Monotonic patterns in carry trades

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Abstract

In this paper we research the existence of a monotonic pattern in the average returns of carry trades to shine light on the forward premium puzzle. Average carry trade returns are tested for monotonicity against ordered interest differentials between a domestic country and 9 other countries. Our paper researches this pattern for 4 different domestic countries; the US, Japan, Norway and Switzerland. The hypothesis of an increasing monotonic pattern in the carry trade returns is tested with an MR-test, Bonferroni bound test and by estimating a multivariate model. All results point towards a significant uncovered interest arbitrage pattern in the returns.

***Keywords*—** Monotonicity, carry trading, forward premium puzzle

Contents

1 Introduction

In theory, there should be no increase in returns when selling bonds in funding currencies and buying bonds in investment currencies when comparing these on interest rate differential between foreign and domestic country. The term carry-trade refers to a currency speculation strategy making advantageous use of borrowing money in countries with a low interest rate and investing it in foreign assets, such as bonds and stocks, at a higher rate. This procedure exploits a viable, uncovered, interest arbitrage when the exchange rate does not correct for yield from the carry trade (thus when the covered IRP does not hold). Currencies with a low interest rate can be referred to as short currencies, or funding currencies, whereas high interest rate currencies are named long, or carry, currencies. A well-known example is the Yen carry trade, where investors borrow money in Japan at low interest rates and invest this in foreign assets with a long currency, such as the Australian Dollar. The carry trade, however, is not without risk. Investors can suffer great losses if the foreign currency depreciates or the domestic currency increases, these losses are even greater with a high leverage factor. Therefore, exchange volatility is a great risk factor for carry trade returns.

This paper addresses the issue whether or not there is a significant uncovered interest arbitrage pattern in the average returns to currency carry trades? The covered interest rate parity (IRP) theory states that there exists an equality between the interest rate differential and the forward and spot exchange rates differential. This means that a difference in interest rates in two different countries will result in a depreciation of the long currency and/or appreciation of the short currency. The uncovered IRP states that the interest rate differential and the expected change in exchange rate between two countries are in equilibrium. Lustig and Verdelhan (2007) and Menkhoff et al. (2012) show that the IRP does not always hold, making room for interest rate capitalization exploits. In the theory of carry trading, there should be a positive relation between the carry trade returns and the interest rate differential, whereas the IRP theorizes that no such pattern should exist.

The carry trade yield is formed by the positive difference in interest rates between the short and long currencies and denoted in the domestic currency. This is referred to as a positive carry, where a negative carry denotes losses from the currency carry trade. Given that the uncovered IRP and the carry trade anomaly expect different results, this paper will try to clarify this discussion by means of tests on exchange data. The anomaly of carry trading suggests increasing returns for larger interest rate differentials. Since the carry trading expects a monotonically increasing pattern when observing ordered interest rate differentials against average returns from positive carries, it is possible to test the different theories by testing the absence of a pattern against the existence of a monotonically increasing relation. This can be tested in two ways, one where the null assumes that the uncovered IRP holds true, and the other where the null hypothesis assumes the existence of a pattern in the carry trade returns. These two test forms could perform differently due to size and power allocation. Therefore it is useful to inspect both cases. This paper will research the existence of this pattern by means of an MR-test, Bonferroni bound test and a random effects multivariate regression model.

2 Literature review

Financial research shows much debate on the interest rate parity theorem, this is due to the fact that there are unexplained arbitrage exploits in the exchange market. Aliber (1973) explains that this profit opportunity is the result of (1) transaction costs, (2) default risk and (3) composite of "non-monetary returns, default risk, non-unitary correlation of returns, and premature repatriation". This can be narrowed down to the incurrence of political and exchange risk.

The forward premium puzzle is a deviation from the uncovered interest parity which makes room for arbitrage opportunities. This deviation can be exploited by carry trades. Research shows that the Peso problem has no major influence over the payoff of a carry trade (Burnside et al. 2008). A Peso problem refers to a small probability of a major event, shaping the market price. Burnside et al. also conclude that the Sharpe ratio of a carry trade portfolio is nearly twice as large as the Sharpe ratio of the U.S. stock market. Furthermore, the carry trade portfolio is not correlated with standard risk factors and shows little difference in returns when hedged or not. However, research from Jurek (2008), Farhi & Gabaix (2008), Farhi et al. (2009), and Burnside et al. (2011) shows that peso problems do have a partial impact on carry trade returns, which would positively affect the stochastic discount factor (SDF). In addition, Menkhoff et al. (2012) examine aggregate volatility innovations and conclude that this is a beneficial systemic risk factor in foreign exchange (FX) markets.

Further research on the uncovered interest rate parity (UIP) shows that the theory mainly applies to very high inflation currencies, in all other cases there is evidence of arbitrage opportunities (Lustig and Verdelhan, 2007). Furthermore, the paper explains that "growth risk in aggregate consumption explains a large fraction of the average changes in the exchange rate, conditional on foreign interest rates" (Lustig and Verdelhan, 2007). Their findings are contradictory to past financial papers on the correlation between exchange rates and aggregate consumption. Therefore it may be useful to correct for aggregate consumption when modeling a carry trade portfolio.

Returns from carry trades are largely a result of persistent differences in interest rates across countries. Recent research shows that "the high interest rate "investment" currencies tend to be "commodity currencies," while low interest rate "funding" currencies tend to belong to countries that export finished goods and import most of their commodities" (Ready et al, 2015). The authors build a model of international trade and currency pricing and conclude that lower precautionary demand results in a higher average interest rate in the commodity country currency, even when the currency is depreciating in times of economic turmoil. This could partially justify the high profitability and Sharpe ratio of the carry trade portfolio mentioned in Burnside et al. (2008).

Methods on carry trade research varies over the authors. Farooqui (2008) analyzes the arbitrage pattern in carry trade returns by means of OLS regression. He concludes that the forward rate is not an unbiased estimator of the future spot rate and that the gap between actual and predicted future spot rates accounts for a viable arbitrage opportunity in the Yen carry trade. Farooqui only analyzes the Yen carry trade with the US between 1993 and 2007. Suominen and Jylhä (2009) use carry trade data with one month maturities between 1976 and 2008 to analyze the effect of arbitrage capital on carry trade returns. This is done my means of an autoregressive model. The same data is used by Burnside et al (2006) when analyzing the carry trade returns by computing Sharpe ratios. At the time of writing this paper, there has not been research conducted on carry trade returns by means of an MR-test.

As previously mentioned, financial theory suggests there is an equilibrium between the interest rate differential and the difference in spot rate and forward rates for two countries. Patton and Timmermann (2008) evaluate such financial models by comparing their expectation to the market performance. This is done by applying several monotonicity tests, including their own monotonic relation (MR) test. Their paper considers models and theories like the CAPM model or the liquidity preference hypothesis. The goal of this paper is to replicate this test and apply it to carry trades for numerous currencies. As a result of the application of the MR test, we hope to contribute to the discussion on the forward premium puzzle by finding a pattern in the carry trade returns.

3 Data

Carry trade observations requires data on interest rates and exchange rates of ten major currencies. Domestic currencies considered are the Swiss Franc, Japanese Yen, US Dollar and the Norwegian Krone. Daily historical exchange rates between these countries and G10 countries from Jan 1979 until Mar 2017 are obtained from the Bank of England. Together with interest rate data from Bloomberg, we calculate each carry trade return after a maturity of time T. We regard maturities of one week, one month and three month investments in the foreign country's central bank. Given the liquidity of cash between countries in the G10, we assume that a 3-month maturity can be considered as a "long-term" investment. The average returns are historically calculated by estimating the potential returns of a carry trade with maturity T at each point t in time. For the multivariate model estimation in the second part of our analysis, we converted the returns to a panel dataset. The panel data consists of the date, carry trade, returns and interest rate differentials. The impact of the maturities on the average returns on the carry trades can be

Table 1: Average returns in percentages per maturity and domestic country

Maturity	USD	JPY	CHF	NOK
one week	0.04%	0.03%	0.03%	0.01%
one month	0.17%	0.15%	0.11%	0.05%
three months	0.55%	0.46%	0.33%	0.16%

seen in $figure$ 1. We also observe that the average returns generally increase with the maturity (one (three) month returns are around 4.5x (14x) larger than the one week returns on average), however in the case of Switzerland we see non-monotonic pattern at the fifth and sixth interest rate differentials. These two are throughout time the Norwegian Krone and Swedish Krona, which are very codependent currencies where the interest rate differentials with Norway commonly larger than those with Sweden. These outliers are inspected with a box plot in $figure$ 2. The density of positive observations in the second ordered interest rate differential are revealed as a small outlier in the three month plot of $figure$ 1. In addition, we can see the distribution of the fifth ordered interest rate differential against the sixth, which exhibits the same properties as the three month plot in $figure$ 1.

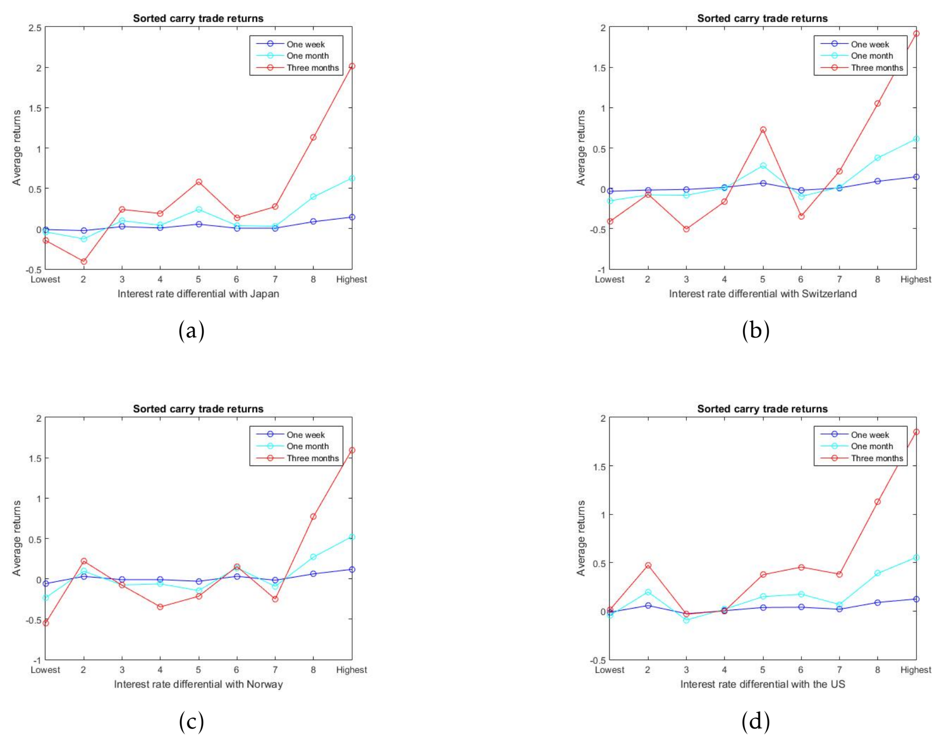


Figure 1: Average returns of different carry trades from 4 separate domestic countries with one week, one month and three month maturities.

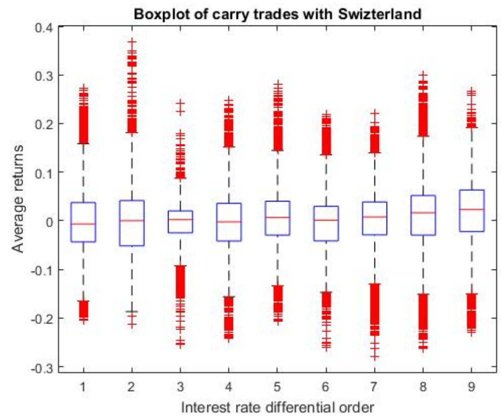


Figure 2: Boxplot of the average three-month returns on carry trades between Switzerland and 9 other considered countries.

4 Methodology

There are many approaches which could help us determine the pattern in the average returns to currency carry trades, however Patton and Timmermann (2008) have developed a nonparametric MR test designed specifically for assessing monotonic patterns from financial theories. They consider well-known economic theories, such as the liquidity preference and the CAPM model. In the case of the CAPM, they test whether empirical returns are increasing for larger values of beta ceteris paribus. If the returns of the carry trades between several countries with another country are ordered by interest rate differentials, then a monotonic relation can be tested with this MR test. The MR test assumes identical or weakly declining returns under the null and the alternative houses a monotonically increasing relation. We apply the same method as described in Patton and Timmermann's (2008) paper, similar notation will also be applied. Assume that we test N+1 returns on carry trades between N+1 countries i and Switzerland ranked on the interest rate differential between country i and domestic country Switzerland. Denote the average carry trade returns as $\boldsymbol{\mu} = (\mu_1, \mu_2, \ldots\ , \mu_{N+1})'$ and define the return differentials as:

$$\boldsymbol{\Delta} = (\Delta_1, \Delta_2, \Delta_N)', \text{ where } \Delta_i = \mu_i - \mu_{i-1}$$

Note that the returns have been reconverted to the domestic currency, at the proper forward exchange rate (country i to Swiss Franc). Thus, at time t we calculate the potential carry trade returns when invested at $t-1$ for each possible observation. For example, a carry trade between USD and EUR is not possible before 1 January 1999. Next, the hypothesis can be tested as follows:

$$H_0 : \boldsymbol{\Delta} <= 0$$
$$Versus$$
$$H_1 : \boldsymbol{\Delta} > 0$$

The alternative hypothesis above can be rewritten as:

$$H_1 : min(\boldsymbol{\Delta}_i) > 0\ for\ i = 1, 2, \ldots, N$$

This motivates the following test statistic:

$$J_T = min(\hat{\boldsymbol{\Delta}}) for I = 1, 2, \ldots, N, where \hat{\boldsymbol{\Delta}} = \hat{\mu}_i - -\hat{\mu}_{i-1},$$

$\hat{\mu}_i$ are the returns of a carry trade with country i and maturity T, reconverted to domestic currency (Swiss Franc). In this paper we assume that the foreign asset is a deposit in the national bank of country i.

The MR test will determine whether or not a monotonic pattern exists in a fixed time frame of returns on carry trades between different countries. Here a time frame refers to the maturity of the trade, invested in using the long currency. In order to make the returns comparable, the foreign bonds must have the same maturity. In addition, it is useful to examine the long and short term effects on carry trading returns. We expect that the short term will be much more volatile, due to political events or significant global financial announcements. In the long term it is more reasonable to assume a decreased volatility from events mentioned above. As a result of this volatility, we hypothesize that it is more likely that a test for monotonicity in the carry trade returns will be rejected in the short term than in the long term. This is also due to the fact that a currency requires time to appreciate or depreciate accordingly. To evaluate this hypothesis we perform the MR test for both long term and short term carry trades. Apart from testing different maturities we compare the results for different subsets of countries. Due to factors, such as political or financial instability, some countries may not be fully representative for our research goal. Therefore it may be useful to compare the results of tests run on these subsets, because they may interfere with our goal of researching the carry trades. At the time of writing this paper, the lowest global interest rate of -0.75% is held by the Swiss National Bank. To test a pattern in carry trade returns we use Switzerland as the 'domestic' currency in this paper. In addition to assessing Switzerland, we also regard the Norwegian Krone, the US Dollar and the Japanese Yen as the domestic currency in three separate cases, one case for each carry trade maturity.

The assets will be ordered by the interest differential and the carry trade returns will be tested for monotonicity. This can be imagined as the testing for an increasing relationship in a graph where the X-axis are ascending interest rate differentials and the Y-axis represents average returns of the corresponding carry trade. If a monotonic pattern is accepted, then the forward premium puzzle can be revealed in a carry trade portfolio.

A similar MR test will be performed, where the null assumes that the carry trade anomaly exists and the alternative holds the uncovered IRP theorem. Given the different size and power of tests with switched hypotheses, it is possible that different results occur.

4.1 Regression

In addition to the MR test for patterns in carry trade returns, a linear relation in these returns can be tested by a simple ordinary least squares regression. If we regress ordered interest rate differentials on carry trade returns, then the slope parameter β can be tested for significance and sign. A positive slope will represent a monotonically increasing pattern in the carry trade returns. The carry trade returns are noted based on the maturity length t. Contrary to the MR-test, a linear regression will not depend on a bootstrap technique when estimating monotonicity of the average returns against interest rate differentials.

This paper will approach the least squares method for monotonicity analysis with a multivariate regression model. Let y_{it} be the average returns on carry trade i at time t and let u_{it} be the interest rate differential between country i and the domestic country at time t. In this paper we will only consider Switzerland as the domestic country, this is due to this country having the lowest overall interest rate of all other considered countries. Then the following model will return a $\beta > 0$ when there is a monotonic relation between the carry trades and the ordered interest rate differentials.

$$y_{it} = c_i + \beta * u_{it} + \epsilon_{it} \ where \ e_{it} \sim N(0, \sigma_i^2)$$

For more precision when estimating the β, we consider splitting the dataset into periods to observe the change in behavior of the average returns over time. In this paper we split the time frame into 39 years. As an alternative to this model, it is also possible to estimate but a single constant. This will not estimate a unique constant per carry trade with Switzerland, but merge this dimension into one intercept. As a result we can see the general intercept against the individual intercepts by comparing both models.

$$y_{it} = c + \beta * u_{it} + \epsilon_{it} \text{ where } e_{it} \sim N(0, \sigma_i^2)$$

The results of these models can be related to the MR-test by means of a t-test, where:

$$H_0 : \beta = 0$$
$$H_1 : \beta > 0$$

To relate the results to the uncovered interest rate parity we expand the hypothesis to:

$$H_0 : \beta = 0 \wedge c_i = 0$$
$$H_1 : \beta > 0 \vee c_i > 0$$

Furthermore, a Hausman test is performed on each dataset to argue the use of a fixed or random effects model. Where a random effects model is preferred under the null hypothesis. The Hausman test returned a P-value of 0 in all three maturity cases, meaning that a random effects estimator is consistent and efficient.

5 Results

In the following subsections, we will present the results of the MR-test and the regression analysis of monotonicity in carry trade returns. The MR-test subsection also approaches the Bonferroni test to observe the influence of an inverted hypothesis.

5.1 MR test

The MR-test results are acquired with 5000 bootstraps and a block length of 10. Higher block sizes account for more serial correlation and a block size of 10 for daily observations is recommended by authors Patton and Timmermann. *Figure* 1 plots the average carry trade returns against the sorted interest rate differentials for each domestic country considered. This is done for all three cases of carry trade maturities. In addition to the MR-test, we also have performed Bonferroni tests for monotonicity. *Table* 2 shows us the P-values for the MR and Bonferroni tests. We can see that an increasing monotonic pattern is not rejected in all but one case, namely when the Norwegian Krone is considered as the short currency. We see that monotonicity is not rejected for the largest maturity of three months for the Norway case. As a robustness check, the same tests were also conducted with different block lengths. These tests yield the same results for all maturities compared to the results in *table* 2 and can be seen in *tables* 3 and 4 in the *appendix*. Patton and Timmermann mention that the MR-test results are not very sensitive to different amounts of bootstraps, we confirm this in our research as well. Results for the tests with different maturities can be found in the *appendix*.

Table 2: MR and Bonferroni test results with a block size of 10 and 5000 bootstraps. The bold P-values are cases where monotonicity is rejected.

P-values	One week		One month		Three months	
Domestic Country	MR	Bonferroni	MR	Bonferroni	MR	Bonferroni
Japan	0.001	1	0	1	0	1
Switzerland	0	1	0	1	0	1
Norway	**0.361**	0.918	**0.453**	0.323	0.012	0.185
US	0	1	0	1	0	1

5.2 Regression

As an alternative to the Bonferroni and MR-tests for monotonicity, we present the results of the multivariate random effects model. The coefficients β in section 9.2 of the *appendix* are comparable to those of the MR and Bonferroni-tests, with regards to a significant increasing monotonic pattern in beta. We expected a decrease in the β coefficients for increased maturities. This is a result of the long-term effect on a highly liquid FX market, because in a period of 3 months the market has had time to adjust the exchange rates of each country accordingly, therefore the average returns are more evened out in the longer maturities cases. However, this could point towards other involved factors apart from the interest rate which influence the slope, such as political instability or inflation. *Figure* 3 shows us the behavior of β over each regression in a

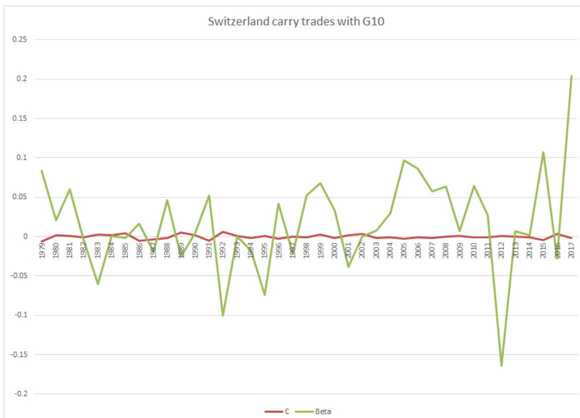


Figure 3: α and β estimation over each year for the multivariate regression of average returns of carry trades between Switzerland and the other G10 countries on interest rate differentials. Note that the regressions lose degrees of freedom for smaller time windows. The graph helps us observe the behavior of the slope over time.

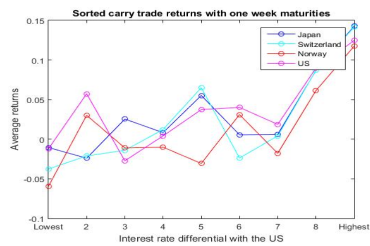
time window of one year. The value of β is, on average, positive. Higher absolute values of β indicate increased volatility in the markets, more specifically a larger difference in average returns between carry trades with low- and high interest rate differentials. There are many factors which influence the returns at year t. Such as the higher values of β near 1998 could be a result of the Asian/Russian crisis and the dip in 2012 could be a result of the strong appreciation of the Swiss Franc against many of our considered countries. The appreciation of the domestic currency against the foreign currency can result in large losses in carry trading.

6 Extensions

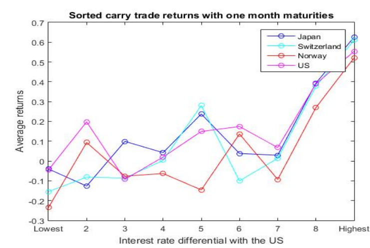
There are some interesting events and predictions occurring at the time of writing this paper, namely the Deutsche Bank predicts an depreciation of several currencies against the Euro. In addition, the returns on stocks and bonds has increased in New Zealand and Australia, due to currency risk and fluctuations in raw material prices. A similar pattern is seen in the Norwegian Krone, because of oil price decreases. Perhaps the speed to convergence can be estimated for such events with a partial adjustment model, which in turn can be related to the IRP.

The influence of current political and commodity market behavior shows that the forward rates rely on many other factors. It can be interesting to look into long-term investments and carry trades at different points in time. Perhaps a pattern in the carry trade returns can be found when analyzing several periods.

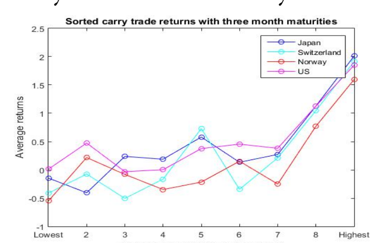
The regression in section 4.1 could be improved by adding an instrumental variable, such as the KOF-index for globalization. It could then be tested whether the arbitrage pattern in carry trade returns are significantly higher between countries with a large KOF differential. Countries with a low KOF index tend to have a higher interest rate, allowing for higher returns. However, carry trades with such countries are often subject to high risk due to high currency volatility. Another extension to the multivariate regression could be to consider more time windows and to compare the slope behavior with times of economic turmoil and stability. As mentioned in the literature review, it could also be insightful to correct for aggregate consumption when modeling a carry trade portfolio (Lustig and Verdelhan, 2007).



(a) Carry trades with maturity of 1 week.



(b) Carry trades with maturity of 1 month.



(c) Carry trades with maturity of 3 months.

Figure 4: Average returns of different carry trades from all four considered countries.

7 Conclusion

Factors such as political instability and fluctuations in commodity markets are not taken into account when defining the forward rates with the IRP. Forward contracts for currencies, formed by banks, do consider these aspects when calculating these rates. In current events, at the time of writing this paper, due to the fall in crude oil prices, we can see an expected depreciation of the AUD and NZD. This can have severe consequences for carry trades with these high interest rate countries. The drop in crude oil prices will affect the NOK less than the AUZ, NZD or a currency such as the Saudi Riyal due to the diversification of the Norwegian government's portfolio. Another element which decreases the average carry trade returns is the risk premium on longer forward rates. We currently see an appreciation of the EUR against nearly all other considered currencies, which has a negative effect on any carry trades from the Europe area. The recent increase of the US interest rate, while ECB maintaining its current interest rate, is a factor of this appreciation. Another observation can be made for the 'safer' trades with less volatile currencies, namely that carry trading between countries with a relatively small interest rate differential generally are more profitable than the previously suggested trades. Research on carry trades defends that there are two 'safe haven' currencies which can yield positive excess returns in periods of economic turmoil, namely the JPN and USD (Coudert et al., 2014). In our results we also observe the these two currencies yield the highest average returns of the four domestic coinage for carry trading.

The results of the MR-test show a significant interest arbitrage pattern in carry trades from Japan, USA and Switzerland. However, the Norway case returns a P-value of 0.361 and 0.453 for the MR-test with maturities one week and one month, and therefore monotonicity is rejected. These results can be seen in table 2. This could be due to the fact that Norway has a relatively small economy which can more easily appreciate or depreciate its currency. The Japanese and American economies in comparison to the Norwegian one, rely much more on external factors. These economies are much larger in scale, therefore the surfacing of interest arbitrage is more probable due to exchange rate lags. A similar reasoning can be applied to the Swiss economy, which is known for its stable economy. For this reason a currency adjustment is less likely to occur than in the Norwegian economy. Interestingly, the Bonferroni test does not reject the null hypothesis of an increasing monotonic pattern for the Norway case in the, by MR-test, monotonicity rejected maturity cases. This indicates a lack of power for the MR-test and that these results are not trustworthy.

The regression results are in line with the MR-test result, given that β is significantly positive. The uncovered interest rate parity hypothesis does not hold true in any of the maturity cases, due to β being nonzero.

Insights in the average returns per maturity per domestic country confirms the conclusion of Ready et al (2008) that commodity currencies, such as the NZD or AUD, functioning as the investment currency in a carry trade with a funding currency, such as the JPY, achieve higher returns on average. In this case the funding currency belongs to a country that exports finished goods and imports most of their commodities.

Given that all cases, apart from the disregarded Norwegian one, accept an increasing monotonic pattern in the carry trade returns, we conclude that there exists a significant interest arbitrage pattern in these returns. This indicates that there are factors, other than the interest rate, involved in the global FX market equilibrium. Therefore the interest rate differential is not an unbiased predictor of the ex post change in the spot rate. This can be regarded as an extension on Farooqui's (2008) analysis on the Yen carry trade with the US. Our, more general, approach considers more countries in a larger time frame for which we arrive at the same conclusion, namely that the forward rate is not an unbiased estimator of the future spot rate. Further research could shine light on the behavior of average carry trade returns at different economical moments in time, such as periods of economic turmoil or more specifically the relation to FX market volatility.

8 Replication

Patton and Timmermann (2010) have developed a monotonic relation (MR) test to examine the existence of monotonicity in financial variables. They tested the theoretically increasing relation between the CAPM beta and subsequent returns by applying their own MR test. The portfolio returns are ordered by their estimated beta and are then tested for monotonicity in the portfolio returns. In $fig.$ 3 this relation is plotted in blue when the increments are increasing as theoretically expected, otherwise they are indicated in red. The data used is from Ang, Chen and Xing (2006), which runs from July 1963 until December 2001. The goal of the MR test conducted in Patton and Timmermann (2010) is to test for monotonicity in financial theories in a more efficient manner. They compare their MR test with other methods, such as the Wolak test or the Bonferroni bound. We arrive at the exact same results, by applying randomizer seed 1234. Given that the replicated results are exactly the same as in the Monotonic relations paper, we can safely assume that this test is replicable. The data is replicated using one thousand bootstraps and one thousand Wolak simulations. The bootstraps are used to estimate the covariance matrix. Once the data is sorted (the portfolios), then the tests are run. This is done for the CAPM beta case in *table* 6. The same tests are applied for monthly term premia in *table* 7. In this table the authors try to test for a monotonic relation (MR) between term premia on US treasury bills and the time-to-maturity. This relation is plotted in *fig.* 5 in the replication subsection of the *appendix*. In addition to testing a MR on term premia and CAPM estimated beta's, numerous firm characteristics are taken into account to test monotonicity in mean return patterns. These results can be seen in *table* 8.

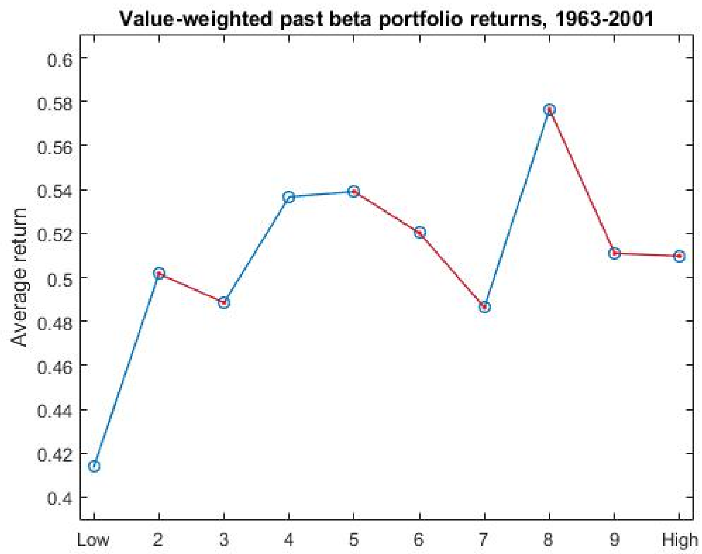


Figure 5: Average returns against ordered portfolios on esimated CAPM betas

The test results for monotonicity of CAPM estimated betas against subsequent CAPM returns can be seen in *table* 6. In this paper we will perform a similar test, based on the theoretical equilibrium from the uncovered interest rate parity (IRP). By the IRP theory, it holds that the interest differential and the expected change in exchange rates between two countries are in equilibrium. However, empirical observations have let many believe that yields of the carry trade anomaly are increasing with the interest rate differential. By applying a similar strategy as Patton and Timmermann, this paper hopes to contribute to the discussion on the forward premium puzzle.

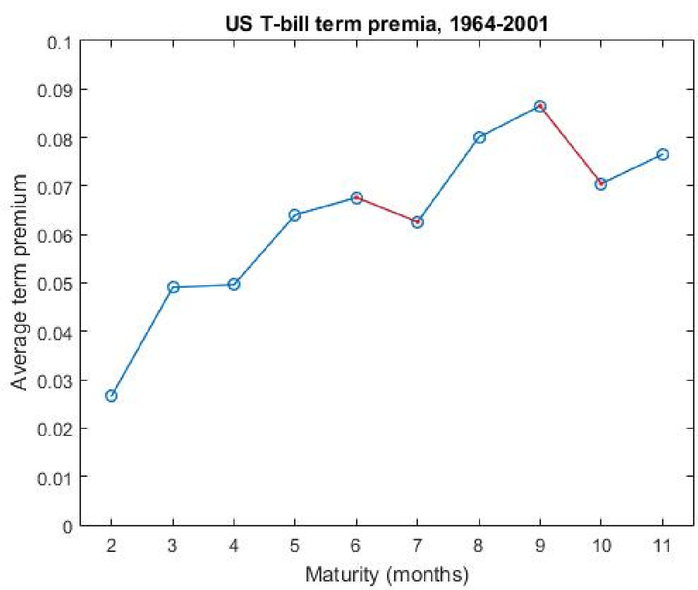


Figure 6: Average monthly term premia for US T-bills, relative to a T-bill with one month to maturity, over the period January 1964 to December 2001.

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9 Appendix

9.1 MR and Bonferroni tests

Table 3: MR-test results with block size of 8

Domestic Country	MR-test P-value	Monotonicity	Bonferroni P-value	Monotonicity
Japan	0.0002	Accept	1	Accept
Switzerland	0	Accept	1	Accept
Norway	0.3514	Reject	0.9180	Accept
US	0.0002	Accept	1	Accept

Table 4: MR-test results with block size of 12

Domestic Country	MR-test P-value	Monotonicity	Bonferroni P-value	Monotonicity
Japan	0.001	Accept	1	Accept
Switzerland	0	Accept	1	Accept
Norway	0.343	Reject	0.9180	Accept
US	0.0006	Accept	1	Accept

9.2 Regressions

Table 5: Multivariate regression results, where bold coefficients are insignificant for a 10 % significance level. Model 1 is a single intercept model and model 2 is the unique intercept model. Each P-value column corresponds to a t-test for the significance of the coefficient adjacent to it.

Maturities	**One week**				**One month**				**Three months**			
	Model 1	P-value	Model 2	P-value	Model 1	P-value	Model 2	P-value	Model 1	P-value	Model 2	P-value
Alpha	-0.0001	0.0045	**0.0000**	0.2054	-0.0002	0.0075	**0.0000**	0.2540	0.0000	0.0296	**0.0006**	0.4616
Alpha 2			**0.0006**	0.3813			**0.0013**	0.4013			**0.0009**	0.3839
Alpha 3			-0.0004	0.0488			-0.0005	0.0619			-0.0014	0.0766
Alpha 4			**0.0015**	0.1553			**0.0001**	0.1924			**-0.0031**	0.2141
Alpha 5			**0.0008**	0.2223			**0.0015**	0.2293			**0.0014**	0.1350
Alpha 6			**0.0031**	0.6135			**-0.0004**	0.7350			**0.0001**	0.9800
Alpha 7			0.0007	0.0076			0.0003	0.0115			-0.0006	0.0268
Alpha 8			0.0009	0.0009			-0.0001	0.0014			0.0001	0.0059
Alpha 9			0.0001	0.0144			0.0016	0.0156			0.0015	0.0144
Beta	0.0177	0.0000	0.0033	0.0000	0.0253	0.0000	0.0466	0.0000	0.0150	0.0000	0.1271	0.0000

9.3 Replication

Table 6: Contains the results of the monotonicity tests on the sorted CAPM beta decile portfolios. Panels A and B denote the case when monotonicity is tested on average returns on CAPM beta decile portfolios, whereas panels C and D show results for the test of post-ranked betas on CAPM beta decile portfolios.

Average returns on CAPM beta decile portfolios					Past Beta				
Panel A:	Low	2	3	4	5	6	7	8	9
Mean	0.414	0.502	0.488	0.537	0.539	0.520	0.486	0.576	0.511
Std Dev	3.534	3.746	3.828	4.024	4.307	4.230	4.417	4.942	5.807

Tests of monotonicity for returns on CAPM beta decile portfolios									
Panel B:	Top minus bottom	t-test t-statistic	t-test p-value	MR p-value	MR all p-value	Up p-value	Down p-value	Wolak p-value	Bonferroni p-value
Statistic or p-value	0.096	0.339	0.367	0.039	0.040	0.648	0.920	0.958	1.000

Post-ranked betas on CAPM beta decile portfolios					Past Beta				
Panel C:	Low	2	3	4	5	6	7	8	9
Estimated beta	0.600	0.659	0.702	0.774	0.856	0.850	0.904	1.013	1.194

Tests of monotonicity for post-ranked beta estimates					
Panel D:	Top minus bottom	t-test t-statistic	t-test p-value	MR p-value	MR_{all} p-value
Statistic or p-value	0.938	9.486	0.000	0.003	0.003

Table 7: Test statistics for term premia. This table presents results of tests for a monotonic relation (MR) between term premia on US Treasury bills (relative to the one-month Treasury bill) and the time to maturity, using data from the Center for Research in Security Prices monthly treasuries files, over the period January 1964–December 2001.

Panel A: Average term premia

	Maturity (in months)									
Sample period	2	3	4	5	6	7	8	9	10	11
1964-2001	0.027	0.049	0.050	0.064	0.068	0.063	0.080	0.086	0.071	0.077
1964-1972	0.023	0.040	0.038	0.052	0.054	0.052	0.069	0.069	0.018	0.050
1973-2001	0.028	0.052	0.053	0.068	0.072	0.066	0.084	0.092	0.087	0.085

Panel B: Statistics for monthly term premia

Sample period (Jan 1964- December 2001)	top-bottom	t-stat	t-pval	MR pval	MR_{all} pval	UP-pval	DOWN-pval	Wolak-pval	Bonf-pval
1964-2001	0.050	2.416	0.008	0.953	0.906	0.000	0.369	0.036	0.020
1964-1972	0.026	0.908	0.182	0.983	0.991	0.003	0.375	0.007	0.004
1973-2001	0.057	2.246	0.012	0.633	0.617	0.002	0.474	0.340	0.704

Table 8: Estimates of expected returns for decile portfolios. This table reports mean returns (in percent per month) for stocks sorted into value-weighted decile portfolios. The sorting variables are market equity (ME), book-to-market value (BE-ME), cash flow price (CF-P), earnings-price (E-P), dividend-price (D-P), momentum , short-term reversal (ST reversal), and long-term reversal (LT reversal).

Panel A: Average returns 1963-2006	ME	BE-ME	CF-P	E-P	D-P	Momentum	ST reversal
Low	1.273	0.824	0.850	0.829	1.002	0.177	1.147
2	1.206	0.948	0.898	0.845	0.938	0.736	1.281
3	1.241	0.989	0.975	0.975	1.029	0.862	1.255
4	1.185	1.013	0.960	0.959	1.006	0.903	1.055
5	1.209	1.014	1.069	0.943	0.912	0.801	1.020
6	1.097	1.110	1.030	1.075	1.006	0.899	0.935
7	1.151	1.188	1.090	1.234	1.045	0.941	0.890
8	1.095	1.216	1.127	1.229	1.133	1.145	0.941
9	1.026	1.269	1.329	1.284	1.122	1.238	0.748
High	0.886	1.396	1.334	1.429	1.074	1.648	0.683
High-Low	-0.387	0.572	0.485	0.600	0.072	1.472	-0.464

Panel B: Tests of monotonicity, 1963-2006	ME	BE-ME	CF-P	E-P	D-P	Momentum	ST reversal
t-statistic	1.536	2.544	2.404	2.683	0.295	5.671	2.364
t-test pval	0.062	0.005	0.008	0.004	0.384	0.000	0.009
MR-pval	0.274	0.000	0.024	0.008	0.336	0.291	0.258
MRall-pval	0.237	0.000	0.012	0.021	0.256	0.242	0.170
UP-pval	0.737	0.045	0.035	0.016	0.353	0.000	0.889
DOWN-pval	0.051	1.000	0.994	0.985	0.651	0.954	0.015
Wolak-pval	0.736	1.000	0.990	0.991	0.810	0.873	0.860
Bonf-pval	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Panel C: Average returns, full sample	ME	BE-ME	CF-P	E-P	D-P	Momentum	ST reversal
Low	1.520	0.872	0.863	0.852	0.924	0.338	1.493
2	1.326	0.973	0.939	0.864	0.984	0.732	1.217
3	1.298	0.977	0.986	1.010	0.934	0.741	1.168
4	1.249	0.970	1.003	1.010	1.024	0.865	1.039
5	1.211	1.054	1.116	1.020	0.902	0.869	1.064
6	1.183	1.101	1.086	1.190	0.991	0.943	1.017
7	1.148	1.115	1.189	1.265	1.086	1.032	0.972
8	1.093	1.272	1.212	1.344	1.145	1.163	0.932
9	1.040	1.306	1.397	1.403	1.109	1.268	0.828
High	0.907	1.410	1.437	1.549	1.094	1.591	0.487
High-Low	-0.613	0.538	0.574	0.697	0.171	1.254	-1.007

Panel D: Tests of monotonicity. full sample	ME	BE-ME	CF-P	E-P	D-P	Momentum	ST reversal
t-statistic	2.350	2.439	3.244	3.665	0.938	5.434	5.060
t-test pval	0.009	0.007	0.001	0.000	0.174	0.000	0.000
MR-pval	0.002	0.000	0.018	0.000	0.692	0.002	0.012
MRall-pval	0.002	0.000	0.012	0.000	0.492	0.002	0.016
UP-pval	0.987	0.027	0.007	0.001	0.169	0.000	0.993
DOWN-pval	0.024	1.000	0.994	1.000	0.606	0.998	0.003
Wolak-pval	0.985	0.999	0.995	1.000	0.530	0.999	0.995
Bonf-pval	1.000	1.000	1.000	1.000	0.361	1.000	1.000

Table 9: Conditional and joint monotonicity tests for double-sorted portfolios. This table shows mean returns for stock portfolios using 5X5 two-way sorts. The sorting variables are market equity, which is always listed in the row, and one of either book-to-market value or momentum.

Panel A: Market equity *x* book-to-market ratio			Book-to-market ratio			MR	Joint MR
Market equity	Growth	2	3	4	Value	p-value	p-value
Small	0.711	1.297	1.337	1.546	1.660	0.023	
2	0.878	1.141	1.411	1.458	1.524	0.004	
3	0.889	1.205	1.210	1.334	1.506	0.057	0.000
4	0.998	0.994	1.222	1.334	1.374	0.044	
Big	0.879	0.968	0.982	1.066	1.074	0.023	
MR p-value	0.687	0.401	0.405	0.069	0.031		
Joint MR p-value			0.342				0.083

Panel B: Market value x momentum			Momentum			MR	Joint MR
Market equity	Losers	2	3	4	Winners	p-value	p-value
Small	0.362	1.154	1.417	1.564	1.973	0.000	
2	0.423	1.034	1.257	1.499	1.777	0.000	
3	0.601	0.979	1.123	1.228	1.728	0.000	0.154
4	0.597	0.992	1.026	1.238	1.583	0.008	
Big	0.645	0.883	0.774	0.975	1.272	0.552	
MR p-value	0.893	0.143	0.001	0.117	0.016		
Joint MR p-value			0.708				0.545