high interest rate currency. Surely, this does not make sense. For curiosity let's think what would happen if the high interest rate currency continues to depreciate like predicted by UIP. Its currency value would get very low making its exports competitive but imports and foreign debt too expensive. In long-run this would be unsustainable and in conflict with PPP. Because real exchange rates mean-revert in long-horizon, perhaps UIP explains better shorter-term fluctuations. But then, if we accept that UIP does not need to work in long-term, carry trade implemented for instance by 30-year government bonds can be profitable. This may be too long investment period for most investors to exploit and definitely we cannot prove it to one way or another due to lack of reliable data. During this paper I will point out further questions, which still remain unanswered but would be more than interesting to find out. One of them comes from the fact that carry trade can be conducted on various investment periods. The nature of carry trade becomes slightly different when investment horizon is lengthened. Chapters 6.1 and 6.2 provide some empirical evidence and aim to clarify the differing risk profiles of various investment horizons.

2.5 Equilibrium derived from effective exchange rates

For individual currency pairs a working equilibrium condition can be derived from each country's nominal effective exchange rate, which is a weighted average of its individual bilateral exchange rates. With effective exchange rate difference we may know the probable long-term direction in the exchange rate. Being a weighted average it should be more stable and therefore also more useful compared to individual exchange rates or purchasing power parities. Usually the basket weights are determined by the trade shares with each country assigning higher weights to important trading partners but GDP weighted effective exchange rate is quite common as well. (Begg et al. 2003: 398.) The latter approach gives highest weight to the U.S. dollar and may be more appropriate when considering the global foreign exchange market. If a currency's effective exchange rate is taken as the equilibrium state, it is possible to track the deviations (potential mispricings) of individual exchange rates from this correctly priced equilibrium. Deviations from equilibrium condition are calculated as a percentage difference between funding currency's and target currency's nominal effective exchange rates. Hence, this indicator is relative to the other currencies and does not tell what should the absolute value of the currency be. The trouble of relying on effective exchange rate difference comes from the fact that it takes the equilibrium state to be constant that does not change at all. This surely is not true but the equilibrium can evolve over time depending on the country's economic development and competitiveness. Furthermore, with portfolio approach we cannot rely on individual currency pairs' effective exchange rate differences.

3 ROLE OF CENTRAL BANKS AND THEIR IMPACT ON EXCHANGE RATES

3.1 Role of central banks

In the foreign exchange market not all players are motivated by profit making, which is the very core of market efficiency based asset pricing theories. Heavy central bank participation makes the foreign exchange market together with fixed income market unique from other financial markets as the asset prices (exchange rates and interest rates) are not let to move free. Because money plays an important role affecting aggregate economic activity and generating business cycles, it is no wonder that central banks want to optimize the amount and cost of money for their domestic economies. In order to do so, each central bank conducts monetary policy that is the management of money supply and interest rates. The central banks of developed countries have identified price stability as their primary target. Other important goals include high employment, economic growth, and stability of financial markets, as well as keeping their currency value optimal to the aggregate economy and its volatility as low as possible. Especially in short-term the goals can be in conflict with each other, i.e. targeting one goal can result to a failure of another goal. (Mishkin 2006: 393-398.)

The main vehicle for inflation targeting is interest rate. Central banks attempt to affect the level of interest rates by target rates, which they try to reinforce by open market operations. Monetary policies impact mainly the short-end of the yield curve while the rest of the yield curve is determined more by the demand for country's bonds. However, if the market does not believe the target rate to be correct, the level shift of the yield curve may not happen. For example, in December 2011 European Central Bank lowered its target rate to 1.0% in order to ease the credit crisis and boost the economic growth. This did not lower even the short-term interest rates for

instance of Italy or Spain, not to mention Greece. In turn, the short-end of Germany's yield curve fell below 0.0% in January 2012 because of the huge demand for its bonds that were viewed as safer. Euro is a case of its own as there are different countries with different inflation, credit, and liquidity risks using one and same currency. During the euro crisis there have been large capital flows from riskier countries into safer countries. It is not always easy to see the effect on the common currency as much of the money has simply moved from Southern Europe to Northern Europe. Overall, the euro area has lost investments and the euro has depreciated against most other currencies.

Large interest rate changes rarely occur as central banks want to keep the inflation as stable as possible. Only if a country faces unexpected and rapidly rising economic crisis, e.g. hyperinflation, central bank may conduct large target rate changes. However, typical target currencies, whose interest rates are already higher, do not have as much leeway as funding currencies to rise them further. On the other hand, if a country is in a recession and the economy needs money stimulation, funding currencies cannot lower them much further if at all compared to target currencies, which in this case have more leeway. Jylhä and Suominen (2011) find that changes in interest rates are positively and significantly correlated with changes in inflation risk and money supply. The latter one is surprising since an increase in the money supply is usually said to lower interest rates (liquidity effect). The relationship is, however, more complicated. Interest rates can rise later on because larger money supply has an expansionary influence on the economy and increases the price level (inflation). Thus, inflation risk seems to be the key determinant of interest rates as it affects both independently and as a result of money supply.

Other main tools of central banks are open market operations, money printing, and reserve requirements (money multiplier). In general, increasing money supply and lowering interest rates boost economic growth and decreases unemployment. On the

minus side they lead to higher inflation in long-term cancelling out the gained short-term benefits. Hence, the monetary policy is balancing between optimal inflation level and economic activity, and therefore conducted on temporary basis: money supply is increased during recessions and tightened when the economy expands too quickly in order to keep the inflation under control. (Veronesi 2010: 239, 242.) As we can see, motives and means of central bank interventions vary over time depending on the current health of the economy, the future prospects, and the ideology that the central bank is implementing.

What is the role of exchange rates in this jigsaw? It is important to remember that changes in exchange rates are caused by actual monetary flows (demand and supply) and expected changes in them. These in turn are an outcome of external factors like monetary policies by central banks, fiscal policies by governments (budget, spending, taxation), and investor behaviour. *Ceteris paribus*, a currency is expected to appreciate/(depreciate) if 1) the domestic money supply decreases/(increases), 2) the demand for the currency increases/(decreases), 3) the domestic GDP increases/(decreases), 4) country's has current account, budget, and trade surpluses/(deficits), 5) the domestic inflation is lower/(higher) than the inflation in another country improving/(reducing) the currency's purchasing power, 6) trade barriers are increased/(decreased), 7) country's productivity improves/(worsens). (Mishkin 2006: 437-439.) Healthy economy generally indicates good performance of the currency as there will be extra demand for its currency thanks to more incoming investments and exports. This is of course the other way around for a currency of a troubled economy. Therefore, currency investors follow closely news and indicators about country's economic and political health, e.g. GDP, inflation, interest rates, employment figures, producer price index, nonfarm payrolls, and retail sales are among the most widely followed. In reality, *ceteris paribus* condition is hardly ever met making the described relationships more blurred. Their exact synergy is more than difficult to identify and no one can be sure about their total impact on the currency value. This only

highlights the fact that the conduct of monetary policy can be very complex.

Also the relationship between interest rates and exchange rates is more puzzling even though UIP predicts a very clear pattern. According to UIP, interest rates are the only factor moving exchange rates. In its strictest sense this is certainly false as it does not take into account the existence of trading costs. Also the sign of an exchange rate change is disputable because there are forces driving the exchange rate also to the other direction than predicted by UIP. The strength of the forces is tightly connected to the aggregate risk-aversion level among investors. When risk-aversion is low/ (high), higher interest rates look attractive/(risky) in search for the highest/(safest) yields. Hence, interest rates give investors a reason to shift money from one country to another and these capital flows across countries can have a large effect on exchange rate movements. Remember that only a fraction of the total currency trading is caused by international trade and the vast majority is due to global investments. In times of low risk-aversion this can lead to appreciation of the high interest rate currencies that is exactly the opposite to the UIP. Later we will learn more about this phenomenon.

3.2 How central banks intervene?

Terada-Hagiwara (2005) and Edwards (2007) remind of the Inconsistent Trinity, which has been the basis of open economy macroeconomics since the 1980s including developed countries' monetary policies. It proclaims the impossibility for a country to maintain a fixed exchange rate, to permit free capital flows, and to have an independent monetary policy directed towards domestic objectives. Since open economies cannot restrain cross-border capital flows, governments are not simultaneously able to control exchange rates and to use monetary policy to target other domestic goals. Hence, Inconsistent Trinity is a declaration against pegged rates and exchange rate targeting is not anymore as visible part in central banks' tool

box as it was in the previous decades. However, especially developing countries are still balancing between the goals by having independent monetary policy, highly managed exchange rate, and some degrees of capital control. In fact, after the Asian Financial Crisis 1997-1998 many Asian countries have been controlling their exchange rates even harder than before. So far, they are coping well but it is interesting to see what will happen in the future because capital flows are difficult to restrain.

While there are different approaches, all central banks intervene the foreign exchange market to a certain degree and none of the currencies are wholly floating. Many say that the exchange rate is the most important individual price of the economy. It is the only number whose fluctuation instantly affects on the economy's wealth, competitiveness, and growth potential. Thus, many economists would like to fix their currency to some degree what has been exceptional during last decades' prevailing neoliberal economic atmosphere. There are still countries, which have fixed their currency value to some other currency, traditionally mostly to the U.S. dollar. The number of countries that use dollar peg, has actually been decreasing as more and more developing countries have started to use basket of currencies. (Pekkarinen & Sutela 2002: 274-275.) For instance, China does not let its currency to flow free in the market but instead uses a basket including all major currencies, which together determine its currency value. Many argue that the Chinese yuan is kept undervalued as part of its export-led growth strategy, which has been boosted further since 2002. Especially the United States that is suffering from large trade deficit with China, has been criticizing China to let its currency to appreciate more. (European Central Bank 2006: 15.) This is probably what will slowly happen as China wants to boost also its domestic consumption.

Actually the debate, whether exchange rates are correctly priced, is very important as exchange rates affect the prices of all assets in the economy and the competitiveness

of firms. Especially firms, which trade internationally, are affected since the success of exports and imports rely on the exchange rate. Appreciation/(depreciation) makes exports more expensive/(cheaper) and imports cheaper/(more expensive). Hence, export-oriented firms benefit from currency depreciation since their products become cheaper in foreign currencies and thus more competitive. Appreciation would have the opposite effect making exports more difficult. Only firms, whose products' demand curve is very inelastic, would be able to pass-through the exchange rate changes to their product prices. Import-oriented firms, on the other hand, prefer appreciation of their domestic currency because then imports become cheaper enhancing their profit margins. Depreciation is undesired as it would make the imports more expensive and thus harm their competitiveness. Big multinational firms are less subject to be affected by exchange rate changes because their business operations are well diversified across the globe offsetting currency changes. Other firms should hedge against exchange rate changes. (Pritamani et al. 2002.)

It is no wonder that central banks want to influence their currency value to be more favorable for the economy as a whole. Central banks follow their exchange rate closely and are ready to interrupt if it gets too far away from the optimal level. For example, in August 2011 the Swiss National Bank told that its currency is overvalued harming country's exports and tourism. The central bank announced the target level of 1.20 franc against euro under which it will not let its currency to appreciate no matter what. So far, the level has survived well, i.e. the central bank has succeeded to maintain it and the market has believed it. If the franc continues to stay close to the 1.20 level, it can become the most popular carry trade funding currency with its zero interest rate because the risk of appreciation seems to be absent. Whether and how long this continues remains to be seen. Certainly, it is difficult and takes lots of money to prevent currency appreciation if the demand for country's assets is as high as it has been during the euro crisis.

In addition to changing interest rates and domestic money supply, central banks can impact exchange rates directly by engaging in currency trading, where they either use their foreign exchange reserves (currently China and Japan together hold around 40% of the total world foreign exchange reserves) or print more money. In order to depreciate/(appreciate) the domestic currency, the central bank can buy/(sell) foreign currency to make it appreciate/(depreciate) against the domestic currency. (Mishkin 2006: 461.) This is exactly what China and many other export-oriented countries have been doing in order to prevent appreciation of their currencies; with their huge trade surpluses they have bought foreign currencies and especially financed current account deficit of the U.S., who overspends (European Central Bank 2006: 34). Large changes in currency values (devaluations/revaluations) are rarely preferred as they affect the dynamism of the whole economy triggering severe economic consequences. For example, if domestic currency depreciates, foreign debt becomes more expensive. Depreciation of the domestic currency typically increases inflation as well. Rapid appreciation, on the other hand, can lead to over-borrowing in foreign currency that can be very risky. If something unexpected occurs, e.g. the exchange rate reverses and the domestic currency starts to depreciate, it will be increasingly difficult to pay the borrowed money back. (Brause 2011: 24-26.)

Besides actual interventions, central banks can influence exchange rates by signaling. Brause (2011: 29-30, 49-51) argues that usually central banks do not report their interventions in public because they have lots of daily operations and they do not want to generate any rumours to make the market turbulent. Signaling future monetary policy changes (e.g. changes in interest rates) is, however, one way to influence inflation and exchange rates as investors change their expectations about future fundamental factors through these signals. In order to keep their credibility also in the future, central banks of course need to act according to what they have signaled. It is important to highlight that central banks do not always achieve their objectives because of the strength of the market forces. If the market does not believe

that central bank can keep the exchange rate where it has promised, speculative attacks may and probably will test this money making opportunity. There are multiple examples, e.g. Asian Financial Crisis 1997-1998, where central banks failed to maintain control over their currency values due to speculative attacks. (Zhang 2001.)

4 INITIAL RESULTS OF CARRY TRADE PROFITABILITY

4.1 Data, portfolio construction, and comparable results of other academics

I obtained the data of daily spot exchange rates and money market rates of G10 currencies (Australian dollar, Canadian dollar, euro, Japanese yen, New Zealand dollar, Norwegian krone, Swedish krona, Swiss franc, UK pound, and U.S. dollar) from Datastream. The time period is from 1997/01/01 to 2012/01/31. The carry trade strategy is that every month three lowest interest rate currencies are sold and three highest interest rate currencies bought. Monthly updating does not dramatically increase the transaction costs because the weights are rather stable. The portfolio needed to be balanced altogether 33 times (one of the target currencies changed 19 times and one of the funding currencies 14 times), which is not much compared to the length of the evaluation period. Therefore, one does not need to consider transaction costs, which anyway are much lower for currencies than for equities. Japanese yen and Swiss franc belonged all the time to the funding currencies while the third one varied. None of the target currencies were permanent but varied between Australian dollar, New Zealand dollar, pound, Norwegian krone, and U.S. dollar.

The research design follows closely Christiansen et al. (2010) except that their time period was 1995-2008 and they updated their portfolio quarterly. They document 4.6% annual excess returns for the carry trade strategy. Ilmanen (2011: 273-274) uses also G10 currencies in 1983-2009. Instead of equal weights, three highest and three lowest interest rate currencies obtain weights of 50%, 30%, and 20%, respectively. With this dynamic strategy Ilmanen succeeds to improve carry trade returns significantly. The portfolio with weekly updating yields 6.1% annual excess returns with Sharpe ratio of 0.61. On average, the dynamic portfolio earns roughly the interest rate difference. Burnside et al. (2011) study the behaviour of 20 major

currencies in 1976-2010 and find that equally weighted carry trade portfolio of 20 currencies has an average annual excess return of 4.6% with a standard deviation of 5.1%. In comparison, average excess return of the U.S. stock market over the same period is 6.5% with a standard deviation of 15.7%. The first glance is that stocks in general yield more than carry trade but at the same time the returns are more volatile. Higher yield is then a compensation for greater risk. However, since the burst of the Internet Bubble in 2000 carry trade has actually outperformed most of the stock markets.

4.2 Results

Table 2 shows the summary statistics for portfolio's expected exchange rate change (i.e. the interest rate difference) and actual change. As it is possible to see, exchange rates have varied much more than predicted by UIP. Also the sign of the mean change is different to UIP, i.e. target currencies on average have appreciated against the funding currencies.

Table 2. Summary statistics for annualized expected and actual exchange rate changes (%).

	Min	Max	Mean	Median	Std dev
Expected change	-4.17	-1.23	-2.83	-2.98	0.04
Actual change	-104.17	4.14*10 ⁸	1.20	7.10	10.24

When running standard UIP regression based on the equation (7), daily interest rate difference seems to have explanatory power over exchange rate change, see Table 3. Since our dependent variable is not serially correlated, OLS parameter and standard error estimates should be unbiased (Petersen 2009).

Table 3. OLS regression for actual exchange rate change.

Independent variable	Alpha	t-value of alpha	Beta	t-value of beta	R ²
Daily UIP	0.0014	(2.63)	11.6287	(2.59)	0.0017

Even though the results are statistically significant, Figure 1 suggests that there is no strong linear relationship between the variables. Actual exchange rate changes vary much more than predicted by UIP and to both directions. Later I show that it is possible to improve the model further by allowing nonlinear relationship between UIP and exchange rate changes.

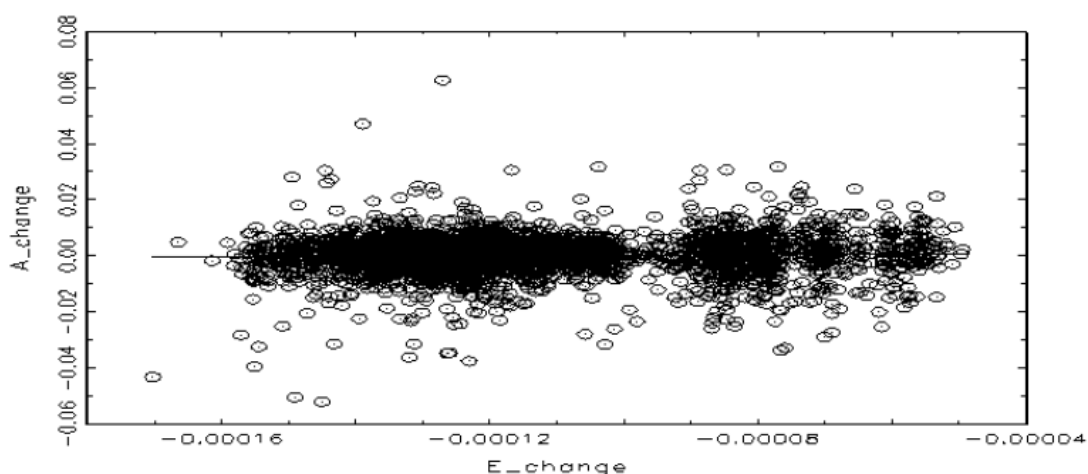


Figure 1. Crossplot of actual and expected exchange rate changes.

Table 4 presents the summary statistics for the portfolio returns. Since carry trade is a zero-investment strategy, mean excess return is the same than average return, which is 4% per year. Median excess return is impressive 10%. In addition to pure returns, there are two different risk-adjusted performance measures in which one should look at if want to compare different strategies with each other. They are Sharpe ratio and Sortino ratio. As normal distribution assumption does not model perfectly the investment risk of carry trade, we should also have a tail risk measure because

Sharpe ratio alone would be misleading. Sortino ratio takes into account that volatility can be asymmetric and return distribution skewed by dividing the distribution into two halves: downside below the mean and upside above the mean. For both halves we can calculate volatility. Of course price variation leading to upside returns is preferable. Sortino ratio is excess return per unit of downside volatility. So, it is otherwise similar to Sharpe ratio except that only downside volatility is used instead of total volatility.

Table 4. Summary statistics for annualized portfolio excess returns (%).

Min	-100.00
Max	4.14*10 ⁸
Mean	4.03
Median	10.08
Std dev	10.24
Skewness (t-value)	-0.55 (-14.12)
Excess kurtosis (t-value)	9.77 (125.10)
Sharpe	0.39
Sortino	0.47

Traditionally carry trade returns have been documented to have significant negative skewness and excess kurtosis, which does not disappear even with diversifying across multiple currency pairs. This is also the case with my portfolio. Negative skewness and excess kurtosis indicate that carry trade returns are vulnerable to greater crashes, i.e. there is a high probability for a small gain and a small probability for a very large loss. The loss indeed materialized. The Global Financial Crisis and especially the latter part of the year 2008 made the target currencies to depreciate strongly, see Figure 2. This caused heavy losses for carry trade investors and therefore the cumulative returns of carry trade, during my research period of 1997-2012, are not so impressive (below 50%).

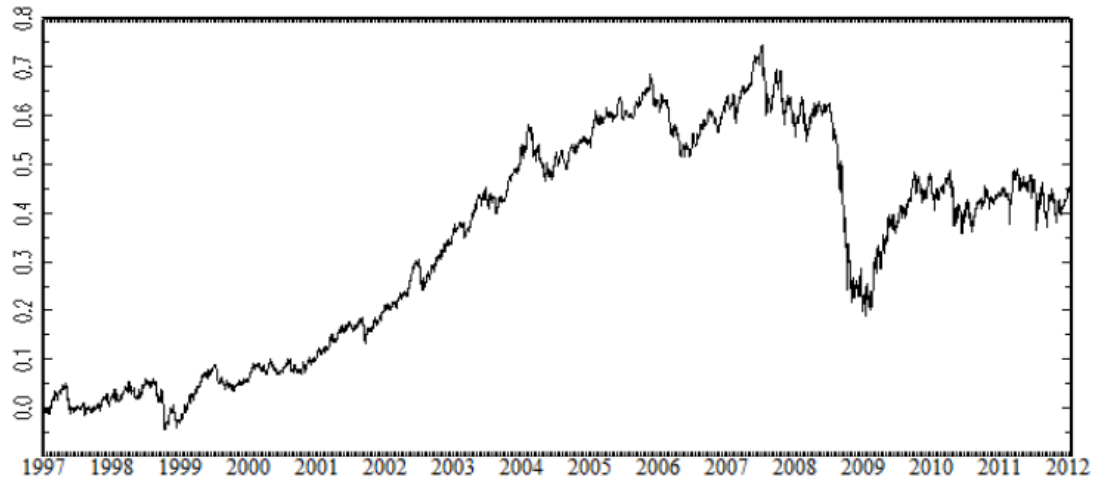


Figure 2. Cumulative returns of the carry trade portfolio.

5 THEORETICAL BACKGROUND

5.1 Risk-aversion

The question really is about what explains the described pattern of carry trade returns and the obvious failure of UIP? One prominent explanation points finger to the assumption of investors' risk-neutrality, which is the core of UIP but clearly does not hold in reality. Financial theory presumes investors' risk-aversion. In this paper risk-aversion reflects investor sentiment with regard to risk and risky investments. Thus, it is a time-varying variable. Risk-aversion increases the price of risk, i.e. investor will hold risky assets (e.g. riskier bonds) only if they are able to earn higher premium (higher interest rate) compared to less risky assets. Changes in risk-aversion contribute to sharp movements in asset prices. When risk-aversion decreases, investors feel they can afford to take more risk, and when it increases, investors collectively move to safer assets. (Coudert & Gex 2006.) Thus, even higher interest rates are a sign of a larger risk, they are tempting and at times of low risk-aversion can attract more incoming investments making the target currency to appreciate. When risk-aversion rises, the flow of incoming investments may turn quickly into outgoing flood lowering significantly the demand for domestic bonds and currency. This makes interest rates to rise further and currency value to depreciate. In turn, demand for safe-haven countries' bonds and currencies increase causing their prices to rise and interest rates to decline further. Hence, carry trade contains a large risk of target currencies' devaluation that seems to materialize when risk-aversion rises. Coudert and Gex (2006) confirm the intuition that risk-aversion tends to increase before financial crises. By doing so it magnifies the actual crises as money disappears from risky investments. Still, many of the crises have been caused by low risk-aversion and excessive risk taking that has lead to bubbles in the financial markets.

How to measure the level of risk-aversion? Clearly, risk-aversion is not directly observable but there are several different risk-aversion indicators each with their own pros and cons. The level of interest rates describes quite well the risk perception towards individual countries. However, there is no global interest rate, which could tell the exact level of aggregate risk-aversion. Furthermore, interest rates may get up also when investors feel less risk-averse and move their investments from bond markets to stock markets. Investors may also demand higher interest rates when other asset classes are giving good returns and again this has nothing to do with increasing risk-aversion. Therefore, we should look for other indicators that are specifically designed to measure the changing risk-aversion among investors.

VIX, which stands for Chicago Board Options Exchange Market Volatility Index, tells the implied volatility on S&P 500 index options, see Figure 3. It represents market's expectations on stock market volatility over the next 30 days. VIX is quoted in percentage points and it is annualized. For instance, if the VIX is 30, which is relatively high, expected annualized change in S&P 500 index is 30% over the next 30 days. Hence, investors expect the S&P 500 to move up or down $30\%/\sqrt{12}=8.66\%$ over the next 30-day period. Because volatility can lead to upside movements as well, a sharp improvement in macroeconomic conditions could lead to high value of VIX and at the same time enormous boost in the equity market making investors less risk-averse. Thus, it is not a perfect risk-aversion indicator. Moreover, as it is related to equity market, it may not be the best indicator for currency market. Nevertheless it is widely used to measure global risk aversion, and if we believe risk-aversion to be universal phenomenon across financial markets, VIX works well enough.

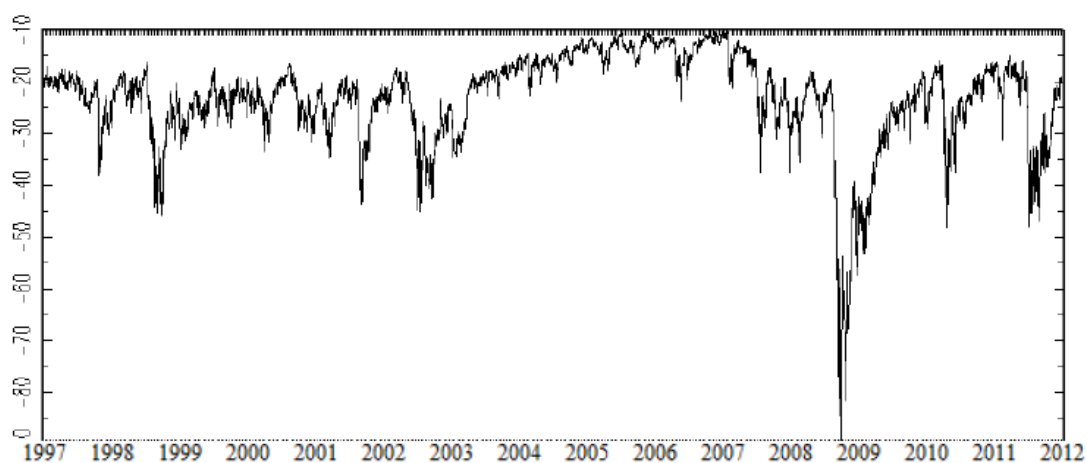


Figure 3. The daily VIX.

TED and credit spreads are also good measures of risk-aversion and not as equity market concentrated as VIX. TED spread (see Figure 4) is calculated as the difference between 3-month LIBOR interbanking market interest rate and 3-month T-Bill rate. Hence, it indicates willingness of banks to provide funding in the interbank market and is an excellent proxy for tightening global liquidity. When risk-aversion is high and banks do not trust each other, TED spread widens indicating that there is no liquidity at the market. This is extremely serious for riskier strategies like carry trade because the liquidity disappears mostly from riskier assets causing their prices to decline. Credit spread (see Figure 5), which usually is calculated as the yield difference between risky corporate bonds and safer government bonds, works in similar way. When risk-aversion rises, credit spread widens due to increased selling of high risk bonds and increased buying of safe-haven bonds. Thus, rising risk-aversion leads to flight to quality phenomenon and widening TED and credit spreads.

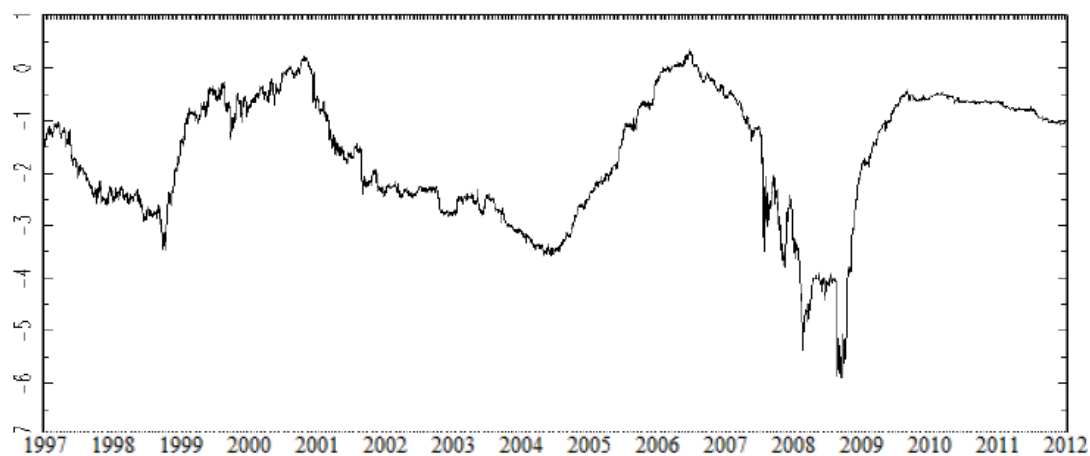


Figure 4. The daily TED spread.



Figure 5. The daily credit spread.

5.2 Safe-haven phenomenon

Unlike other securities, currencies do not have absolute values but instead relative values to other currencies, i.e. exchange rate is a comparison of two currencies. All currencies cannot simultaneously appreciate or depreciate because appreciating currencies have always depreciating counterparts and vice versa. Therefore, in every market condition there are appreciating currencies, which can be exploited. This

confirms that currencies should not be treated as one similar investment category because their risk-exposure clearly varies depending on the current market situation. During turbulent times namely U.S. dollar, Japanese yen, and Swiss franc are usually viewed as safer investments. Hence, the money inflows make them to appreciate against the currencies that suffer from money outflows. The pattern is revisited when risk-aversion is lower, which is the more common state of nature. Because of this safe-haven currencies earn on average a lower risk premium than other currencies (Christiansen et al. 2010). Even if their interest rates were low, the tendency to appreciate during market turmoil makes them very risky funding currencies for carry trade. During my research period the yen and the franc have been continuously funding currencies, i.e. their interest rates were among the three lowest. The interest rates of the U.S. have varied more and the dollar has belonged also to the group of target currencies. A target currency behaving like a safe-haven would be ideal for carry trade since it would reduce the overall risk if there was no fear of devaluation during market turbulence.

Nowadays, there are no safe-havens in the sense that they would be completely isolated from global financial storms. Still, some countries' assets are viewed as safe. Why is that? There are both rational and psychological reasons for the safe-haven phenomenon. Clearly, a safe-haven country should be perceived as low-risk. Low interest rates are common for safe-haven countries but do not automatically give the safe-haven status since low interest rates may indicate low economic growth or even deflation (e.g. Japan). Furthermore, during the past decades the U.S. has possessed high interest rates from time to time and still it has been perceived as safe. Habib and Stracca (2011) study 52 currencies in 1986-2009 and find some common features for safe-haven currencies. Size and liquidity of a country's financial markets is important in order to prevent liquidity from drying up during crises. Equally important is the net foreign asset position, which is value of the assets that country owns abroad minus the value of the domestic assets owned by foreigners. In addition, the public

debt to GDP ratio as well as development and liquidity of the foreign exchange market (measured by the bid-ask spread) are associated to safe-haven status. None of the features alone explain well the exchange rate behaviour so it is all about the overall picture. Moreover, safe-haven currencies are not the force of nature but they can vary depending on the health of the country. So far, dollar, yen, and franc are all highly liquid currencies and the economies of U.S. and Japan among the strongest of all. Smaller Switzerland, in turn, has benefited from the good reputation of Swiss banking sector and currency's explicit gold backing.

There are also psychological factors maintaining the safe-haven phenomenon and hence it could be classified as a market anomaly. For example, the dollar was viewed as a safe-haven currency during some critical periods of the Global Financial Crisis in 2008, even though the crisis started from the U.S. and it was obvious that the U.S. will suffer large economic damage. Also safe-haven label seems to be more dominant than money supply, e.g. during the autumn 2011 the dollar appreciated against most other currencies due to safe-haven status although the U.S. printed huge amount of money to boost its economic growth. So, no matter of the domestic economic conditions, safe-haven currencies do appreciate more than the fundamentals predict because of the herding of investors. Therefore, we can conclude that market psychology explains at least partly the existence of safe-haven currencies in the foreign exchange market.

5.3 From risk-aversion to asset pricing

Risk-aversion leads to the principle that excess returns can be only due to greater risk. This seems to fit also to the case of our own, i.e. carry trade returns are a compensation for bearing risks. The pattern of steady small returns during normal times and a large loss during market turbulence can be described as a tail-risk or selling put options/catastrophe insurances proposed by Cochrane (1999): “Most of

the time they earn a small premium. Once in a great while they lose a lot, and they lose a lot in times of financial catastrophe, when most investors are really anxious that the value of their investments not evaporate.” Cochrane's idea, which is now a central principle of modern asset-pricing theory, starts from the presumption that on average investors are risk-averse and therefore most investors prefer securities that do well in recessions. Thus, securities that perform badly need to pay a risk premium during good times in order to attract investors. In turn, for safe-haven assets investors accept lower long-term returns because they provide a hedge when it is needed, i.e. they work as catastrophe insurances. This may explain why high interest rate currencies usually do not depreciate and sometimes even appreciate against low interest rate currencies in normal times. Like 2008 showed, target currencies obviously hold risks related to financial distress, which materialized when risk-aversion increased and investors abandoned their risky assets (flight-to-quality). Hence, target currencies on average provide risk premium in normal times. From this perspective carry trade can be thought of as a trading strategy that aspires to exploit the risk premium. Then, forward premium puzzle is not really a puzzle since the documented carry trade returns are only due to bearing time-varying risks.

Next I review the concept of stochastic discount factor (SDF), which Cochrane (2005) has introduced to describe how assets are valued. SDF can be thought of as a function of investors' marginal utilities. Hence, SDF is time-varying and obtains high/(low) values in states where marginal utility is high/(low). On average, investors' marginal utility is highest/(lowest) during turbulence/(boom) when nothing/(everything) seems sure, i.e. risk-aversion and marginal utility walk hand in hand. It means that the same payoff provides more marginal utility during recession (when risk aversion is high) than in good times. This is the reason why counter-cyclical safe-haven currencies are more desired than other currencies: they have positive covariance with SDF. For asset valuation purpose it would mean that they must be more expensive and therefore offer lower average returns. Because most of

the time we can draw an equal sign between safe-haven currencies and carry trade funding currencies, this indeed explains why UIP hypothesis fails. Its presumptions are in stark contrast with the principles of SDF since UIP would assume low interest-rate currencies to yield higher returns (appreciate). In reality the higher expected returns (i.e. risk premium) is associated with pro-cyclical target currencies, which have negative covariance with SDF. Again these are averages and because SDF varies over time, neither risk premium nor asset prices are constant but can vary significantly.

5.4 Predictability – can returns be predicted?

It is a different story whether exchange rates can be predicted. If yes, the question is how far or rather how close? Modern financial theory accepts that asset prices are to some extent predictable. This holds particularly in long-term but not so much in short-term. To understand this we need to first understand that predictability has much to do with changes in risk-aversion. For example, during a long boom period target/(funding) currencies may have appreciated/(depreciated) strongly and become overvalued/(undervalued) due to low risk-aversion level. If risk-aversion suddenly changes, the mispricings become visible to all market participants and can be corrected quickly. Like stated earlier, high prices of target currencies and low prices of funding currencies can also be tracked macroeconomically. Hence, it is important to demonstrate also the mean-reversing pattern that clearly exists behind long-run exchange rate movements although it does not show in our daily frequency data. If we can consider also the risk aspect, i.e. time-varying SDF, exchange rate movements become more predictable also in shorter-term.

5.4.1 Long-run predictability, i.e. mean-reversion once more

The question is what causes the push back to equilibrium. Surely, it has much to do

with the change in investors' risk-aversion. After all, there is clear evidence that target currencies tend to appreciate when risk-aversion is low and depreciate when risk-aversion rises rapidly. Another plausible explanation highlighting mean-reversing behaviour may be equally true but maybe not as dominant as risk-aversion. Equilibrium theories assume that exchange rates are too important for the economy as a whole and therefore they should not be thought only as an asset. Macroeconomic fundamentals drive long-term mean-reversion and then there are also central banks, whose importance has not disappeared, remember e.g. Switzerland 2011. Central bank definitely wants to act if country's currency value is too far away from its optimal level no matter of the phase of the business cycle or risk-aversion level. Hence, exchange rates cannot wander infinitely to one direction. This needs to be taken into account especially if modelling long horizon carry trade because on average large devaluations of target currencies happen only after they have first become overvalued. This can be thought of as a process where exchange rates wander slowly away from their fundamental equilibrium values but reverse quickly back when turbulence hits the market. It would be more than interesting to cross-check this finding in a longer time frame to see whether the mean-reversion can happen also slowly and during low risk-aversion, which would undermine the hypothesis of recession risk premium.

Furthermore, there are still lots of observations where high interest rate currencies appreciate even equilibrium models show considerable overvaluations. Thus, apparently the changes in risk-aversion resulting into the transition from risky assets to safe-haven assets and vice versa, indeed, are the leading factor driving the currency values. Next we could ask what causes the changes in risk-aversion? This can get us back to macroeconomic conditions because obviously something has got too wrong from investors' perspective to change their view towards risk and why investors are less willing to hold risk. Thus, there is not one without the other, i.e. risk perspective and macroeconomic equilibrium approaches are closely related.

Changes in risk-aversion can be thought of as a trigger. When risk-aversion is low, investors still know that the exchange rate may be misvalued but they feel that they can afford to take the risk of potential large devaluation. When risk-aversion increases due to some reason, exchange rate can move very fast back to its equilibrium.

Deriving a fundamental equilibrium state for a portfolio is not easy task to do. For this purpose I formed cumulative UIP condition, which forecasts the current exchange rate level if UIP had hold all the time since the obversation period began. The problem with forward exchange rates is that they are calculated every time with the current spot rate and interest rate difference, i.e. they do not take into account that the spot rates can be temporarily mispriced. Cumulative UIP tries to provide a solution to this problem. Figure 6 shows that during expansions, which are generally characterized by low risk-aversion, high interest rate currencies become overvalued and low interest rate currencies undervalued. These mispricings get much smaller as a result of the turbulence induced mean-reversion of 2008 giving some credit to long-term equilibrium theories.



Figure 6. Cumulative actual change (A) and cumulative UIP (U).

Still the cumulative UIP does not work too well reinforcing our intuition that UIP may not be the optimal equilibrium condition for long horizon. OLS regression (see Table 5) verifies that deviations from cumulative UIP cannot explain daily variation in exchange rates.

Table 5. OLS regression for actual exchange rate change.

Independent variable	Alpha	t-value of alpha	Beta	t-value of beta	R ²
Cumulative UIP	-0.0003	(-0.43)	0.0005	(0.49)	0.0001

Now we come to the question what is the time horizon where returns can be predicted. It is well known that macroeconomic predictability (mean-reversion) is long-term phenomenon. Because SDF (risk-aversion and marginal utility) does not change much in short frequencies, neither it can explain much of the daily variation in returns (more though than mean-reversion). Instead SDF does change over the business cycle indicating that predictability is connected to phase of the cycle. Moreover, Bekaert et al. (2007) argue that the reason for more accurate long-term predictability comes from more visible macroeconomic fundamentals. In short horizon fundamentals do not necessarily appear as much as in long-term because noise may dominate the exchange rate behaviour. In long-run random noise cancels itself out at least to some degree and fundamentals can therefore show up better.

5.4.2 Shorter-run predictability

A number of studies emphasize monthly horizon as the shortest time period, where returns show glimpses of statistical predictability. Shorter time periods have been said to follow random walk. Actually for proofing carry trade profitability this would be good news as random walk without a drift would mean that UIP condition is not fulfilled. After all, UIP assumes a very clear exchange rate behaviour, i.e. predictable

change towards the UIP condition. Of course that predictability is very different from the risk-aversion induced predictability of our theoretical background.

There are some strong aspects supporting also shorter-term predictability. Technical analysis particularly is so widely used even for intraday trading that it undermines the random walk hypothesis. Technical analysis means forecasting future price movements through the study of past market data, primarily price and volume. In the 1990s it was used either as a primary or secondary source of trading information by over 90% of foreign exchange traders in London (Allen and Taylor 1992) and Hong Kong (Lui and Mole 1998). Many argue that its importance, at least, has not decreased since the 1990s. Why would it be used if not for enhancing profits? Hence, it might be that short-term predictability exists but it has been just difficult to capture in statistically significant way. After all, long horizons result mechanically from short horizons. Predictability is also a statistical feature as regression coefficient for explanatory variable and model's R^2 rise with the horizon when explanatory variable is persistent. As interest rate differential is highly persistent, this explains why UIP works statistically better at longer horizons.

6 RISK PROFILE OF CARRY TRADE

Even though traditional asset pricing models (e.g. CAPM and Fama & French three factor model) have some explanatory power over stocks, Burnside et al. (2011) do not find any proofs that carry trade excess returns are compensation for conventionally measured risk. Advocates of market efficiency argue that observed carry trade excess returns simply provide evidence of an yet unidentified risk factor. Since Fama (1984) there has been continuous debate about existence of some kind of time-varying risk premium and even today much of the foreign exchange research is directed to get more comprehensive understanding of this risk premium. In center of the research are such factors as country-specific risks, systematic risk arising from other financial markets, (il)liquidity, peso problems, currency speculation, and central bank behaviour.

6.1 Country-specific risks

For short-term carry trade (like our strategy) the main source of risk is exchange rate movements whereas longer-term risk has multiple faces. It seems that the overall risk premium of carry trade is higher in long-run because both interest rate and exchange rate movements can be larger. Imagine you have calculated a forward foreign exchange rate for ten years from now using current interest rates of 10-year maturity bonds. During this time the term structure can change substantially and the interest rates that were used for determining the forward exchange rate may get completely different. Higher interest rate risk can be seen from the upward sloping term structures that are a norm with very few exceptions. Obviously, investors require higher risk premium to hold long-term bonds than short-term bonds. Where does the risk premium for long-term bonds come from, i.e. what could result in big capital losses to require higher interest rate? Veronesi (2010: 642, 644) says that expectations on future inflation is one obvious explanation. Even risk-free

government bonds are not completely risk-free. They may be credit risk-free (not always) but not inflation risk-free the only exception being inflation linked bonds. If inflation is expected to rise, central banks act accordingly and rise interest rates. Also investors demand higher nominal interest rates to offset the expected higher inflation. Then, bond prices decline, and even investor holds the bond until its maturity, inflation eats at least some of the profit. Hence, the longer the investment period, the greater the effect of inflation.

Inflation is a risk for carry trade also due to its direct influence on exchange rates. If PPP held, high inflation should be accompanied by currency depreciation. The possibility of large devaluation of high interest rate currencies is the greatest risk for carry trade. Ilmanen (2011: 355) reminds that currency depreciation may not happen if the central bank is credible and inflation is expected to be in control. But if the inflation continues to be too high, currency depreciation is going to happen sooner or later because large PPP violations are not sustainable in long-term. Like always in macroeconomics neither the relationship between inflation and devaluation is so straightforward as there are also other factors affecting exchange rates. Devaluations can occur after a period of low inflation as well, what happened in the Asian Financial Crisis 1997-1998. In addition to market reactions, also central banks can execute devaluations. The announcement of Swiss central bank in 2011 shows that even central bank originated devaluation risk has not disappeared completely for G10 currencies. Thus, carry trade speculates not only against UIP and PPP but also against all other potential devaluation risks. Furthermore, the relationship between inflation and exchange rates works two-way. Depreciating currency increases inflation by making imports more expensive and exports cheaper, *ceteris paribus*. So, inflation increases both directly due to higher prices of imports and indirectly due to increased demand for exports resulting in higher prices of exports and money inflows to the country. This is of course other way around for appreciating currency.

Longer investment horizon has also higher credit risk and liquidity risk. If there appears a real risk of default due to economic difficulties, investors will abandon those bonds causing their interest rates to sky rocket and currency value to decline. Default is not the only outcome to be afraid of because also downgrading affects both bond prices and exchange rate. Downgrading is a real worry if investors plan to sell their bonds before the maturity. Credit rating agencies hold key role in the relationship between downgrade risk and interest rate. Liquidity has enormous effect on carry trade profits and will be discussed later with more details from the perspective of risk-aversion. For now it is enough to know that different risk-free assets can have very different levels of liquidity. Especially small countries' bonds may not have much liquidity in the secondary market. Thus, in order to avoid liquidity risk investor should hold the bond until its maturity but that in turn may expose the investor to higher inflation and default risks.

All of these above mentioned risks are more or less country-specific, i.e. devaluation, inflation, credit, and liquidity risks are rarely same between low and high interest rate countries. This is interesting since most financial theories claim that idiosyncratic risk should not be compensated by excess returns and only systematic risk factors matter. For example, Cochrane (1999) says that any risk factor, which can result in a risk premium, must affect large group of investors as their collective actions drive asset prices. Still, we clearly cannot ignore the described country-specific risks. This is particularly the case because carry trade has only limited number of currencies to choose from. When constructing a carry trade portfolio, the impact of country-specific risks can be reduced but never completely eliminated. Moreover, it seems that they fit Cochrane's classification better than for instance company-specific risks simply because countries are bigger in size and have a larger effect on the global economy. Country-specific risks also match with Cochrane's (2005) more current definition of systematic risk factors, whose main idea is the co-variation with stochastic discount factor.

6.2 Another look at interest rate risk

Now we could ask whether short-term carry trade is less risky since there is not so much inflation, credit, and liquidity risks. If the answer is yes, should it mean that long-term carry trade yields on average higher returns? This immediately rises a question whether it is really true that UIP holds better at long-term? Again it would be interesting to examine also long-term carry trade returns. Bekaert et al. (2007) examine UIP at both short and long horizons by conducting a vector autoregression. The data include U.S., UK, German, and Japanese exchange rates and zero-coupon bond yields with maturities of 3, 12, 24, 36, 48, and 60 months in 1972-1996. Their results show that exchange rate deviations from UIP are mainly currency dependent, not so much horizon dependent. In other words, for some currencies UIP holds both at short and long horizons whereas for some other currencies UIP does not hold in any horizon. This affirms that either the exposure to systematic risk factors must vary across countries or country-specific risk factors have something to do with carry trade risk premium. Sometimes UIP deviations can be larger at longer horizons. This is inconsistent with many of the previous research, which claim UIP to correct itself eventually. However, it is not in contrast with my finding that cumulative UIP is not a good predictor of future exchange rates even though in long-run there exists some mean-reversion.

Chaboud and Wright (2005) have a distinctive approach. They study the exchange rates of dollar, yen, deutschemark/euro, franc, and pound in 1988-2002. The data is in 5-minute intervals, which makes it possible to focus on the precise periods, where interest accrues to the open carry trade positions. A position, which is not kept open overnight, does not receive interest differential because intraday interest rates are zero, i.e. interest does not accrue continuously but on discrete daily intervals. The authors want to examine whether exchange rates jump over those time periods when

interest actually accrue to offset the interest differential, i.e. does UIP hold or is there arbitrage opportunities. The idea is similar to arbitrage considerations in stock prices on ex-dividend date. Overall, UIP works well. The best fit is with the dollar-pound currency pair, where the slope coefficient in the UIP regression is close to one. So, if exchange rates bounce back to UIP condition when interest accrues (for most bonds this is at daily frequency), one could think that the deviations cannot get very far from the equilibrium state. The authors admit that the results do not apply every time and there is lots of noise. We also have to notice that tiny deviations, which may not be statistically significant, can grow into larger deviations as time passes by. For future pondering, it would be great to find out if there is a difference, which maturities predict future spot foreign exchange rates better than others, and why?

No matter whether UIP condition is fulfilled or not, interest rates do move exchange rates. Interest rate changes are a risk for carry trade also because the interest rate differential is always the starting point for the strategy. The difference, however, varies over time and across different maturities. For our strategy, only the former matters because we are merely trading the assets of same maturity. Although we do not need to care about the latter, I will first point out some problematic questions of changing term spreads as they show how unrealistic it is to assume perfect fit of UIP in all circumstances. So, what happens when the interest rate difference changes across maturities? On average, short-term interest rate difference is more stable than long-term rate difference. The reason is that since the long-end of the yield curve cannot be influenced so much by central banks (if they do not take part in bond purchases), long-term interest rate difference can have more variation reacting faster to changes in investor behaviour and macroeconomic expectations. Yield curve can move up and down as a whole (level change) as well as change its slope and curvature. Since forward foreign exchange rates for some future time are calculated by using corresponding maturities of current interest rates, the short-end of the term structure (e.g. 3-month rate) determines the short-term forward rates and the long-

end (e.g. 10-year rate) determines the long-term forward rates. Can there be a situation where interest rate differences of 1 month and 1 year maturities are in conflict with each other indicating opposing exchange rate movements? In principle these cases are possible but not common and we do not have to pay too much attention to these. Still, this highlights that UIP is not so straightforward and there probably cannot be cases where UIP could work in every time horizon.

For the question, what happens when the difference changes inside the one and only maturity, we have also empirical evidence. A rule of thumb is that when the difference increases/(decreases), the target/(funding) currency becomes more attractive for investors causing it to appreciate. This is especially the case when the aggregate risk-aversion level is low, which is the more normal situation. Like Figure 7 shows, during my research period the portfolio interest rate difference was at its highest level prior to the Global Financial Crisis.

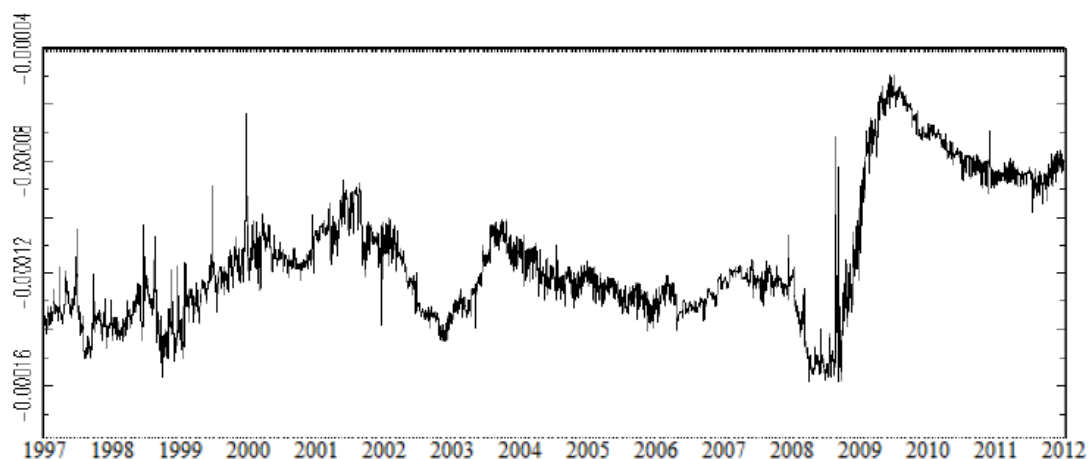


Figure 7. Daily interest rate difference between portfolio's target and funding currencies.

This was due to increase in investors' risk-aversion (see Figures 3, 4, and 5) that lead to flight-to-quality, i.e. abandonment of higher risk bonds making their interest rates to rise further and safe-haven countries' interest rates to decline. Large interest rate

differentials are common feature for times of substantial crash risk (Brunnermeier et al. 2008).

Lustig et al. (2011) question the importance of varying interest rate differentials by claiming that more important factor in changes of carry trade returns is exchange rate movements because in market turmoil target currencies depreciate and funding currencies appreciate, not because of their interest rates significantly mean-revert. Anyhow, the previous figure showed that the crisis lead not only to the mean-reversion of exchange rates but also to the mean-reversion of interest rates as the interest rate difference narrowed significantly after the crisis had become global. Never before during the research period had interest rate difference been so narrow. This was due to the necessity of high interest rate countries to lower their target rates in order to boost economic growth. Still, in the beginning of 2012 the difference was historically very narrow, which may have influence on the carry trade returns that have not risen significantly from the end of 2009 (see Figure 2).

For instance, Ilmanen (2011: 274) argues that on average with carry trade what you see is what you get, i.e. carry trade earns roughly the interest rate difference, no more or less. He (ibid: 420) goes even further by calling interest rate difference the expected return and exchange rate change the unexpected return, i.e. the former is the expected return investor is on average expected to get. Surely, this does not happen always because this expected risk premium is only due to the fact that holding a higher interest rate currency is riskier and unexpected return can lead to major loss. Anyway, because the difference has been smaller as a result of the global downturn, this may explain the smaller returns. It will be interesting to see what happens when the interest rate difference one day increases to a more typical situation. Will there be a return back to the golden times prior 2008 or is the success story of carry trade finally over? Something has changed already. As a result of the Global Financial Crisis investors have started to pay more attention to expected growth differentials

between countries and structural factors, such as current account positions. Countries with high economic growth expectations, i.e. emerging markets, have seen their currencies appreciating. In the future, carry trade investors could go even more after developing countries' currencies, which typically have much higher interest rates than G10 countries. Surely, inflation and devaluation risks as well as transaction costs are higher for emerging currencies but the profit possibilities are tempting.

Equally important compared to the current interest rates are the expectations of the future interest rates and the story behind them. Rising/(declining) interest rates mean declining/(rising) bond prices. So, if the interest rate is expected to rise in the near future, investors may delay bond purchasing. Moreover, if risk-aversion is high, investors may back down completely. On the other hand, if the interest rate is expected to decline, bond investment currently is attractive. The same is true with currency values. If a currency is expected to depreciate/(appreciate), the foreign investments to the country may decrease/(increase). (Pekkarinen & Sutela 2002: 144-145.)

6.3 Systematic risk arising from other financial markets

Lustig et al. (2011) study behaviour of 35 currencies in 1983-2009 with monthly investment horizon and find large co-movement (either positive or negative) in exchange rate changes that gives at least a partial explanation to the forward premium puzzle. Earlier also Brunnermeier et al. (2008) have documented excess co-movement among currencies with similar interest rates. Lustig et al. claim that similar pattern in exchange rate changes indicates the existence of some kind of common risk factor. The authors continue that because country-specific risk factors (e.g. hyperinflation and default risk) can be neutralized by diversification, only common or global risk can compensate investors with excess returns. Exposure to the common risk factor increases monotonically from negative for low interest rate

currencies to positive for high interest rate currencies. The common factor seem to have much to do with changes in global equity market volatility as currencies with higher interest rates tend to depreciate/(appreciate) against currencies with lower interest rates when volatility is high/(low). Like mentioned earlier, carry trade is usually conducted by investing in a few currency pairs meaning that country-specific risk does not disappear completely. Thus, even though the global equity market turbulence surely has impact on carry trade returns, the authors' inference may lead to wrong conclusion because they do not consider other than global factors for the risk premium.

Menkhoff et al. (2012) investigate behaviour of 48 currencies in 1983-2009. Also they argue that excess returns of carry trade are a compensation for time-varying systematic risk, which is related to equity market volatility. High/(low) interest rate currencies yield higher returns when volatility is low/(high). The relation is more profound in the sample of developed countries but almost the same in the full sample of 48 currencies. The time-varying volatility risk also explains relatively well returns of equity and bond markets that should not be surprising, if all of them are correlated. General level of volatility is related to economic cycles being low in bull markets and high in bear markets. Moreover, from my perspective volatility is a direct consequence of risk-aversion and flight-to-quality is the reason behind the co-movement of all risky assets during turbulence.

Koijen and Vrugt (2011) find that carry trade is correlated positively only with commodities whereas the correlation with equities and bonds is negative. In practice, strong commodity price linkage is important determinant to currency value especially for big commodity producers, e.g. Australia, Brazil, Canada, New Zealand, and Russia. When connected to business cycles, the results suggest that carry trade and commodity risk premiums are pro-cyclical whereas equity and bond risk premiums are on average counter-cyclical. This is not surprising as often the

currencies of the commodity producers suffer during global recessions when demand for the commodities declines and their prices correspondingly. (Bank for International Settlements 2008.)

Baillie and Chang (2011) study carry trade for nine different currencies in 1978-1998 and find that UIP is more likely to hold when volatility is abnormally high and there is a large differential between the interest rates of the preferred funding currency and the second lowest funding currency. All else equal, profit-maximizing investors would prefer to fund carry trades with the lowest cost currency and invest in the highest yielding currency. The lower the interest rate of the preferred funding currency relative to alternative funding currencies, the more attractive it is to fund carry trade with this particular currency. This is surprising because the intuition is that the preferred funding currency should depreciate further due to heavy borrowing, i.e. just the opposite to the finding of Baillie and Chang. The explanation is that wide interest rate difference between the preferred and other funding currencies is typical for market turbulence. We already know that abnormally high volatility is associated with a rise in investors' risk-aversion that is when UIP holds better. The authors succeed to discover also other peculiarities. UIP holds more likely when Swiss franc is not the preferred funding currency. In turn, UIP is more likely to fail when carry trade is conducted by using the yen as a funding currency and the dollar as a target currency, i.e. the dollar does not depreciate against the yen at least as much as predicted by the interest rate difference.

6.4 Liquidity risk

Many argue that carry trade excess returns are a premium for liquidity risk. For instance, Brunnermeier et al. (2008) suggest liquidity to be the key driver in negative skewness of carry trade returns because rapid decrease in liquidity can lead to currency crashes. Menkhoff et al. (2012) argue too that stronger price movements

(volatility) indicate lower liquidity. It is hard to see the volatility and liquidity effects independently from each other because they are so closely related and neither of them can be observed directly. The authors do not rule out an explanation that volatility is "just a summary measure of various dimensions of liquidity, which are not captured by liquidity proxies". Typically liquidity risk stems from the uncertainty at what price investors are able to close their open positions when the market starts to go to wrong direction. In stock markets illiquidity and risk are strongly related but the foreign exchange market is said to be the most liquid because of its enormous turnover. Indeed, major countries' currencies as well as their bonds have much liquidity on the individual level. Moreover, Perraudin and Vitale (1996: 89) find that decentralized markets, such as the foreign exchange market, are less subject to crashes than are centralized markets because liquidity does not disappear as rapidly. The Global Financial Crisis undermined this notion although it did not lead to widening of bid-ask spreads for major currencies. Instead carry trade investors were hit especially due to problems in assuring funding liquidity. The investors faced increased funding constraints when banks become more concerned about their own access to capital markets and demanded higher margins. Like wider TED spread indicated, money did not circulate well between banks and from banks to customers intensifying (il)liquidity spirals. (IMF 2008.)

The foreign exchange market differs from stock markets in the wide use of leverage to enhance profit margins. Leverage magnifies the liquidity risk because liquidity can disappear very quickly when risk-aversion rises and investors want/need to cover their open positions. Then, there may not be enough buyers in the market that can cause more panic and lead to even larger price drops. (Bank for International Settlements 2008). What happens in the time of market turmoil, is that investors want to get rid of their risky carry trade positions. This leads to abandonment of long positions because highly leveraged short positions need to be paid back. Thus, target currencies experience heavy money outflows and funding currencies inflows causing

them to depreciate and appreciate, respectively. In normal circumstances, carry trade involves huge amount of capital. The estimates vary somewhere between \$1 trillion and \$6 trillion. If the money starts to move to some direction, it has an enormous effect on exchange rates and the overall global economy, as we will learn next.

The most popular funding currency has been the yen as Japan has tried to tackle the deflation that the country has been experiencing for over a decade by zero interest rates. In normal times, this lead to depreciation of yen and appreciation of target currencies. In the beginning of 2007 the yen carry trade was estimated to be worth \$1 trillion. The Global Financial Crisis reversed the pattern. Investors panicked and sold their investments of higher interest rate currencies pushing their values down. The money flowed to the opposite direction leading to appreciation of yen. During a few months time starting in July 2008 yen appreciated dozens of percents against high interest rate currencies. When the most popular funding currency appreciated so much, it is not surprising that unhedged carry trade strategies made big losses in 2008. Even Japan was hurt from the appreciation of its currency as its economy is highly dependent on exports. (Vistesen 2009.)

Lowenstein (2000: 42) argues that using leverage is extremely risky and investors actually give up control of their other investments as well. The securities may seem unrelated but they are not if they are owned by the same investor. When market turbulence hits to some of the investments and especially if they are leveraged, investor may be forced to sell what he can instead of what he should. Hence, risk in ensuring funding liquidity is critical for carry trade as lack of it can lead to forced fire sales in illiquid market. This connection is interesting and may explain why different asset classes are heavily correlated during market turmoil. Thus, carry trade risk premium may indeed arise from other financial markets even the connection does not seem present during good times.

6.4.1 Algorithmic trading

The rise of algorithmic trading is contributing to the overall carry trade risk if it is leading to reduction in liquidity during turbulence. Algorithms are computer programs that use both past and real-time data to detect profitable trading opportunities. Hence, they can speed up price discovery and improve market efficiency that is embraced by many scholars. Use of algorithmic trading started in the U.S. equity market in the 1990s. In the foreign exchange market algorithmic trading has grown extremely rapidly since 2005 and today it is an important part of currency trading. Chaboud et al. (2009) study, what effects algorithmic trading has in the interdealer market. Their data consists of three most traded currency pairs: euro-dollar, dollar-yen, and euro-yen in 2006-2007. In the interdealer market majority of transactions nowadays involve at least one algorithmic counterparty. Increasingly often machines are trading with each other. Their effect on exchange rates depends on how the algorithms are designed and programmed to act under different market conditions. If algorithms are programmed similarly, their trading strategies are correlated that may cause problems in the form of taking same side of the market resulting in exaggeration of market movements. The authors, indeed, find that trades conducted by machines are more correlated than human trades. Since many algorithms are programmed to avoid volatile times, they may also decrease liquidity during turbulent times. This is a real concern also from the perspective of carry trade.

When comparing human trades and algorithmic trades further, the authors find that human trades are more essential for price discovery for euro-dollar and yen-dollar currency pairs, whereas algorithmic trades are dominant for euro-yen exchange rate. There seems to be a logical explanation for this. Human traders are the informed ones since beforehand programmed algorithms can never be as up-to-date about fundamentals as capable humans. That is why, they are leading the price discovery process in the two largest currency pairs. The price discovery for the third exchange

rate, euro-yen, happens more or less by the cross-rates of euro-dollar and yen-dollar. If euro-yen exchange rate is briefly out of the line, machines simply are faster than humans in exploiting this arbitrage opportunity emerged by cross-rate price formation.

6.5 Peso problems

Negative skewness and excess kurtosis indicate that the risk profile of carry trade seems to result from rare but extreme crashes. Jurek (2009) investigates the existence of this so-called crash risk premium by using option data on foreign exchange rates in 1999-2008. He forms crash-neutral carry trade portfolios, in which exposure to rapid devaluations of the high interest rate currencies has been hedged. If the crash risk premium explains the carry trade returns, the hedged portfolio should not earn any excess returns. However, results show that hedging decreases the returns by 15-35% but does not cancel them out completely. In other words, carry trade strategies continue to deliver excess returns. When Adaptive Markets Hypothesis is discussed, we will notice that the overly cheap hedging may have been due to the fact that the market did not recognize the obvious arbitrage opportunity by the combination of carry trade and appropriate options. Today the situation must be wholly different. Anyway, although the crash risk is obviously contributing to carry trade risk premium, the existence of serious peso problem is questioned because carry trade strategies restarted to be profitable already in 2009, and the 2008 losses were actually relatively small compared to the cumulative returns from the past decades (for my shorter research period the 2008 losses were remarkable).

6.6 Speculation and trading itself

6.6.1 Speculation

Unlike stock speculation, which is widely accepted practice, currency speculation is blamed causing problems to national economies. It has been approximated from 70% to 90% of foreign exchange trading to be speculative, i.e. the investor has no plan to actually make the currency delivery but rather just speculates on the movement of that particular currency. Carlson and Osler (2000) find that high levels of speculative activity increase volatility. Furthermore, because of the noise trader risk, which refers to the possibility that mispricings can get worse in short-term due to trading of noise traders, trend chasing and bubble boosting can be rational strategies. Trends and eventual reversion create excess volatility, which causes extra costs to producers and consumers. However, for speculators high variability of returns can offer profit-making opportunities.

Osler (2000) points out that most research do not capture the essence of currency trading if their data is not sufficiently high-frequency. For example, minute-to-minute trading is common for algorithms. Also the usage of stop-loss methods makes investment horizons shorter as most of investors do not sit and wait that their investments would bounce back. 80% of foreign exchange positions are held for less than one week and 40% are held for less than two days. Osler (2003) finds stop-loss usage in almost every currency trading position. Extensive use of leverage can explain why stop-loss methods are so popular. When trend goes over certain limit to wrong direction from an investor's point of view, stop-loss quickly closes the risky leveraged position in order to minimize losses. Price trend, thus, extends further in short-term leading also to increased volatility.

Jylhä and Suominen (2011) study currency speculation of hedge funds by using data of 11 currencies in 1979-2008. The authors find carry trade returns to be correlated with the returns from various hedge fund indexes. What can explain this? First of all, hedge funds certainly engage in carry trade and because of their size, their actions can affect exchange rates. For example, in the autumn of 2008 there were significant

money outflows from hedge funds, which then had to abandon their carry trade positions contributing to the depreciation of the high interest rate currencies. Still, the authors suggest that the index returns must be more affected by systematic factors also common to carry trade than pure carry trade investments.

6.6.2 Trading itself

Plantin and Shin (2006) point out that carry trade reinforces the violation of UIP as investors take short positions in low interest rate currencies preventing them from appreciating and long positions in high interest rate currencies helping them to appreciate further. Excess returns of carry trade, thus, become self-fulfilling at least in short-term. Surely, this cannot continue forever since it leads to overvaluation of the target currency and undervaluation of the funding currency. Another popular trading strategy, which strengthens short-run misvaluations, is momentum. In momentum strategies investors take long positions in currencies with positive past returns and short positions in currencies with negative returns. Baillie and Chang (2011) say that if momentum traders respond to past price movements instead of expectations about fundamentals, the trend will be reinforced and moves further away from its equilibrium.

Osler (2000) and Jongen et al. (2006) agree that use of technical analysis reinforces trends. Their idea is similar to Goodhart's (1988), who argued that exchange rate changes might be determined by current balance of technical analysts and fundamentalists. Jongen et al. find that as exchange rate moves further away from its fundamental value, fundamentalists get driven out of the market. Technical analysis remains active and continues to push the exchange rate trend further. In some point, the bubble will burst and the valuation is reversed by investor and/or central bank activity. When the exchange rate is moving back to its fundamental value, both fundamentalists and technical analysts agree on the direction of the rate and remain

active since both strategies are profitable. This speeds up the price push back to its fundamentals and thus the value corrections (reversals) can happen fast. In practice, fundamentalists and technical analysts should not be seen only as opposite forces since most traders use both indicators in their decision-making.

Although carry trade and momentum are independent strategies, they are also linked to each other. Carry trade funding/(target) currencies that are heavily borrowed/(invested in), seem to depreciate/(appreciate) over time and thus have short/(long) position in momentum portfolios. Thus, carry trade and momentum strategies together can amplify exchange rate movements and violate UIP more than they would do individually. (Baillie & Chang 2011.) Even the two strategies have some similarities, Burnside et al. (2007) find that the momentum and carry trade returns are generally uncorrelated and therefore diversifying across both strategies reduces overall risk. Momentum trading is more diverse than carry trade because for trend chasing strategies it does not matter if the exchange rates are moving up or down as long as they are moving to some direction.

6.7 Central bank activity

Clearly central bank interventions, which can lead to large correction in exchange rates, are a risk for carry trade and may explain a part of the gained excess returns. Central banks sometimes push exchange rates and are sometimes pulled into the market, depending on the current market situation and their goals. Sager and Taylor (2006) see that central banks are increasingly using small part of their foreign exchange reserves to wealth creation (e.g. by currency derivatives) particularly in Asia. On the other hand, Neely and Weller (2011) find that central bank interventions are rather responses to strong trends that exist in the market. In other words, central banks are pulled into the market because their currency values run too far away from their target ratios. Mark and Moh (2007) study dollar-deutschemark and dollar-yen

currency pairs in 1976-1998 and, indeed, find that the forward premium puzzle intensifies during times when central banks intervene. For the dollar-yen pair, the puzzle is present at all times but is much stronger during interventions. For the dollar-deutschemark pair, the puzzle exists only during times of intervention. So, if you happen to own a manual for central bank policies, their interventions and hence UIP deviations should not come as surprises but they could be exploited.

7 BEHAVIORALIST CHALLENGE TO MARKET EFFICIENCY – ARE EXCESS RETURNS ANOMALIES?

7.1 Behavioral biases

As risk-based explanations falter to give a complete answer for the carry trade excess returns, attention is now turned to behavioral finance and market frictions. Behavioral finance assumes market participants to be subject of various cognitive biases documented in the psychology literature that impact their trading decisions. Common starting point to all of these biases is the acceptance of investors' bounded rationality or irrationality that hinder the diffusion of fundamentals into asset prices. Thus, it may be possible to identify profitable trading strategies, like carry trade. Neely and Weller (2011) say that exchange rates clearly reflect mass psychology moving from confidence, optimism, and greed to pessimism, fear, and panic. These can explain the described pattern of carry trade returns: an initial underreaction to UIP (non-depreciation of target currencies) and a delayed overreaction (quick appreciation of funding currencies). Even though the usage of stop-loss strategies and algorithms takes some burden away from human decision-making, we cannot completely deny the impact of psychological biases on exchange rates. Indeed it is market psychology behind the aggregate risk-aversion levels.

One of the most often quoted behavioral bias among investors is overconfidence. Oberlechner and Osler (2009) conducted a survey among North American foreign exchange dealers and found a vast majority of them to overestimate their own abilities (“better-than-average-effect”) and private information (“miscalibration”), and underestimate risks and uncertainty. Burnside et al. (2010) say that overconfidence indeed can offer an explanation to the forward premium puzzle. Overconfident investors overreact to their signals about future inflation causing overreaction to the interest rates. This happens especially to the interest rates of

target currencies, whose inflation risk is usually higher. Then the interest rate differential is larger than it should be under perfectly rational world making the forward exchange rate mispriced compared to the spot rate. The idea that forward exchange rate could be misvalued is interesting and has not been considered much in the literature. It could explain why spot exchange rate does not react fully to forward rate. Overconfidence, like any other psychological attribute, is time-varying being lowest on times of market turbulence. Thus, UIP seems to hold better/(worse) when investors are less/(more) overconfident.

7.2 Microstructure of the foreign exchange market

Among behavioral finance there is strong school that says more emphasis should be put into the research of microstructure of the foreign exchange market. Instead of macroeconomic fundamentals, the microstructure literature concentrates on smaller market frictions in the foreign exchange market that affect decision-making of investors and thus exchange rates. Especially the importance of transmission of information among market participants and the resulting heterogeneity in their expectations and behaviour is highlighted. (Sarno & Taylor 2001.) Different expectations stem from information asymmetries. Investors are different and possess different amount of information, e.g. some have private information. Moreover, information can be difficult to interpret and all market participants do not have enough resources and/or skills to learn the complicated relationships of the economy. Investors also attach different weights on public information, which is based on their past experience and success in forecasting exchange rate changes as well as the forecasting technique they use. Thus, investors can interpret even the same information very differently. That is why new fundamental information diffuses only slowly to exchange rates. (Jongen et al. 2006.)

Froot and Thaler (1990: 188-190) argue that for UIP failure it is enough that some of the investors are slow in responding to changes in interest rate differential. These

investors may need time to think about trades before executing them, or they simply cannot respond quickly to recent information. Push to equilibrium state may be hindered further if rational investors try to exploit other group's slower movements. In practice, interest rate differential is quite stable undermining this explanation. Neither there is any evidence that UIP fails only when interest rate differential changes. Jongen et al. (2006) use survey forecasts for the major three exchange rates along several forecast horizons in 1989-2004. There can be identified distinct periods of high and low dispersion, where market participants disagree how the exchange rate will change. The dispersion of expectations is positively related to forecast horizon, i.e. dispersion increases when forecast horizon gets longer and vice versa. Hence, investors seem to disagree more on what will happen in long-term than in short-term. Earlier the same result was found also by Sarno and Taylor (2001). This is interesting as exchange rates are said to bounce back to their fundamentals in long-term (e.g. Meredith & Chinn 1998). Perhaps, fundamentals are not at all easy to interpret.

Also Sager and Taylor (2006) say that more emphasis should be put to understand the different customer types and their distinct trading motives. Macroeconomic equilibrium models fail to offer accurate exchange rate forecasts because they do not consider these market frictions. The authors divide market participants along how active/passive and informed/uninformed they are. Active traders are clearly motivated by profit-making opportunities or they have other bright goals, which they want to target, e.g. central banks. Passive traders' foreign exchange exposure comes from other sources than currency speculation, e.g. from international trade. Passive investors either leave their exposure unhedged or they hedge it without much consideration about the future direction of exchange rate movements.

Informed/uninformed investors can be divided along how relevant information (either public or private or both) they possess. Central banks have the best data

available that is relevant to their own currency. Thus, central banks and all the market participants, which get first hand information about central bank interventions and changes in the foreign exchange reserves, are among the informed ones. Also financial firms, whose core business is to follow the currency market, can be said to be informed. Furthermore, order flow (net demand = demand - supply) is very important source of private information that only few market participants have. Current order flow cannot be easily estimated because dealers keep their customers' orders strictly confidential, e.g. order flow information used by research is only got much later. Since large dealers see more customer orders, they are potentially better informed than smaller dealers. Typically large dealers that have access to the information of order flow and overcrowded carry trade positions, participate in swing trading, which means selling a currency when it is overbought and buying a currency when it is oversold.

Order flow is a powerful determinant of exchange rate changes particularly because it allows the wider market to learn about the private information and trading strategies of better informed traders. It has, however, been unclear how the information in order flow gets into the exchange rate. Osler et al. (2011) illustrate this process by showing how asymmetric information affects exchange rate discovery. Everything starts from the facts that foreign exchange trading takes place in the two-tier market and not all market participants share the same information. Dealers know their customers by type and trade size. Thus, it is possible for them to identify on average, which customers are informed and which uninformed. The interdealer market is, in turn, anonymous and large trades are commonly split into smaller trades. Hence, interdealer trading by itself is less likely to carry much information. The authors find that after trading with informed customers, such as financial firms, dealers place similar orders in the interdealer market. As a result, exchange rate moves within the interdealer market to the direction dictated by the increased trading. This new currency value is then used by dealers in their quotations

to customers. Thus, new information, which informed customers brought to the market, is not reflected into the dealers quotations immediately but only after a round in the interdealer market. Sometimes it may take even few days until the order flow information is revealed to the whole market. On the other hand, trading with uninformed customers, such as commercial firms, does not trigger extraordinary trading activity or move considerably exchange rates in the interdealer market.

Akram et al. (2008) study high frequency data of dollar-euro, dollar-pound, and dollar-yen currency pairs and find numerous brief deviations from the law of one price, which enable excess returns even after transaction costs. These arbitrage opportunities have gone undetected by earlier research because sufficient short-interval data has not been available. The authors say that the decentralization of the foreign exchange market is an important reason for the arbitrage opportunities. Information gathering is difficult because the quotations of numerous dealers are not easily observable. Hence, transactions may and do occur at the same time at different prices. Frequency, duration, and size of the arbitrage opportunities, however, disappear rapidly indicating that the foreign exchange market works quite efficiently after all.

7.3 Adaptive Markets Hypothesis

Lo (2004) proposes a new perspective called Adaptive Markets Hypothesis (AMH) that tries to reconcile the opposing views of market efficiency and behavioral finance. Lo hopes AMH to be taken as an improved version of Efficient Market Hypothesis (EMH), just being more realistic version of it by also taking into account the behavioral biases affecting the decision-making of market participants. Basically, market participants are heterogeneous and boundedly rational. When new information arrives, not all of the participants can act perfectly rationally because learning is difficult, costly, and takes time. Therefore, the forces that drive prices to

their fundamental levels are weaker and operate over longer periods than what EMH predicts. Prices will eventually get back to their fundamental values because the competition will cancel out any excess profit opportunity. Prices reflect at any current point as much information as dictated by the combination of environmental conditions and the nature of market participants. Thus, according to AMH, profit opportunities will generally exist in financial markets, but the forces of learning and competition will gradually make these opportunities to disappear. However, there will appear new profit-making opportunities, which will then go through similar cycle of learning and competition. Because learning takes time, more complex trading strategies will last longer (be profitable longer) than simple ones.

The idea of AMH is supported by Schwert (2002), who found that certain well-known stock market anomalies (the size effect, the value effect, the weekend effect, and the dividend yield effect) have weakened or disappeared after they were published in the academic literature. Immediately after the anomalies became common knowledge traders started to exploit them by adopting investment vehicles that implemented the profitable strategies. Gradually the named anomalies were either weakened or arbitrated away. This could happen also to carry trade and other strategies that exploit the recession risk premium. Something has happened already. Ilmanen (2011: 287) points out that earlier the tail risk of carry trade returns was much cheaper to eliminate via options compared to the similar risks in equity markets. This is not the case anymore as traders have learnt to exploit the predictable patterns.

8 MODELLING CARRY TRADE RETURNS

8.1 Background for modelling

Both UIP and PPP are normative approaches, i.e. hypotheses how exchange rates should behave. My approach is positive that means I aim to describe how the world really works in practice. Obviously UIP and PPP have their weaknesses and we can call them oversimplifications that put all their eggs in one basket. UIP claims interest rate difference to be the sole source of exchange rate movements while PPP stresses differing price levels. Apparently variation in exchange rates could be better explained by multiple factors although picking up the right factors is more than difficult to do. The correlation to different risk factors is seldom stable but instead can vary significantly through time depending on the current state. Furthermore, individual factors may seem to have explanatory power purely because they are correlated with other factors (maybe even unidentified factors).

Surely, there are several macroeconomic factors driving the time-variance of the carry trade returns, just to name a few e.g. inflation, GDP growth, or any other factor that can lead to large devaluation of the target currency. The problem is that models built on the macroeconomic factors have not succeeded to capture the dynamics of the exchange rates very well at least in short-term. The problem might be due to the nature of the models commonly used because macroeconomic fundamentals are difficult to measure exactly and put into indicators (the joint-hypothesis problem). Nonlinear relationships cannot be pictured satisfactorily with linear, one regime OLS regression models. Hence, the explanatory power of the macroeconomic variables may show only when modelled with the appropriate method (e.g. Korhonen 2005). Later we will also learn from market frictions literature that fundamentals are not interpreted homogeneously among investors. Furthermore, commonly macroeconomic data is not high frequency enough and it seems that the effects of

macroeconomic fundamentals are incorporating into exchange rates too slowly to provide a meaningful explanation for short-term exchange rate changes. Accurate macroeconomic data is published with lags and sometimes even revisited later. For a successful trading strategy we need variables, which both work and are available now. If we do not have lagged values at our disposal, we are not able to exploit the information. Ideally we would prefer all our model's exogenous variables to be lagged values because if we succeed to find predictability, we are one step closer to a money-making machine (in this paper money-making means that on average odds are on your side).

Another problem is that most macroeconomic time series often contain unit roots. With time series variables we have to be careful since apparent and statistically significant causal relationship could exist only due to common external factors or just coincident (spurious regression). For instance, exchange rates of similar countries are frequently cointegrated, i.e. they share a common stochastic trend (co-movement) that is caused by a common external factor, e.g. economic state. (Cowpertwait & Metcalfe 2009: 211-217.) Hence, it is important to have a plausible theory behind that can verify the results. Our case is a little bit simpler because we use carry trade returns and differencing removed persistence, i.e. consecutive data points in the return time series are not correlated with each other. Moreover, even though macroeconomic factors can be very complex, they are merely just pure data failing to take enough into account the psychological side of the financial markets. My aim is to fill this gap by considering various risk-aversion indicators and whether they can predict exchange rate movements more precisely.

8.2 Model

In order to model the carry trade returns and risks, I use Logistic Smooth Transition Regression (LSTR) -model, which allows a nonlinear relationship between

explanatory variables and exchange rate change (in contrast UIP is a linear model). LSTR1-model makes it possible to describe processes whose dynamics (i.e. mean and variance) is different between two regimes, e.g. expansions and recessions. Thus, due to time-varying risk premium, carry trade returns can be related to distinct regimes (normal times and market turbulence). The exact transition period is often difficult to measure or forecast but STR helps to model the period by assuming regime transition to be a continuous process depending on the transition variable. The smooth (time-taking) transition between regimes seems to fit well for the foreign exchange market, which is characterized by heterogeneous participants like investors, speculators, traders, central banks, and tourists. Some of them have motives that are something else than profit making, e.g. multinational firms may want to hedge their foreign exchange exposure. Thus, they can be referred as noise or liquidity traders, who need to buy or sell currencies while conducting international trade, no matter of the level of exchange rates. Also motives of central banks differ from the rational profit making assumption, which is the core of market efficiency based asset pricing models. The advantage of using STR-model is that it does not assume perfectly rational investors but accepts investors heterogeneity. Taken all this together, it is unlikely that all the market participants would change their currency trading at the same time and manner. Clearly, a smooth transition from one regime to another is more realistic.

The STR-modelling cycle consists of specification, estimation, and evaluation. In specification phase we test our linear base model (UIP) against STR-model. First, we need to choose potential transition variables and then perform F-test to see whether the linear relationship between independent and dependent variable could be modelled more accurately by allowing a smooth regime change depending on one of the transition variables. If the null hypothesis of linearity is rejected by one or more transition variables, STR-model will be an improvement to the linear base model. Then, it would mean that the carry trade returns are not regime-independent

suggested by linear UIP framework but they react asymmetrically to interest rate differentials depending on the different regimes. For a transition variable we will choose the variable, which has the strongest rejection of linearity (lowest p-value). In estimation phase the STR-model parameters are estimated. The statistical software that I utilize, JMulTi, uses conditional maximum likelihood, which is more suitable than OLS for estimating nonlinearly behaving parameters. Then, alternative models can be compared by information criteria (JMulTi exploits Akaike, Schwarz, and Hannan-Quinn criteria). Last, model fitness can also be measured by R^2 , which is the proportion of variance explained by the selected risk factors. In the last phase the model is evaluated by misspecification tests.

STR-model is presented in equation (9).

$$\Delta S_{t \rightarrow T} = x_t' \varphi + (x_t' \theta) * G(\gamma, c; z_t) + \varepsilon_{t \rightarrow T} \quad (9)$$

where φ (linear part of the model) and θ (nonlinear part) are the parameter vectors, x_t is the vector of explanatory variables (exogenous variables (STR) or lags of endogenous variable (STAR)), and ε is the independent and identically distributed error term. G is a monotonously increasing function of the transition variable z_t and bounded between 0 and 1, see equation (10).

$$G(\gamma, c; z_t) = \frac{1}{1 + e^{-\gamma(z_t - c)}} \quad (10)$$

G determines the degree of reversion towards the UIP condition. Slope parameter γ indicates how rapidly the transition of G from 0 to 1 takes place. Slope parameter γ should be standardized, i.e. made scale-free by dividing it by the standard deviation of the transition variable. (Teräsvirta 2004.) With high gamma values (measured in hundreds or thousands) STR-model is more difficult to estimate because it

approaches a switching regression model. A moderate value of gamma, e.g. $\gamma = 1$, imposes a slow transition whereas $\gamma = 10$ indicates already a rapid change between the regimes. Coefficient c represents the point of transition between the two extreme regimes.

8.3 Different STR-models

Because our theoretical background assumes two regimes, STR-model with one location parameter c is enough. This is the so called LSTR1 model. If we wanted to highlight the mean-reversing behaviour of the exchange rates, i.e. if we had a longer-term data frequency, we could define a different transition function: either LSTR2 (second order logistic function) or ESTR (exponential function). Both of them assume three regimes, where the inner regime represents the equilibrium state and two symmetrical outer regimes the deviations from the equilibrium. Clearly, the exchange rate behaviour is different between the inner and outer regimes due to the dynamics of mean-reversion, i.e. the larger the deviation, the faster the mean-reversion. The main difference between LSTR2 and ESTR is that the former is built around two location parameters (the regime switching points between inner and two outer regimes) whereas the latter one utilizes only one location parameter (the midpoint of the inner regime). Both of them have their own pros and cons but in this paper we do not need to go deeper to them. Furthermore, there are widely used autoregressive versions of all of the above mentioned STR-models (i.e. STAR-models), which are utilized especially in explaining the mean-reversion property of real exchange rates. For example, Korhonen (2005) uses ESTAR-model and finds that real exchange rates follow random walk when deviations from PPP are small but become increasingly mean-reverting when deviations increase.

Sarno et al. (2006) utilize ESTR-model and find that small deviations from UIP are normal in the foreign exchange market and not due to large market inefficiencies.

Their weekly data consists of spot and 1- and 3-month forward exchange rates for dollar, yen, pound, franc, and German mark/euro in 1985-2002. The authors claim that a certain range of deviations is caused by limits to speculation and opportunity costs of capital. When currencies' Sharpe ratios are small, even statistically significant deviations do not attract speculative capital to exploit them because their economic importance is too small and there exist more attractive investment opportunities (the inner regime). However, when Sharpe ratios are large enough, the deviations are corrected rapidly towards the UIP condition (the outer regimes). Thus, it is the size of the deviation that induces the mean-reversing behaviour of exchange rates.

Also Baillie and Kilic (2006) find strong nonlinearity in the relationship between spot and forward exchange rates. Their data comprises of monthly observations of spot and 1-month forward exchange rates for G10 currencies in 1978-2002. The authors use LSTR1-model and find that it is not only the size but also the sign of the forward premium that matter. The deviations from UIP are persistent when U.S. dollar's forward premium is negative (i.e. discount) or relatively small positive. This means that UIP fails particularly when U.S. interest rates are high and the dollar is expected to depreciate. In turn, when positive forward premium is large enough, adjustment towards UIP state happens fast. In other words, UIP holds when U.S. interest rates are low and the dollar is expected to appreciate. Earlier also Wu and Zhang (1996) have obtained similar results. What could explain this documented asymmetry? Baillie and Kilic discuss the familiar explanations of transactions costs, limits to speculation, and heterogeneous investors, but perhaps there is something more. The explanation could have much to do with the central roles of U.S. economy and the dollar in global economy. For example, Menkhoff et al. (2012) find signs that in addition to time-varying volatility risk, carry trade excess returns are related to "dollar risk factor", which means other currencies' tendency to simultaneously either appreciate or depreciate against the dollar. Being a safe-haven currency, the dollar

has not been viewed as highly risky even at times of high interest rates in the 1970s and 1980s. High interest rates with little risk tempt investments that indeed explains why the dollar has not depreciated like predicted by UIP.

Interest rate differential is not always used as an explanatory variable in STR-models. For instance, Christiansen et al. (2010) explain carry trade returns by LSTR1-model that has two independent variables: equity and bond returns. The authors try six different transition variables and find that TED spread and foreign exchange market volatility work better than VIX, bid-ask spread, order flow of JPY/USD, and equity market volatility. Liquidity and volatility factors have high correlation with each other that is not surprising as typically liquidity is lower and volatility higher during market turbulence. Moreover, the authors argue that liquidity and volatility have direct effect on asset returns. Carry trade returns are positively correlated with equity returns and negatively correlated with bond returns, illiquidity, and volatility. The correlations increase dramatically in turbulent times when equity markets traditionally lose value and bond markets gain. In fact, in normal times there cannot be seen any correlation between carry trade and bond returns. Equity and bond returns can explain part of the carry trade returns namely because all financial markets are regime-dependent and co-move during market turmoil when illiquidity and volatility are higher.

I do not succeed to find significant linear correlation between carry trade and equity market returns, see Table 6, which is surprising as they both fall in the category of risky assets. In fact, the sign of the beta coefficient shows to another direction than proposed by Christiansen et al. When testing the relationship with LSTR1-model, there emerges some significance with the present S&P 500 returns (not lagged) but it is not as strong as using interest rate difference as an explanatory variable.

Table 6. OLS regression for carry trade returns.

Independent variable	Alpha	t-value of alpha	Beta	t-value of beta	R ²
One-day lagged S&P 500 returns	0.0002	(1.5462)	-0.0120	(-1.5382)	0.0006
S&P 500 returns	0.0002	(1.5507)	-0.0150	(-1.9165)	0.0009

8.4 Modelling

Like the results from Table 3 showed, we can form our linear base model by taking UIP as the independent variable. After all, interest rate differential is the starting point for carry trade. With carry trade there is no underlying theory offering the appropriate transition variable. However, since our theoretical background claims and empirical evidence shows that the carry trade returns vary depending on the business cycle, i.e. predicted carry trade returns are high at the bottom of a business cycle and low at the top of a boom, we can try various indicators of recession and investors' risk-aversion. In this paper I try the following three transition variables, which all aim to answer to question how financial risk and risk-aversion is changing.

- ⤴ VIX
- ⤴ TED spread calculated as a difference between 3 month T-bill and LIBOR
- ⤴ Credit spread calculated as a difference between 10-year maturity U.S. government bond and Moody's Baa-rated corporate bonds

Since widening TED and credit spreads as well as increasing VIX are signs of turbulence, I needed to change the sign for all of these potential transition variables in order to make the model work according to our theory. Now when z_t is increasing/(decreasing) or equally getting better/(worse), G approaches 1/(0). When G is 0.5, z_t is equal to the location parameter c . When G approaches zero, exchange rate change follows linear UIP model, see equation (11).

$$\Delta S_{t \rightarrow T} = \alpha_l + \beta_l(r_t^* - r_t) + \varepsilon_{t \rightarrow T} \quad (11)$$

When G is larger than zero, exchange rate change becomes nonlinear depending on the value of the transition function G . STR-model can also be viewed as linear model with time-varying parameters, see equation (12). Footnotes l and nl stand for linear and nonlinear, respectively.

$$\Delta S_{t \rightarrow T} = (\alpha_l + G * \alpha_{nl}) + (\beta_l + G * \beta_{nl})(r_t^* - r_t) + \varepsilon_{t \rightarrow T} \quad (12)$$

All the exogenous variables are one-day lagged compared to the actual exchange rate changes. Because of the similar daily frequency, we do not have any overlap with our data. Hence, our parameter and standard error estimates should be valid without correction. The independent variable, i.e. predicted exchange rate change of the portfolio, naturally does not vary much because interest rates are very persistent. Still, Augmented Dickey-Fuller test with nonzero mean (i.e. includes an intercept) shows that the interest rate differential does not contain unit root. All the transition variables either contain unit roots (TED spread and credit spread) or are close to unit root processes (VIX). For purposes of forecasting or building a trading strategy, persistence of a transition variable is not a bad thing because it helps to identify the regime changes more accurately than more randomly varying variables.

8.5 Results

The hypothesis of linearity is rejected for all of the transition variables. Based on the information criteria, TED spread seems to work best. Table 7 shows parameter estimates for our STR-model, where interest rate differential is the independent variable and TED spread the transition variable. Only gamma is not statistically

significant. Location parameter is TED spread of 4, which we can utilize in our trading strategy. Model's R^2 is low but it is higher than with linear models.

Table 7. Parameter estimates for the STR-model.

Parameter	Estimate	t-value
Alpha (linear)	0.0386	4.89
Beta (linear)	295.35	5.35
Alpha (nonlinear)	-0.0372	-4.77
Beta (nonlinear)	-284.63	-5.23
Gamma	2.1493	1.61
C	-4.0481	-4.73
Std dev of residuals	0.0065	
R^2	0.0142	

Based on Figures 8 and 9, modelled exchange rate changes do not capture too precisely the noise of actual changes. The higher volatility from 2009 onwards is not captured at all by the model. Still, the overall large outlines are similar and volatility clustering is centered for 2008.

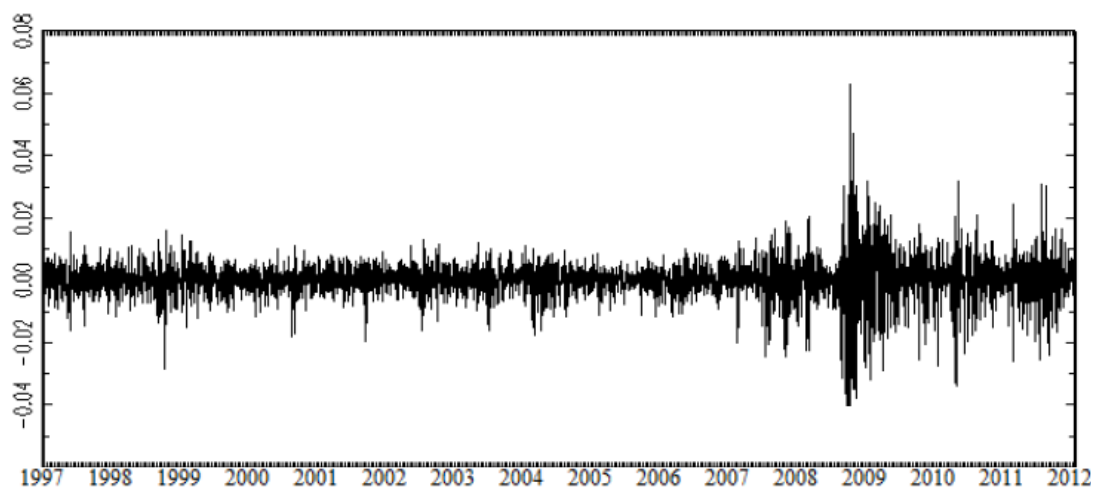


Figure 8. Actual exchange rate changes.

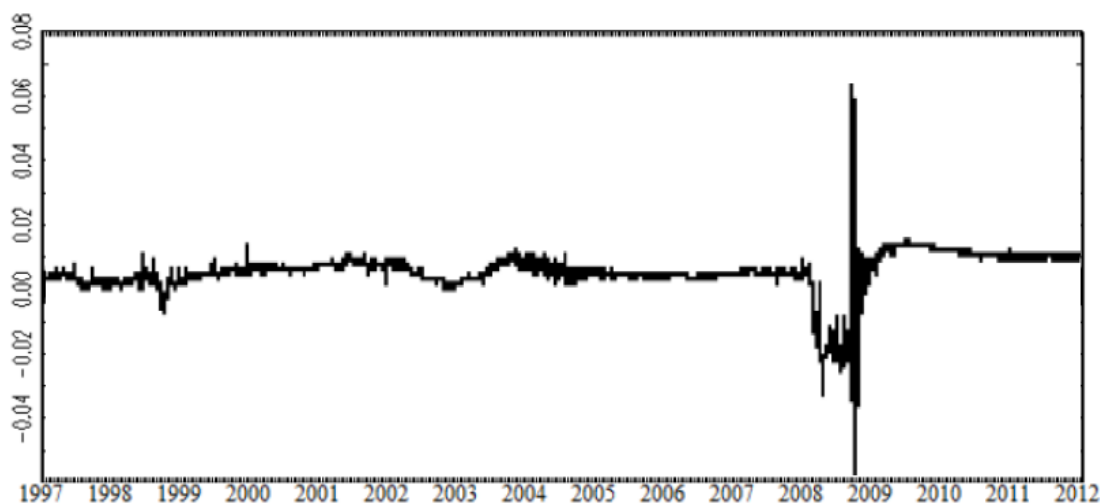


Figure 9. Modelled exchange rate changes.

Figure 10 shows the model's transition function G over time. Most of the time G is close to value of 1 meaning that also the nonlinear part of the model works collecting risk premium. Like Figure 4 showed, TED spread has widened moderately in 1998 and 2004 and hugely in 2008 that can be seen from the transition function. During the last crash only the linear part of the model works (G is close to 0) indicating that the risk materialized.

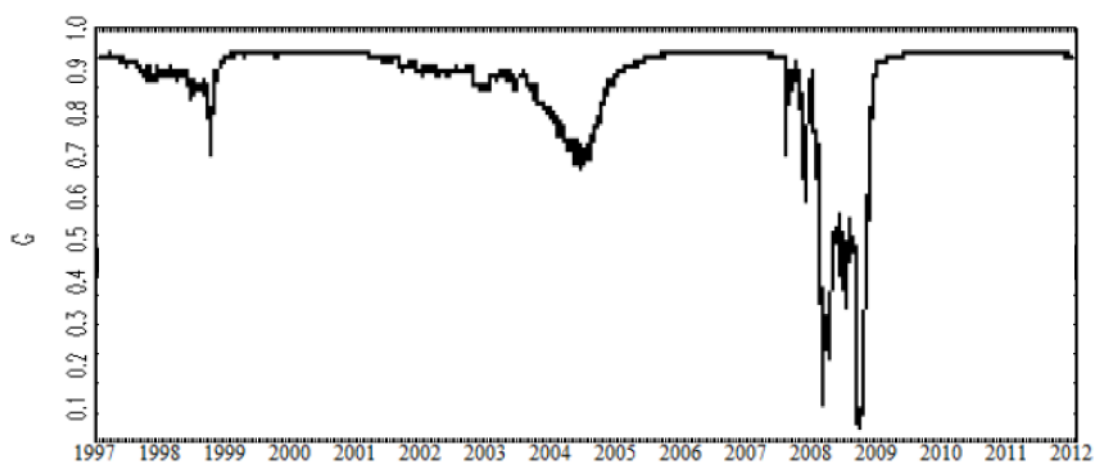


Figure 10. Transition function over the research period.

Figure 11 shows the transition function once more. When TED spread is below 2, G is close to 1 meaning that the nonlinear part of the model works fully. From 2 on the value of G starts to decrease indicating that the carry trade returns should be decreasing as well. The gamma value slightly above 2 means that the speed of the transition is moderate that can be seen also from the figure.

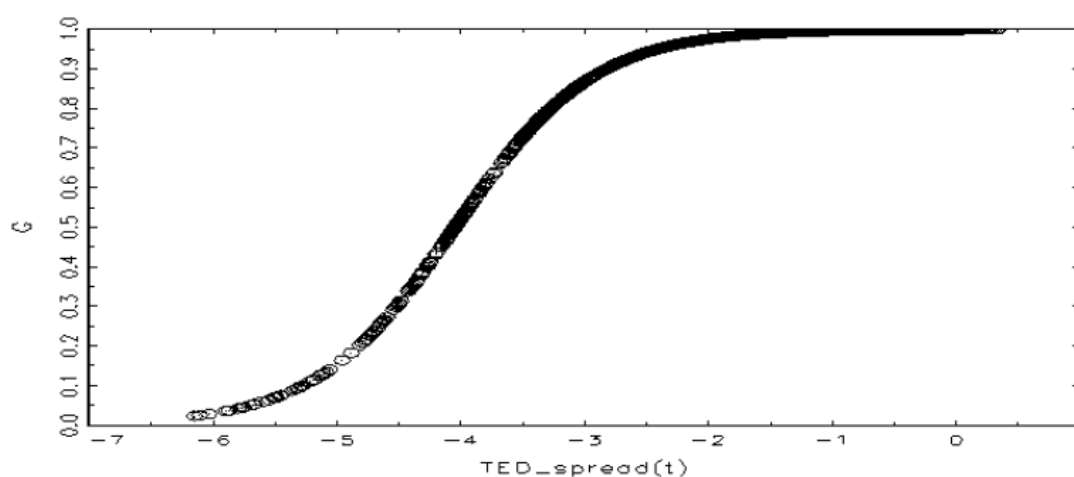


Figure 11. Crossplot of the transition function and the transition variable.

Misspecification tests reveal that there still remains nonlinearity in the relationship between interest rate differential and exchange rate change. The model's residuals are not serially correlated (Figure 12) but there remains heteroskedasticity (Figure 13), which we should try to understand. It may signal unknown time-series dependencies that were not captured by the model. Due to these imperfections, we cannot be 100% satisfied with our STR-model. What we can do next is to build a trading strategy based on the model and test whether it yields a better performance than simple carry trade strategy.

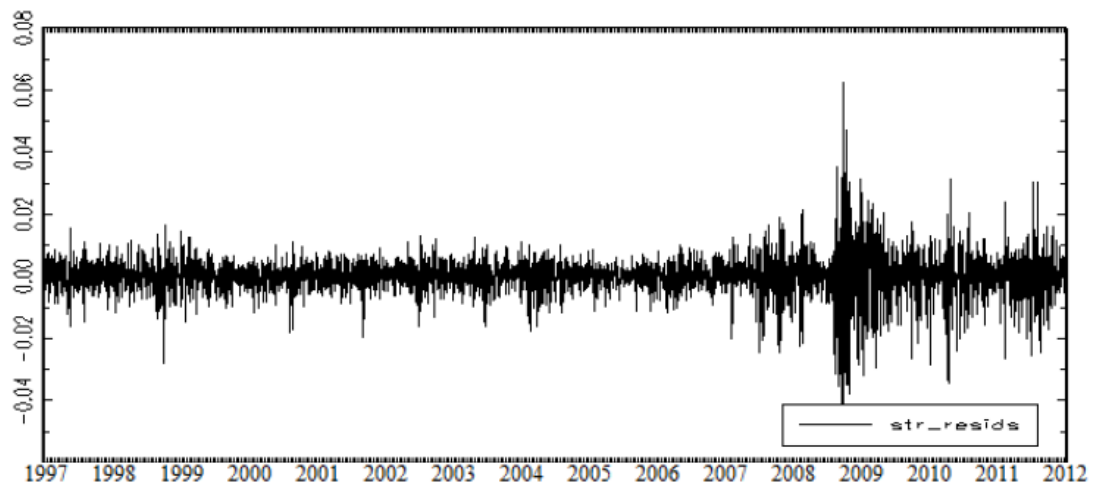


Figure 12. Residuals.

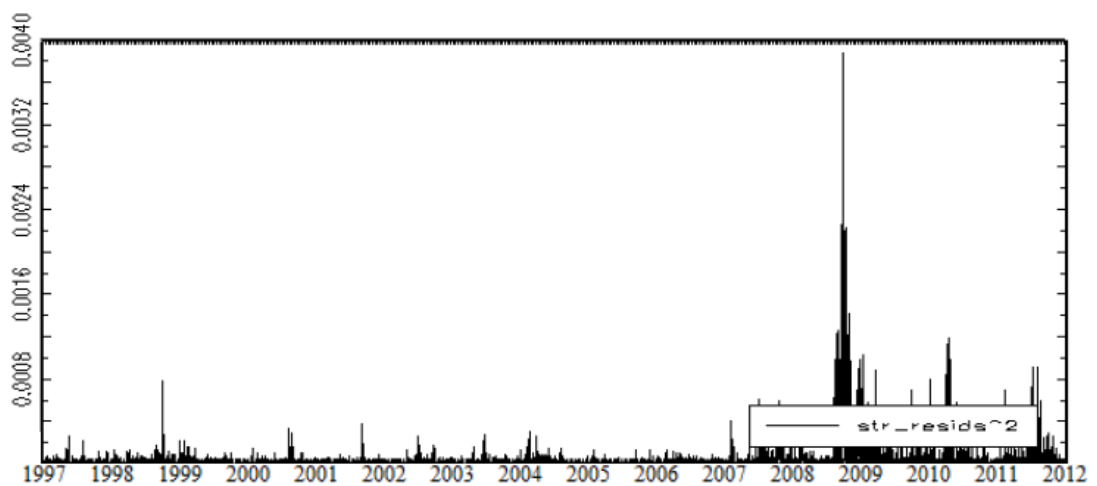


Figure 13. Squared residuals.

8.6 Trading strategy utilizing the previous results

Our strategy changes the signs of long and short positions when the regime changes (i.e. when TED spread crosses the location parameter at value of 4) aiming to take advantage of the different behaviour of exchange rates between the regimes. Then, it

can be found out whether using TED spread as a signal creates economic value. Of course, this predictability coming from the transition variable never means for sure but it is just to know that odds may be on your side. There can be numerous false alarms before hitting the target, e.g. investor could open carry trade position too late or close it too early resulting in worse trading results than would have been by simple carry trade strategy. Table 8 shows that the successful timing based on changes in risk-aversion improved substantially carry trade returns. Mean excess return is now 7.5% and median 11.5%. Also skewness is smaller.

Table 8. Summary statistics for annualized excess returns of the strategy (%).

Min	-100.00
Max	3.33*10 ⁷
Mean	7.52
Median	11.53
Std dev	10.24
Skewness (t-value)	-0.26 (-6.74)
Excess kurtosis (t-value)	9.79 (125.36)
Sharpe	0.73
Sortino	0.91

Even more remarkable is that the cumulative returns based on the strategy (Figure 14) are almost 200%, i.e. the initial investment is tripled whereas the simple carry trade portfolio had to settle for returns of 50% that just beat moderate level of inflation (2.5% per year). In long-term investment cumulative returns tell much more than mean returns particularly if there has been a crash. For curiosity, I tried also a strategy that changed regimes at TED spread of 3 (plot X in Figure 14), in which Figure 11 indicated the transition function to speed up considerably. This yielded even better outcome. The cumulative returns are close to 250%. Hence, even STR-modelling proposed a location parameter of 4, value 3 turned out to be better as it

changed the sign of the positions earlier. TED spread of 3 was already a sign of turbulence and therefore waiting until it got to 4 would have lost the beginning of the 2008 crash/profit-making opportunity.

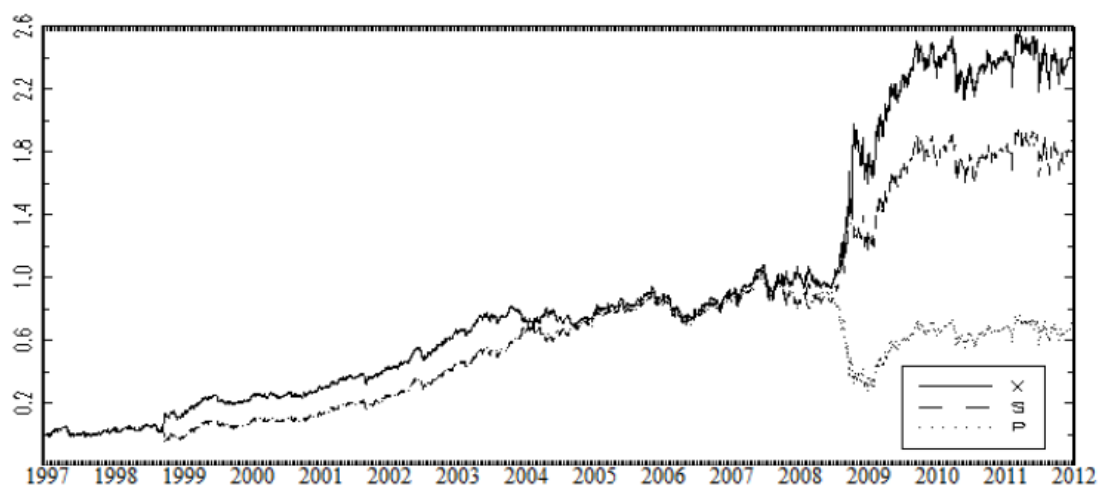


Figure 14. Cumulative returns of the portfolio (P), the strategy (S), and the experiment (X).

9 CONCLUSION

The goal of this paper was to seize the forward premium puzzle and form an overall picture that surrounds the carry trade. As the equilibrium models are based on pure assumptions, which seldom hold true in the real world, the future exchange rates cannot be predicted by using these models alone. Investors heterogeneity and psychological biases definitely impact trading decisions and thus exchange rates, as do the institutional features of the foreign exchange market. However, they are probably not the sole source of the UIP deviations and subsequent carry trade excess returns. Most of the financial literature emphasizes that if UIP does not hold, there must be a risk premium that explains the difference. Clearly the risk premium is not constant over time since the research has not been able to capture it in order to make forward exchange rates unbiased predictors of future spot exchange rates. The risk premium appears to be nonlinearly connected with interest rate differentials in contrast to linear presumption of UIP. The joint-hypothesis problem is important since risk premiums (especially time-varying) are unobservable directly. Thus, none of the risk factors identified in this paper are easy to be proven completely right or wrong.

The main contribution of this paper was to emphasize the role of risk-aversion in determining the carry trade returns. Indeed, there is lots of evidence that carry trade gains in normal times when risk-aversion is lower and loses in times of turbulence. The famous classification “picking up nickels in front of steamrollers” describes how carry trade is vulnerable to any sudden reversal in exchange rates. Financial turbulence is often associated with extreme returns and the convergence of uncorrelated assets. Flight-to-quality phenomenon together with decreasing funding liquidity explain the reported correlations between risky assets in one hand and safer investments on the other. If it is possible to identify current and future market conditions, investors are able to enjoy steady carry trade profits during good times

and turn around the strategy or acquire alternative investments for market turmoil. Like the results showed, turning the 2008 crash into profit-making opportunity was crucial for the overall cumulative returns. This was possible by using one of the risk-aversion indicators as a trading signal. In our case, TED spread worked best but based on the initial modelling also credit spread and VIX would have given similar results. Hence, we can conclude that the LSTR1-model works and exchange rate movements can be forecasted (to some extent) by the combination of interest rate differential and change in risk-aversion, which acts as a trigger between slow appreciation regime and rapid depreciation regime. The final remark is to remind that one should be cautious in future trading since markets do evolve over time and what has worked in the past (e.g. TED spread around 3-4), may not work in the future. For future research I would recommend to test my findings in a different time period. Also it would be very interesting to see corresponding results with other currencies and different interest rate maturities.

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