NHH

An Empirical Analysis of the Unbiasedness Hypothesis

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Abstract

This thesis has two main aims, split into two parts. The aim of the first part is to see if the unbiasedness hypothesis holds for some of the world's most liquid currency pairs. The objective is to gather new data on spot and forward rates with three different maturity lengths from 1996 up until 2018, and test these data using mean comparison t-tests and time series regression analyses.

The results reveal that the unbiasedness hypothesis does not seem to hold for most currency pairs for the one month, one week or overnight maturities. There are also some evidence indicating the presence of the forward premium puzzle for some currency pairs, especially in the monthly and overnight maturities.

The aim of the second part is to uncover potential statistical relationships between the deviation from the unbiasedness hypothesis and leading explanatory variables. In extension, these relationships could be used to predict future deviations from the unbiasedness hypothesis and thus increase excess return from carry trade. The objective for this part of the thesis is to collect data on various relevant economic variables and test the explanatory power of these variables, using regression analysis and a direction of change-model.

Most notably, we find that the Baltic Dry Index has served as a positive, leading indicator of deviations from the unbiasedness hypothesis in the period of our analysis. We also find evidence of a relationship for the CBOE Volatility Index which varies with the length of maturity, and a negative relationship for the S&P 500 index. However, we do not find any relationship between the deviation from the unbiasedness hypothesis and the USD denominated LIBOR, the Brent crude oil price or the bid-ask spread for the foreign exchange spot.

Preface

The idea for this thesis came to us while taking the International Finance course at NHH, where we first heard about the systematic empirical failure of the unbiasedness hypothesis and the presence of the forward premium puzzle. We were intrigued to learn that the foreign exchange market, which is the world's largest financial market and is thought to be efficient, in fact has such large and persistent deviations from interest rate parity that could be exploited in order to earn a form of quasi-arbitrage. This sparked an interest in us which we wanted to explore further in this thesis.

Throughout the process of writing this thesis we have learned much about the workings of the foreign exchange market, as well as the art and science of academic writing and econometric considerations when conducting quantitative empirical analyses. Although the process has felt slow and difficult at times, it has also been highly rewarding and we are glad to say that we are proud of the end result.

Even though a master thesis is an independent academic work, it would not be possible without help. Therefore, we would like to thank Petter Løkken (Norges Bank) for his preliminary help and guidance, as well as our thesis supervisor Darya Yuferova who has contributed with many valuable suggestions.

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1. Introduction

The foreign exchange market is by far the largest and most liquid financial market in the world. In 2016 the turnover averaged $5.1 trillion per day across all foreign exchange instruments, a fourfold increase since 2001 (BIS, 2016). It is no surprise that the foreign exchange market has seen a large increase in turnover during the last decades as global trade has increased immensely following the advancement of technology, removal of capital barriers and increased globalization. However, much is still unknown about the workings of the foreign exchange market and in this thesis we will take a closer look at the *unbiasedness hypothesis* and a phenomenon that has become known as *the forward premium puzzle*.

In this thesis we will conduct two broad analyses which will be split into two parts. The first part of the paper focuses on testing the unbiasedness hypothesis. We will discuss different methods of testing the hypothesis, conduct empirical tests on a number of currency pairs with different maturities using new data up until 2018 and then conclude based on the results. The aim of this first part is to establish whether or not the unbiasedness hypothesis holds and whether there is any indication of the presence of the forward premium bias in some of the most actively traded currency pairs. Since we are selecting currency pairs based on liquidity we expect the deviation from the unbiasedness hypothesis to be smaller, compared to currency pairs selected on the basis of their interest rate differential. Consequently, we will be putting the well-known failure of the unbiasedness hypothesis to the test.

The second part of the thesis will take a closer look at the possible failure of the unbiasedness hypothesis and see if we can uncover patterns in the excess return made from carry trade. We will do this by means of a direction of change-model and regression analysis based on the difference between the forward premium and the ex-post change in the spot rate. Through these tests we can determine whether there are any significant relationships between this difference and relevant, leading explanatory variables. To the best of our knowledge, there has not been conducted previous research using this approach before. By using these methods with unconditional empirical market data we aim to enable investors to more reliably predict the magnitude and direction of future deviations from the unbiasedness hypothesis in order to be able to increase carry trade profits. Furthermore, the academic aim is that any uncovered relationships between the deviation from the unbiasedness hypothesis and explanatory variables might better equip future research in revealing the underlying cause of the deviation.

One of the most central theories in international finance is interest rate parity. Interest rate parity represents a no-arbitrage equilibrium between the domestic and foreign money market, assuming free capital mobility and perfect substitutability. In other words, according to interest rate parity we should expect to get the same return by investing in the domestic money market as we would get in the foreign money market. Since the nominal interest rates reflects the investors expectations about future inflation, high interest rate currencies should on average depreciate relative to the low interest rate currencies (Burnside et al., 2011). Consequently, any difference in nominal interest rates between the two currencies is offset by expectations of future appreciation or depreciation.

Interest rate parity can be divided into covered and uncovered interest rate parity. Covered interest rate parity refers to situations where the foreign exchange risk is hedged by a forward foreign exchange contract, while uncovered interest rate parity refers to the unhedged equivalent. When both covered and uncovered interest rate parity holds, the forward foreign exchange rate is an unbiased predictor of the future foreign exchange spot rate, assuming rational expectations and risk neutrality. This is known as the unbiasedness hypothesis.

The failure of the unbiasedness hypothesis is a well-known puzzle in empirical finance. While interest rate parity dictates that a high interest currency should depreciate (relative to low interest rate currencies) in order to regain equilibrium between domestic and foreign money market returns, empirical research has shown that these high interest currencies do not depreciate as much as dictated by interest rate parity (Fama, 1984). In reality, research has found that the high interest rate currency on average tends to appreciate relative to the low interest rate currency. A meta-study conducted by Froot and Thaler (1990) found that a 1 percentage point increase in the interest rate differential leads to a 0.88 percent appreciation of the high interest rate currency on average. This result was later supported by Chinn and Meredith (2004) who showed that these findings also hold for data up to the year 2000.

This peculiar phenomenon, where the high interest rate currency appreciates compared to the low interest rate currency, is what is known as the forward premium puzzle[1]. The term stems from the forward premium, which is defined as the difference by which the forward rate

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[1] Also referred to as the forward discount puzzle, the forward premium anomaly and the Fama puzzle

exceeds the spot rate, while the opposite is referred to as a forward discount. The forward premium is often used interchangeably with the interest differential, which is an implication of interest rate parity (Bansal and Dahlquist, 2000).

The forward premium puzzle can be exploited by investors through several channels, such as through the spot market or the derivatives market. To conduct a carry trade in the spot market investors would borrow money in a low interest rate currency in order to invest in another currency with a higher interest rate. In the derivatives market, carry trade can be conducted using futures, swaps, options or forwards. The latter will be the focus of this paper. In the forward market, a carry trade is conducted by going long in the high interest currency forward, which is trading at a forward discount, and simultaneously going short in the low interest currencies forward, which is trading at a forward premium.

Up to 2007, investors often took out loans or shorted JPY or CHF, due to their low interest rates, and at the same time took long positions in high interest rate currencies, such as AUD and NZD (Johnson, 2018). As discussed, interest rate parity suggests that the the high interest currency should depreciate in the spot market, but on average it often appreciates. Therefore, the investor gains the best of both worlds by receiving a discount equal to the interest rate differential and capital gains through currency appreciation, a quasi-arbitrage which is a direct contradiction to interest rate parity. Since no payment is made before the time of maturity there is no need to take the time value of money into account.

As more investors seek to further diversify their portfolios, the demand of foreign exchange has increased and is starting to be viewed as an asset class in its own right by some investors (Garnham, 2009). Today, many banks offer various indices that track popular foreign exchange trading strategies such as carry, value and momentum, offering all types of investors an accessible alternative to these strategies. One example of a carry trade index is the Deutsche Bank G10 FX Carry Basket Index which goes long in the three highest and short in the three lowest yielding currencies of the G10 currencies each quarter (Deutsche Bank, 2007). Figure 1 shows the excess return, including transaction costs, of the index from 1980 up to and including 2006. From this graph we see that the index has yielded positive returns for 20 of 27 years. Furthermore, figure 2 tells us that the average excess return over the time period was 4,9%, while the standard deviation was 8,4%. This is equal to a sharpe ratio of

0,59 which exceeds the sharpe ratio for both the Deutsche Bank valuation and momentum index of 0,46 and 0,35 respectively (ibid).

	1980-2006	1990-2006	2000-2006
Excess Returns*	4.9%	5.1%	7.0%
Volatility	8.4%	7.9%	7.2%
Sharpe ratio	0.59	0.65	0.98
Max. Drawdown	-31%		

excess returns (over risk-free rate), includes transactions costs

* Includes transaction costs and carry, and excludes legacy Euro currencies, save DEM. Including them, would have reduce 1980-2006 returns by 0.8%

Source: DB Global Markets Research

Source: DB Global Markets Research

Figure 1: Annual returns of Deutsche Bank G10 FX Carry Basket Index

Figure 2: Summary statistics of Deutsche Bank G10 FX Carry Basket Index

The research in this thesis has important implications for investors who speculate in the foreign exchange market, businesses who hedge foreign exchange risks, as well as central banks and other institutions who are interested in the development of the foreign exchange rate. Additionally, the research could be important within academia, seeing as finding a high degree of covariance between the deviation and other economic variables could be valuable for future research into the nature of the deviations.

Even though investors do not understand the true cause of the forward premium puzzle, the lack of insight into the underlying causes of the historical excess return by carry trade apparently does not stop them from investing in the strategy. This means that if we find a leading variable, investors can exploit this relationship in order to more reliably earn quasi-arbitrage, regardless of whether or not we fully understand why the relationship exists. Hence, we are not necessarily trying to explain what type of risk we are compensated for or the exact way to model the risk premium. Also note that transaction costs fall outside the scope of this thesis.

The upcoming chapters are outlined as follows. In chapter 2 we will explain the theoretical foundation in-depth and go through the previous relevant research on the topic. In chapter 3 we will discuss the methodology used to test the unbiasedness hypothesis and how we will look for relationships with other explanatory variables. Chapter 4 is dedicated to the data

description where we will discuss the data used in our analyses. The results of our analyses will be presented in chapter 5, before we go on to present our conclusions in chapter 6. In the seventh and final chapter we will present some of our suggestions on further research.

2. Theoretical Foundation and Literature Review

2.1. Interest Rate Parity and The Forward Premium Puzzle

We can divide the foreign exchange market into a number of financial instruments, including spot transactions and outright forward contracts, which together accounts for 46% of overall turnover in the foreign exchange market (BIS, 2016). Spot transactions entails the exchange of two currencies at the prevailing market rate and intended to close within two banking days, while outright forward contracts is an agreement to exchange two currencies at a predefined future date and exchange rate. While the spot rate is determined by the market through supply and demand, the forward rate is set by the bank, usually based on the spot rate adjusted for the interest differential.

The theoretical relationship between the spot rate, the forward rate and the interest rates of the two currencies, called covered interest rate parity (CIP), can be expressed formally as follows:

$$(1 + i_t) = \frac{1}{S_t(h/f)} \cdot (1 + i_t^*) \cdot F_t^k(h/f) \qquad (1)$$

Where i_t represents the domestic interest rate, i_t^* represents the foreign interest rate, $S_t(h/f)$ represents the spot rate quoted in domestic currency per foreign currency at time t, and $F_t^k(h/f)$ represents the forward foreign exchange rate with maturity equal to k, also quoted in domestic currency per foreign currency at time t.

From eq. 1 we see that investing one unit of the home currency at the domestic interest rate is equal to exchanging that one unit at the prevailing foreign exchange spot rate, investing the foreign currency at the foreign interest rate and then hedging the foreign exchange risk using a forward contract. Note that all the variables are known at time t and that we have eliminated all risk, which implies that investors can earn true arbitrage if CIP does not hold.

We can also transform the CIP equation to reveal another important relationship in international finance, which is that the forward premium (or discount) has to approximately equal the interest rate differential:

$$\frac{F_t^k(h/f) - S_t(h/f)}{S_t(h/f)} = \frac{i_t - i_t^*}{(1 + i_t^*)} \qquad (2)$$

In other words, we should expect to get approximately the same return in the forward market and in the interest rate market. We also see that the approximation is more accurate when the foreign interest rate is low since the denominator on the right-hand side is closer to 1. In this thesis as well as other academic papers, the forward premium and interest differential is used interchangeably (see for instance Bansal and Dahlquist, 2000). Also note that empirical literature often uses the somewhat simpler log-approximation:

$$ln\, F_t^k(h/f) - ln\, S_t(h/f) = ln\, i_t - ln\, i_t^* \qquad (3)$$

In the same way that the CIP theory is used for hedged foreign exchange risk, uncovered interest rate parity (UIP) is used for unhedged foreign exchange risk. UIP states that the return from uncovered investments in foreign money markets should on average equal the return from the domestic money market. Therefore, if uncovered interest rate parity holds there is no compensation for any uncertainty in the future spot rate.

$$(1 + i_t) = \frac{1}{S_t(h/f)} \cdot (1 + i_t^*) \cdot E_t[S_{t+k}(h/f)] \qquad (4)$$

In this case, $E_t[S_{t+k}(h/f)]$ represents the conditional expectation of the future spot rate at time t+k based on all available and relevant information at time t.

Note that both the formula for CIP and UIP are identical with the exception of the last factor on the right-hand side. If both covered and uncovered interest rate parity holds we can set them equal to each other, and thus the forward foreign exchange rate is an unbiased predictor of the future foreign exchange spot rate (assuming rational expectations and risk neutrality). This is called the unbiasedness hypothesis:

$$F_t^k(h/f) = E_t[S_{t+k}(h/f)] \tag{5}$$

As mentioned, interest rate parity assumes capital mobility and perfect substitutability of assets. The first assumption means that capital has to be free to move between countries. For example, there cannot be any capital barriers or exchange controls set up by the government such as a fixed currency rate. The latter assumption means that domestic bonds and foreign bonds are considered the same, i.e., they have the same expected return. We also noted that the unbiasedness hypothesis assumes rational expectations and risk neutrality. Rational expectations imply that the average forecast error is zero, meaning that the market expectation is not biased in one direction or the other. Risk neutrality implies that investors only care about expected returns when making investment decisions and not the associated risk in absolute terms.

2.2. Part 1: Testing The Unbiasedness Hypothesis

For decades economists within the field of international finance have been trying to understand the persistent forward premium puzzle, and over the years there has been a lot of debate about what causes the puzzle to arise. Some even question if there is a puzzle at all (see for instance Roll and Yan, 2000). The forward premium puzzle can seem strange on multiple levels, perhaps especially since the systematic failure of the unbiasedness hypothesis apparently opens up reliable quasi-arbitrage possibilities. This is an inefficiency that one would think would not occur in the world's largest financial market. However, whether the failure of the unbiasedness hypothesis is incompatible with an efficient market hypothesis in the FX market is not completely clear. On the one hand, the unbiasedness hypothesis does not allow for a risk premium or any significant transaction costs, so its failure does not necessarily reject the efficient market hypothesis (Gregory and McCurdy, 1984). On the other hand, a systematic and large empirical deviation from interest rate parity, beyond what could be reasonably explained by a risk premium or transaction costs, could reject the efficient market hypothesis. If this is revealed to be true, the puzzle would prove to be a large anomaly given the size of the foreign exchange market.

There are several possible causes of the forward premium puzzle even though all the assumptions hold. We might encounter both short and longer periods of deviations from interest rate parity, for example due to default risk and political risk (Bekaert & Hodrick, 2013, p. 201). However, we would expect these risks to be diversifiable across time and currency pairs. In order to be able to explain a more systematic deviation from the unbiasedness hypothesis we need to look at more fundamental explanations. A number of different explanations have been put forward, and the most commonly discussed causes are expectational errors, a time-varying risk premium or a combination of the two (Cavaglia, Verschoor, & Wolf, 1993). While these explanations might be able to explain part of the phenomenon, none has been able to fully resolve why the empirical deviations from interest rate parity are so large. In this paper we will take a closer look at some of the most important theories.

2.2.1. Expectational Errors

If we assume that foreign exchange rate risk is fully diversifiable (i.e. there is no systematic risk) there will be no risk premium, since investors are not compensated for idiosyncratic risk. Similarly, if all investors are risk neutral, meaning that investors only care about expected return, then there will not be any additional compensation for taking on risk. If one or both of these assumptions hold, then any deviation between the forward rate and the future spot rate has to be due to expectational errors.

Expectational errors could arise due to several causes, and one such cause could simply be irrational investors. By irrational investors we mean investors that are not making investment decisions that result in an optimal level of utility, for example because they are not adhering to the principles of logic or not taking all available information into account. The presence of irrational investors could lead to potential long-term changes in foreign exchange rates due to the interaction between noise traders and rational investors, which causes interest rate parity to fail (Al-Zoubi, 2011). This is a direct violation of the rational expectation assumption which was required for the unbiasedness hypothesis to hold.

Another possible cause which is often discussed is learning problems. This theory says that exchange rates are affected by the investors' learning process after a regime change, such as from fixed to floating exchange rate regimes (Lewis, 1989). However, the errors do not seem

to disappear over time, which contradicts the theory of learning problems tied to permanent regime changes (Froot and Thaler, 1990). A slightly different way to look at learning problems is that investors might be slowly adapting their expectations about the exchange rate when shifts in macroeconomic fundamentals occurs (Al-Zoubi, 2011).

Another popularly discussed cause is called peso problems, which refers to a sustained excess forward premium over a long period of time as a result of investors' expectations of a future large depreciation (Al-Zoubi, 2011). The peso problem can arise when foreign exchange investors assign small probabilities to certain large and infrequent events such as devaluations, changes in monetary policy, changes in exchange rate regimes, wars or some other major event (Sercu, 2009, p. 415). In such cases, our conventional tests of efficiency in the forward exchange market are not always valid (Krasker, 1980).

Frankel and Froot (1989) conducted an interesting test of the expectational error hypothesis by surveying foreign exchange traders about their expectations regarding future foreign exchange rate movements. This allowed them to decompose the deviation into two categories, one portion attributable to the risk premium and one portion attributable to expectational errors. They reject the hypothesis that the entire deviation is due to a risk premium, but they could not reject the hypothesis that the deviation was entirely due to expectational errors. This finding does however not necessarily mean that investors are irrational, as they could also be subject to learning problems or there could be a peso problem.

2.2.2. Time-Varying Risk Premium

If foreign exchange risk is not diversifiable, due to presence of systematic risk, or if investors are risk averse, we cannot interpret the forward premium (discount) as a pure estimate of the expected rate of appreciation (depreciation) in the future exchange rate. In this case the forward rate has to equal the expected future exchange rate plus a potential time-varying risk premium:

$$F_t^k(h/f) = E_t[S_{t+k}(h/f)] + \rho_t \tag{6}$$

If we keep our assumption of rational expectations, the error term should be zero on average and any deviation between the forward and the expected future spot rate has to be due to a (time-varying) risk premium, here represented by ρ_t. However, it is important to keep in mind

that this assumption is controversial, as discussed in the expectational errors subchapter above (see also Chinn, 2007, p.3).

The hypothesis of a time-varying risk premium could explain the empirical deviations from interest rate parity. Under the assumption that the capital asset pricing model (CAPM) holds, or a variation of it, a risk premium could be explained by a covariance between foreign exchange prices and a market portfolio. CAPM makes a distinction between systematic and unsystematic risk, where the unsystematic risk can be diversified away. This leaves the systematic risk, which can be measured by the covariance between the asset's price and the market portfolio. If the exchange rate covary with a market portfolio, the foreign exchange rate risk cannot be completely diversified away.

However, while CAPM can be useful in explaining risk premiums for individual stocks in the equity market, it is not as straightforward in the foreign exchange market. The issue with utilizing CAPM in the foreign exchange market is that there is not a clear market portfolio, as there is in the equity market. For example, stocks are weighted by their relative market capitalization in an equity market portfolio. While we could use a country's relative GDP as a measure for the currency's weight in the foreign exchange portfolio, this is not necessarily the best measure. Another issue is the fact that the foreign exchange market is a zero-sum game in aggregate, since one currency has to depreciate for another to appreciate.

If we take the perspective of an investor with an equity-based portfolio, who is considering investing in a foreign currency, we can use the equity market as the market portfolio. If the exchange rate covaries with the equity market portfolio, the investor should be able to change the risk of the portfolio by buying or selling the currency. If holding this currency increases the risk of the investor's portfolio, the investor will require a premium to hold the asset. On the other hand, if the currency reduces the overall risk of the portfolio, the investor should be willing to pay a premium in order to attain this risk reduction (Bekaert & Hodrick, 2013, p. 216). This can help explain why an investor is willing to go long in a forward contract even though the investor clearly pays a premium. Under CAPM, the time-varying risk premium theory therefore implies that a positive yield from carry trade strategies is compensation for bearing systematic risk and is not necessarily the result of an inefficient market. This could be due to a higher degree of exposure to global risk factors, or that the inflation environment in these currencies are riskier relative to other currencies (Bekaert & Hodrick, 2013, p. 238).

However, a large issue with risk premium-based explanations is that some research has found that investors needs to be unreasonably risk averse to justify the magnitude of the premium (see for instance Mark, 1985 or Deutsche Bank, 2007).

There are also ways in which the risk premium could arise from indirect factors. A study by Rime et al (2017) argues that segmented money markets, meaning that different market participants borrow and lend at different rates, could cause the bias in the forward rate. Similarly, Borio et al. (2016) argues that costs related to balance sheet changes inhibits deviations from CIP to be exploited. A bank that conducts a CIP arbitrage trade by borrowing and lending in the respective LIBOR markets, might affect the credit risk of the counterparty and thus affect the cost of funding, which renders the trade less profitable and further preserves some of the CIP deviations. Therefore, only market participants with high credit ratings are able to exploit the bias. Borio et al. (2016) goes on to argue that this effect is stronger after the global financial crisis because the risk factors are more correctly priced after the crash of the interbank market. This can therefore help explain why Du et al. (2018) have found that the deviations from CIP are larger after the financial crisis. Following this train of thought we can see that it is not necessarily the volatility of the currency that causes the bias to arise, but the instability of the arbitrage exploiters.

2.2.3. Other Potential Causes

In addition to expectational errors and time-varying risk premiums there are other proposed causes, with varying degree of support.

An important discussion is potential issues of the econometric implementation. One such discussion was brought up by Baillie and Bollerslev (2000) who argue that there is a nonlinear relationship between the spot rate and the forward discount. They propose that when the forward discount is large, it is likely to point in the right direction. However, it is likely to point in the wrong direction when the forward discount is small, perhaps because transactions costs are large relative to potential gains (Chinn, 2007). Baillie and Bollerslev (2000) also find that the forward premium had a very persistent autocorrelation, and that the slope coefficients has a wide dispersion due to small sample sizes. They conclude that the forward premium puzzle arises as a result of these statistical phenomenon, which is also argued by Roll and Yan (2000).

A number of other theories are tackling the puzzle from completely different angles. One such theory has been introduced by Burnside et al. (2009) who use a microstructure approach to separate the impact of adverse selection (between market makers and traders) and risk considerations. They argue that this adverse-selection problem can rationalize a negative relationship between the forward premium and the ex-post rate of appreciation.

Theories based on a behavioral point of view have also been proposed. For instance, Burnside et al. (2011) propose that overconfident investors overreact to their perceived superior information about future changes in spot rate, causing greater overshooting in the forward rate compared to the spot rate. Other theories stipulate that career risks among professional portfolio managers can be part of the explanation. Since portfolio managers care about their reputation (and their career) they shy away from assets with strong signs of danger, such as currencies with a forward discount (Sercu, 2009, p. 416).

2.3. Part 2: Predicting Deviations From The Unbiasedness Hypothesis

After analyzing the exchange rate data for presence of the forward premium puzzle we will look into the possibility of uncovering relationships with the deviation from the unbiasedness hypothesis and relevant explanatory variables. By means of regression analysis and a direction of change-model, we will test several possible explanatory variables against the difference between the forward premium and the ex-post change in spot rate, to see if they can help us forecast the direction and magnitude of the bias in forward prices. Although there is, to the best of our knowledge, no empirical research using this exact approach, a lot of related research into deviations from interest rate parity and the prediction of future spot rates has been conducted. In this section we will discuss some of this previous research.

To be able to predict the deviation out of sample we are reliant on the deviation being systematic in nature. The theoretical foundation for predicting the deviation is that the forward premium puzzle is caused by some fundamental and generalizable cause, such as a time-varying risk premium or that investors are slowly adapting their expectations about the future exchange rate in reaction to changes in macroeconomic fundamentals. If the forward premium puzzle is in fact caused by unsystematic irrationality among investors, then any possible results from our tests might be spurious and not able to predict future deviations.

Tying floating exchange rates to macroeconomic fundamentals (such as money supplies, prices, outputs, and interest rates) has been proven to be challenging and has been a longstanding puzzle in international finance (Engel and West, 2005). Meese and Rogoff (1983) tested three empirical exchange rate models out of sample against a random walk model and found that the random walk outperformed the empirical models at every maturity. In addition, they found that the forward rate was outperformed by the random walk model.

Furthermore, a recent study by With and Ørjasæter (2017) showed that several Scandinavian investment banks has failed to outperform a random walk model, as well as the forward rate, in predicting the future exchange rates' direction and magnitude. The closest we are to an accepted forecasting model for long-term foreign exchange rates is the theory of purchasing power parity. However, since purchasing power parity only has some predictive power when it comes to long term exchange rates, its usefulness is rather limited (Rogoff, 1996).

To make matters more complicated, a survey by Fratzscher et al. (2015) indicated that there is a time-varying relationship between exchange rates and macro fundamentals. The survey asked 46 professional foreign exchange market participants on a monthly basis to rate the factors determining future foreign exchange rates in order of importance. They found that these rankings varied significantly over time. Hence, the market participants, who sets the foreign exchange rates, continuously change their views of what the driving forces of the price changes are. The practical implication of this result is that a model that works today might not work tomorrow.

In the following subchapters we will discuss different sets of relevant variables that might be useful as explanatory variables for predicting deviations from the unbiasedness hypothesis.

2.3.1. Liquidity

By looking at the liquidity in the foreign exchange market, Mancini et al. (2013) found that illiquidity represents costs to carry trade investors. They showed that low interest rate currencies tend to have high liquidity and low liquidity sensitivities, while high interest rate currencies have low liquidity and high liquidity sensitivities. Therefore, the high interest rate currencies tend to appreciate in liquid markets, while the low interest rate currencies depreciate, widening the deviations from interest rate parity. This argument substantiates the theory of a time-varying risk premium, since the excess return made by carry trade is viewed as compensation for the liquidity risk taken when investing in high interest currencies. This is compatible with the notion that low interest currencies, such as the US dollar and the Japanese Yen, are traditionally considered "safe havens" where investors place their money during market turmoil. Under this theory the low returns from safe haven currencies is a reflection of their relatively low liquidity risk.

2.3.2. Volatility

According to research conducted by Menkhoff et al. (2012) high interest rate currencies are negatively related to changes in global foreign exchange volatility, while low interest rate currencies are positively correlated. The high interest rate currencies therefore have a risk premium due to the negative returns experienced in times of high volatility, while low interest rate currencies serve as a hedge since they have a positive yield in the same circumstances. This also argues for a time-varying risk premium. Combined with the results from Mancini et al. (2013), who showed that liquidity affected returns, these results can explain the returns seen during the global financial crisis, where the dollar appreciated amidst the stock market crash (McCauley and McGuire, 2009).

By testing the implied volatility of currency options' predictive power on the future volatility, Jorion (1995) found that it outperformed statistical time-series models in predicting the future volatility, even when the time-series models are given the advantage of ex-post parameter estimates. Additionally, Ammann and Buesser (2013) found evidence of a negative variance risk premium for several currency pairs and that the variance risk premiums were correlated with the CBOE Volatility Index, also known as the VIX-index. There are, in other words, indications that volatility in the stock market has an effect on the deviation from the unbiasedness hypothesis in exchange rates.

2.3.3. Monetary Policy

As discussed, empirical studies have shown that predicting future exchange rates is difficult. Du et al. (2018) however, showed that the CIP deviations increased as the difference in nominal interest rates between the currencies increased. By using a carry trade strategy, they achieved a positive excess return by betting on this phenomenon. This arbitrage opportunity is supported by the profit produced by carry trade funds such as the Deutsche Bank G10 FX Basket Index.

Although Du et al. (2018) found that there are profitable carry trade opportunities in interest rate differentials, Lustig, Stathopoulos and Verdelhan (2015) showed that long maturity bond yields are very similar across countries on average, despite persistent differences in short term rates. This supports theories such as purchasing power parity, which is somewhat successful in forecasting long-term exchange rates. On the basis of this, the deviations from the unbiasedness hypothesis therefore seems to be a short-term phenomenon. This is also backed up by several researchers such as Chinn and Meredith (2004) who found that the deviation from interest rate parity decreases as the forward maturity increases.

These studies show conflicting results and it is therefore unclear whether factors related to monetary policy affect the deviations from unbiasedness. We expect the market to be particularly observant of the policy of central banks, such that these factors should not cause any bias. However, as the studies mentioned above show, there seems to exist a bias in foreign exchange forward rates, especially in the short term, which can be partly explained by changes in monetary policy.

2.3.4. Trade and Productivity

Since a great deal of the foreign currency trade is related to the goods market, it is natural to assume that the commodities and goods trade can have an effect on the foreign currency exchange market. Ready et al. (2017) found that countries that specialize in exporting commodities tend to have high interest rates, whereas countries that export finished consumption goods tend to have low interest rates. They argue that currencies of commodity exporting countries are more procyclical and that investors hence requires a risk premium.

In regard to specific commodity prices Ferraro, Rogoff and Rossi (2011) looked at the relationship between oil prices and exchange rates and found that oil prices could forecast exchange rates in the short term but breaks down at monthly and quarterly maturities. This was found for both the CAD/USD and NOK/USD pairs.

If commodities and trade have an impact on foreign exchange rates, then it is also possible that transportation costs affect exchange rates. Ready et al. (2017) show that carry trade profits are at its highest when transportation costs are high, possibly because transportation costs are high when global goods markets are the most segmented. They conducted this research by looking into the effect the Baltic Dry Index, a popular index for shipping costs, has had on exchange rates.

Increased shipping costs could be a cause for deviations from unbiasedness since high costs should reduce demand for global trade and thereby lower demand for foreign currencies, all else equal. However, high transportation costs during periods of low global trade cannot be maintained, as demand for transportation is low. In this regard, high shipping costs should be correlated with smaller deviations from unbiasedness. Hummels (2007) argues however, that fuel costs and port congestion, which both tends to rise during good times, could be factors that make transportation costs increase relatively more than the demand for foreign currencies. He goes on to argue that bulk ocean shipping costs are volatile because most prices are determined in the spot market as opposed to long-term contracts, making transportation cost variability larger than the variability in foreign exchange rates. Transportation costs should therefore increase more in good times relative to the increase in global trade, making the relative transaction costs larger in good times.

Verdelhan (2010) suggests that the forward premium puzzle is caused by consumption growth shocks, assuming rational expectations. He claims that the stochastic discounting factor is low when consumption is close to the habit level. Thus, when a country experiences a positive consumption shock the domestic currency appreciates, while the stochastic discount factor goes down, rendering a profit on the domestic investor's foreign treasury bills. In other words, one should be able to detect a relationship between consumption growth and changes in the forward premium.

2.3.5. Regulations

Du et al. (2018) elegantly showed how the nonrisk-weighted capital requirements of banks after Basel III has increased the deviations from CIP. Tight control of equity requirements in the financial industry means that banks must use more equity, rather than debt, when performing trades. Since equity holders require a higher return than creditors, the deviations from CIP must be larger in order to justify the investments.

In accordance with Basel III the capital requirements are inspected in the quarterly balance sheets. This has had the implication that forward contracts with maturities shorter than three months are priced at low deviations from CIP as long as they do not show up on the bank's balance sheet, because deals can be funded with more debt. Since a 7-day contract will only affect the disclosed balance sheet if the contract is bought less than 7 days before the end of a quarter, the deviations from CIP are significantly higher during this period than any other period during the quarter. We could interpret this as the market being aware of these CIP deviations, but that government regulation inhibits the market forces from exploiting the deviation. However, it is clear that Basel III cannot be the sole reason for the failure of the unbiasedness hypothesis, as the puzzle has existed longer than the relatively new regulatory changes.

3. Methodology

3.1. Part 1: Testing The Unbiasedness Hypothesis

A formal test of the unbiasedness hypothesis can be conducted in a number of different ways and there still seems to be a debate within academia over the best way to test the hypothesis. The most common type of test utilizes linear regression analysis, but there are several requirements for valid hypothesis testing that have often been overlooked in application (Gregory and McCurdy, 1984). In this chapter we will discuss two different ways of testing the unbiasedness hypothesis and some difficulties tied to these tests.

Before we begin to discuss econometric models and issues, there are some factors we need to keep in mind when discussing the unbiasedness hypothesis. First of all, the conditional expectation of the future spot rate, $E_t[S_{t+k}(h/f)]$, is unobserved and is hence difficult to

include in an econometric test. Consequently, we have to make an assumption of rational expectations in order to use ex-post unconditional rates, $S_{t+k}(h/f)$, rather than survey data. The rational expectation assumption implies that the measurement error of the true expected depreciation is random and thus zero on average (Froot and Frankel, 1989). We can express this formally as follows:

$$S_{t+k}(h/f) = E_t[S_{t+k}(h/f)] + \varepsilon_{t+k} \tag{7}$$

We can alter the unbiasedness hypothesis (eq. 5) to the following:

$$F_t^k(h/f) = S_{t+k}(h/f) - \varepsilon_{t+k} \tag{8}$$

A second issue is known as Siegel's paradox. If we were to examine whether the forward rate could be an unbiased predictor of the future exchange rate, we would get two different answers depending on whether we defined the exchange rates as home currency per foreign currency or vice versa. Consequently, if the basic unbiasedness hypothesis holds for one currency pair, for example NOK/USD, then it cannot hold for the inverse of that currency pair, i.e. USD/NOK (Sercu, 2009, p. 399). This is a mathematical impossibility, which might be easier to comprehend when we look at the formal mathematical formulation:

$$F_t^k(h/f) = E_t[S_{t+k}(h/f)] \neq \frac{1}{F_t^k(h/f)} = \frac{1}{E_t[S_{t+k}(h/f)]} \tag{9}$$

The third issue to point out in this context is the existence of transaction costs. Interest rate parity does not take this into account, and thus uncovered interest rate arbitrage cannot perfectly align the expected future exchange rates and forward premium (Sercu, 2009). Note that Bekaert and Hodrick (1993) found that taking the bid-ask spread for one month maturities into account altered the beta estimates trivially.

Moreover, the forward market is not a walrasian market (Burnside et al., 2007). This means that the forward rate is not necessarily the market clearing price, where supply and demand is in equilibrium. Forward contracts are non-standardized and the forward exchange rate is set by the banks, usually by adjusting the spot rate for the cost of carry, which in terms of currency means the difference in interest rates. This is the conventional way of setting the

forward rate, but banks also set the forward rate to reflect increased risk due to factors such as uncertainty and volatility.

The issue with the fact that the forward rate is not a market clearing price is that it does not fully reflect the markets expectation of the future spot rate. This is often overlooked by other researchers. A possible alternative to the forward rate is the futures rate, which should give a more accurate depiction of the market's expected future exchange rate since it is traded on an exchange, compared to forwards which are traded over the counter. However, futures have a lot less flexibility concerning maturities and contract sizes. Futures also has a disadvantage since it requires the investor to deposit a margin, contrary to forward contracts which does not require any monetary transaction before the time of maturity. Consequently, futures do not have the default risk associated with forward contracts. This marking-to-market feature of futures also means that the futures and forward rates are not necessarily the same at all points in time.

3.1.1. Mean Comparison Test

We start our discussion of formal econometric tests by looking at one of the simplest possible tests to get an initial indication of how well interest rate parity holds on average. We will refer to this test as the weak form test.

Since the unbiasedness hypothesis assumes rational expectations the forecast error should be zero. We can thus test whether there is a statistically significant difference between the average realized percentage change in the spot rate and the average forward premium (or discount), using a mean comparison t-test. We will refer to this difference as the "deviation" or simply "the difference":

$$D = \bar{s} - \overline{fp} \tag{10}$$

Where $\bar{s}$ refers to the unconditional mean change in the spot rate, and $\overline{fp}$ refers to the mean forward premium.

Our null hypothesis for this, and all other tests of the unbiasedness hypothesis, is that the unbiasedness hypothesis holds (i.e. no deviation). In the case of the weak form test the null hypothesis is that the difference, D, is zero.

A good way to visualize the results of this test is by plotting the average realized changes in the spot rate and the forward premium on a graph. If CIP holds perfectly they should line up on a 45-degree line, often referred to as the interest rate parity line. Due to transaction costs and random fluctuations this will not be the case, thus we expect the plots to be randomly scattered around the 45-degree line and be statistically close to it.

This weak form test has a large disadvantage in that it only takes the overall mean performance into account, and thus we cannot uncover the entire picture. For instance, the forward premium can systematically miss the conditional expectation of the future change in the spot rate at every moment, but the unconditional unbiasedness hypothesis $\bar{s} - \overline{fp}$ could still hold on average (Sercu, 2009, p. 400).

3.1.2. Time Series Regression Test

A stronger form alternative to the weak form test is to use regression analysis in order to examine the deviation between the ex-post rate of appreciation and forward premium at different points in time. Based on eq. 8 it might be tempting to run the following regression:

$$S_{t+k} = \alpha + \beta \cdot F_t^k + \varepsilon_{t+k} \tag{11}$$

This would however be naive, since foreign exchange rates are in essence asset prices and have the same issue with non-stationarity which makes forecasting asset prices notoriously difficult. The top graph in figure 3 below displays how both the USD/GBP foreign exchange spot rate and the 1 month forward foreign exchange rate has developed since the end of 1996 to 2018. From the graphs we see that the spot and forward rate are very persistent in their co-movements over time. Consequently, if we were to test the levels of the spot and forward rate we would almost certainly fail to reject the unbiasedness hypothesis, even in instances where the hypothesis should be rejected. In other words, running the naive regression (eq. 11) would most likely lead to spurious results (Bekaert & Hodrick, 2013, p. 235).

However, we can try to reduce a non-stationary process to a stationary one, and thus reduce the probability of spurious results. One way to do this is by utilizing the relative change rather than the levels. The bottom graph of figure 3 shows the development of the difference

between the spot and the one month forward rate, in terms of percent. We see that their difference in terms of percent never exceed 1% in absolute terms, except for during the global financial crisis.
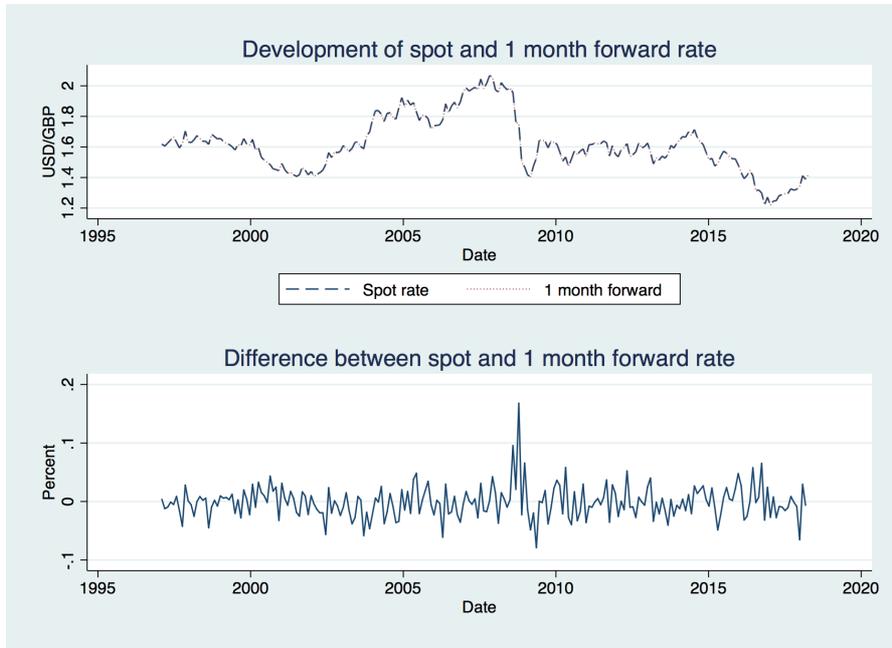
Figure 3: Development of USD/GBP spot rate, 1 month forward and their difference

We can transform eq. 8 to a percentage change form by dividing both sides by S_t and subtracting 1 in the form of $\frac{S_t}{S_t}$. We can then run the following regression:

$$\frac{S_{t+k} - S_t}{S_t} = \alpha + \beta \cdot \left(\frac{F_t^k - S_t}{S_t}\right) + \varepsilon_{t+k} \tag{12}$$

Calculating the percentage change, $\frac{S_{t+k} - S_t}{S_t}$, is essentially the same as taking the first difference of the variables in their log form, $\ln S_{t+k} - \ln S_t$. Thus, we can change the above regression to a log-form:

$$\ln S_{t+k} - \ln S_t = \alpha + \beta \cdot (\ln F_t^k - \ln S_t) + \varepsilon_{t+k} \tag{13}$$

The main difference between the log-change and the percentage-change form is that the log-change formula calculates the rate of return in terms of a continuously compounded rate, and

percentage formula calculates the non-compounded rate of return. The lower the rate of return is, the closer these two calculations are to each other. Hence, using the difference in spot and forward rate in their natural logarithmic form is approximately the same as using the percentage change. The null hypothesis is exactly the same for both versions. So why choose to use log-change, instead of percentage change? One reason is that it "solves" the practical issues tied to the Siegel paradox (see Sercu, 2009, p. 399). This is because logarithms make our regression independent of whether the exchange rates are quoted in domestic currency per foreign currency or vice versa (Fama, 1984). The drawback is that there can be a slight discrepancy between the log-approximation and the percentage change version. That being said we will focus on the log-version for this thesis, since this has become the standard convention for empirical research on the forward premium puzzle.

Keeping in line with the notation used for the weaker test we denote the ex-post change in the spot rate as s_{t+k} and the forward premium as fp_t^k. For all practical purposes we can express both eq. 12 and 13 as follows:

$$s_{t+k} = \alpha + \beta \cdot fp_t^k + \varepsilon_{t+k} \tag{14}$$

This regression test has become the most common way to test the unbiasedness hypothesis in empirical literature. Eq. 14 constitutes a joint test of both foreign exchange market efficiency (rational expectations) and covered interest rate parity (no risk premium). Formally we can express our null hypothesis for this as $\alpha = 0, \ \beta = 1$. An alpha value equal to 0 can be interpreted as no time-invariant risk premium (see note 4 in Gregory and McCurdy, 1984). A beta value equal to 1 means that a one unit increase in the forward premium on average yields a one unit increase in the realized appreciation in spot rate. In other words, a perfect linear relationship between the two, as hypothesized by interest rate parity. On the other hand, a negative beta value would be indicative of finding evidence of the forward premium puzzle.

The joint hypothesis test means that we are unable to decompose the results into parts due to expectational errors and parts due to a risk premium. This is problematic because there is no clear interpretation of the results (Pilbeam, 2006). Finding a beta estimate significantly different from 1 could reflect a time-varying risk premium, irrationality or both.

3.2. Part 2: Predicting Deviations From The Unbiasedness Hypothesis

Our goal for the second part of the thesis is to find an explanatory variable that can predict the deviation from the unbiasedness hypothesis we found in the first part. In order to achieve this we will gather data on selected variables which we think, based on economic theory and previous research, might covary with the deviation and test these hypotheses.

3.2.1. Time Series Regression Analysis

Similarly to our tests of the unbiasedness hypothesis one of our main tools for predicting deviations from unbiasedness hypothesis is time series analysis. Finding a leading indicator would be useful in predicting future deviations, and possibly enable investors to increase the profitability of carry trade strategies in the foreign exchange market. To test if a variable is a leading indicator we run a regression with a lagged log-difference of the explanatory variable, which will tell us if there is a significant relationship between the coming deviation from the unbiasedness hypothesis and a past change in the explanatory variable. The regression can be expressed as follows:

$$(ln\ S_{t+k} - ln\ S_t) - (ln\ F_t^k - ln\ S_t) = \alpha + \beta \cdot (ln\ M_{t-1} - ln\ M_{t-n}) + \varepsilon_t \qquad (15)$$

Where k is the maturity length, M is the explanatory variable and the left-hand side is the difference between the ex-post rate of appreciation and the forward premium, i.e. the ex-post deviations from the unbiasedness hypothesis. Subscript n defines the length of the period of the lagged change in the explanatory variable.

When conducting the regression test we have to make sure that all relevant information is unconditional at time t, i.e. available to the investor at the start of a carry trade. We are using closing exchange rates which is set at 16:00 London time, which does not coincide with the end of the trading day for the explanatory variables. For example, the S&P 500 closes at 16:00 New York time, which is five hours behind London. Hence, we cannot perfectly align the change in an explanatory variable to the start of a carry trade. This means that we have to use the percent change in the explanatory variable from time $t - n$ to $t - 1$ in order to be certain that the information is available at time t.

In our regression test we use two different strategies for n, one short term and one slightly longer term. For the short term we set $n = 2$ regardless of the maturity length. By doing this we test to see if the very recent changes in the explanatory variables is taken into account in the pricing of forward contracts, as we would expect in an efficient market.

The longer-term strategy is to set $n = k$, i.e. the same length as the contract maturity we are testing. For instance, when looking at the one month maturity, we would test whether the prior month's change in the explanatory variable affects the next month's deviation. This enables us to see whether the changes in the explanatory variable experienced during the previous contract length is taken into account by the market participants in the next period. For the overnight maturity we do not use maturity length periods, because the maturity lag of an overnight contract is one day, which is the same as in the short-term strategy.

The practical interpretation of the regression coefficients can yield interesting insights into possibly more profitable carry trade strategies, which is best explained by an example. Take the NOK/USD pair, which is quoted in NOK per USD. If we find that the difference between the rate of appreciation and the forward premium for NOK/USD regressed on an explanatory variable yields a positive beta coefficient, the interpretation is that the difference increases when the variable increases. The increase in the deviation from unbiasedness arises because the change in the rate of appreciation is relatively larger than the change in the forward premium. This means the future USD spot rate appreciates relative to the NOK, compared to the expected future spot rate. The best way to take advantage of this relationship is therefore to buy the USD forward following an increase in the explanatory variable and sell the USD at spot at the time of maturity.

When interpreting the beta coefficients one must also keep the constant terms in mind, which tells us what the deviation is given no change in the explanatory variable. This is especially important when the coefficient of the explanatory variable and the constant has opposite signs. For instance, a positive explanatory beta implies that the rate of appreciation increases relative to the forward premium given a positive change in the explanatory variable. One would therefore expect that the deviations from unbiasedness to increase. If the constant is negative however, the actual deviation could go from negative to less negative, or even zero. Therefore, the deviation from the unbiasedness hypothesis has decreased in absolute terms. To find the true predicted deviation from unbiasedness we must therefore calculate the sum of

the right side of eq. 17. In summary, interpreting the signs of the coefficients alone is not sufficient when determining whether the relationship between the explanatory variable and the deviation leads to increased quasi-arbitrage opportunities.

3.2.2. Direction of Change-model

An interesting relationship to look into when testing the predictive power of a variable is whether the sign of the change in the explanatory variable tends to have a positive or negative relationship with the sign of the change in the dependent variable. I.e., whether the variable forecasts the correct direction of the change in deviations from the unbiasedness hypothesis. This can be done by looking at the signs of the coefficients from the univariate regressions, but as a robustness check we also implement a direction of change-model. This is different from the regressions because we exclude the magnitude of the change from the equation, focusing solely on the direction. Thus, we look at how often the variable predicts the correct direction on average. A result that matches the sign of the beta coefficients from the regressions can therefore be viewed as a stronger result than if the signs are conflicting.

We create a variable, V, which is equal to 1 if the change in the explanatory variable, M, has the same sign as the change in the deviation from unbiasedness, and equal to 0 if the signs are opposites. We then create a variable, DoC, which is equal to the mean of V. For any given explanatory variable we have:

$$DoC_M = \frac{1}{N}\sum_{t=1}^{N} V_{M,t} \tag{16}$$

Where t is time and N is the number of observations. If the explanatory variable has no power in predicting the direction of the changes in the deviation DoC should be equal to 0.5. A mean significantly larger than 0.5 would indicate a positive relationship between the signs of the variables, whereas a mean significantly less than 0.5 indicates a negative relationship.

The direction of change-test is run with both daily and maturity lagged changes, identical to our time series regressions. This means that we are testing the relationship between the direction of change in the dependent variable with the previous time period's direction of change in the explanatory variable.

3.2.3. Selection of Explanatory Variables

As discussed in the literature review there has been conducted several studies on the relationship between various explanatory variables and exchange rates. For our analyses of predictable deviations from the unbiasedness hypothesis we select some of the most interesting variables to explore further.

As discussed, research into liquidity risks in the foreign exchange market has provided some interesting results in the past. Since liquidity data in the foreign exchange market is hard to come by we chose to use the bid-ask spread as a proxy. The theory is that when liquidity is high, the bid-ask spread is low, making it more desirable to trade in the foreign exchange market and thus increase the activity in the market. A lower bid-ask spread should therefore mean that exchange rates are more correctly priced and, in theory, decrease the bias.

For volatility we have several testable metrics. In order to capture the relationship between exchange rates and the stock market we will look into the VIX-index as an explanatory variable. The VIX-index is popularly referred to as the "fear-index" and is a measure of the market expectation of future volatility in the stock markets, calculated from the implied volatility in stock option prices. An increase in the VIX will therefore signal increased future market volatility expectations. As safe haven currencies have been known to appreciate during times of high volatility, we expect there to be a correlation between the VIX and foreign exchange rates. We do however not know if there is a relationship between the VIX-index and the deviation from the unbiasedness hypothesis. Thus, we would like to test for this possible relationship.

Whereas the VIX indicates expected volatility, the S&P 500 Index can yield information about the current level of volatility in the stock market. Specifically, the S&P 500 covers the 500 largest companies listed on NYSE or NASDAQ, by market capitalization, and is one of the most important indices in the stock market. As stock market volatility is linked to the market participants' expectations of future earnings and the economy in general, increased market volatility should correlate with volatility in other financial markets. Changes in S&P 500 should therefore have some kind of explanatory relationship with the foreign exchange market and perhaps the deviation from the unbiasedness, which we would like to test for. Finding a significant correlation between the S&P 500 and the deviations from unbiasedness

would be an indication of the presence of a systematic risk component in foreign exchange rates.

When it comes to monetary policy there are different testable alternatives. According to interest rate parity there is a clear connection between the interest rate differential of two currencies and the forward premium. However, we would like to test for a possible connection between the relative change in a USD denominated interest rate and the deviation from the unbiasedness hypothesis. If the foreign exchange markets are efficient then any change in interest rates should immediately be reflected in the forward premium. We would like to test this hypothesis to see whether this is the case or not. Since interest rates set by the central banks are rarely changed, it will therefore be more beneficial to look into the interbank market rates. Thus, we chose to use the USD denominated London Interbank Offered Rate (LIBOR) as the basis for this test.

To examine whether we can find a relationship between transportation costs and the deviation from the unbiasedness hypothesis, we will test to see if the Baltic Dry Index has any predictive power as an explanatory variable. An increase in the Baltic Dry Index could indicate an increased segmentation in global trade and thus reduced demand for foreign currencies, or on the other hand, possibly indicate increased demand for transportation and thus also increased demand for foreign currency. Since a great deal of the changes in exchange rates are driven by trade, a study into the relationship between transportation costs and the deviation from the unbiasedness might provide interesting insights.

While Ferraro, Rogoff and Rossi (2011) found a relationship between the oil price and exchange rates, we will look into the possibility of the oil price as a predictor of the deviation from the unbiasedness hypothesis. Currencies of commodity dependent countries such as Norway are highly correlated with the price fluctuations of the commodities which they export. However, the oil price's effect on the forward price's ability to predict the future spot is not as straightforward in its reasoning. It will therefore be interesting to see whether the market is able to take the expected oil price changes into account when setting the forward price of the NOK.

As for regulation, useful time series data is very hard to come by and we will therefore not pursue this any further. We do however think that it is an interesting discussion and look forward to seeing more research into this in the future.

3.3. Econometric Issues

In order to ensure the validity of tests we need to make sure that our data satisfies certain assumptions that is necessary for time series data. The Gauss Markov conditions are considered to be the ideal set of conditions, but these are very restrictive and not likely to hold in reality. However, as the number of observations goes towards infinity we can apply a more practical set of asymptotic assumptions. In this subchapter we will go through the results of the various econometric tests conducted to ensure that these assumptions hold. For more detail on the econometric test results see appendix III.

The first condition requires that the model is linear in parameters, meaning that we can write the model as follows: $Y_t = \alpha + \beta_1 x_{1t} + \beta_2 x_{2t} + u_t$. We see that the specification of eq. 14 and eq. 17 meets this requirement.

Condition number two is that there is no perfect collinearity between independent variables. This simply means that we cannot have two independent variables that move identically. When running univariate regressions, such as when testing the unbiasedness hypothesis, we will only have one independent variable. Hence, collinearity will not be an issue.

The third condition requires that the time series are stationary and weakly dependent. We already discussed that exchange rates exhibits signs of a non-stationarity. The Dickey Fuller test results confirms that the levels of every spot and forward rate could not reject the null hypothesis of a unit root for any currency pair no matter the maturity length.

There is general agreement among researchers that the logarithmic spot rate is integrated of order one, meaning that the first log-difference should be stationary (Baillie and Bollerslev, 2000). When testing the rate of appreciation (by taking the log-difference of the spot rate) the Dickey-Fuller test did reject the null hypothesis for all currency pairs across all maturities, as expected. The forward premium, however, displays persistent and slowly decaying

autocorrelations, so much so that some researchers believe it contains non-stationary components (ibid). While all our Dickey-Fuller tests of forward premiums with overnight maturity rejects the null, the weekly and monthly maturities test results revealed that only one forward premium rejected the null of non-stationarity, which was the CAD. This is a common finding for the one month maturity, which leads the regular t-test to an overstated significance (Sercu, 2009).

The fourth condition is referred to as the zero conditional mean assumption, which is one of the most important assumptions. It is also one of the largest differences between the Gauss Markov assumptions, which requires strict exogeneity, and the asymptotic assumptions, which only requires weak or contemporaneous exogeneity.

Weak exogeneity requires that the error term cannot be correlated with any explanatory variable at time t. This is much less restrictive and more likely to hold compared to the strict exogeneity required by Gauss Markov. One way to check if this condition holds is to plot the predicted residuals against the explanatory variable and see if the average residual is dependent on the independent variable, in this case the forward premium. These graphs can be found in the appendix III, where we also superimposed a LOWESS-curve which serves as a tool to see whether the average residual changes with the forward premium. According to these graphs the mean residual seems to be quite constant, and the residual appears to be uncorrelated with the explanatory variable. This indicates that we fulfill the zero conditional mean assumption.

As an additional and more formal test we also ran the Ramsey regression specification-error test (RESET) for omitted variables, since omitted variable bias is often a large cause of violations of the zero conditional mean assumption. This test concluded that Ramsey tests cannot reject the null hypothesis of no omitted variables, for any currency pair with the one month and one week maturity. The overnight maturity however rejects the null for EUR and SEK.

Condition number five is that our data is homoskedastic. In order to test this condition we ran both the Breusch-Pagan test and the White test for all currency pairs. The Breusch-Pagan and the White-test rejected the null hypothesis of homoskedasticity for several currency pairs in various maturity lengths, and especially for AUD/USD and EUR/USD. We used robust

standard errors for all regressions when testing the unbiasedness hypothesis. We also found evidence of heteroskedasticity in the explanatory variables used to predict deviations from the unbiasedness hypothesis, which we also correct for using robust standard errors.

The sixth and final condition is that our data cannot display serial correlation, also called autocorrelation. A major cause of autocorrelation is overlapping data. For instance, if we ran the conventional regression test (represented by eq. 12 and 13) using daily observations on a one month maturity we would have a large issue with autocorrelation. Thus, we need to remove the overlapping observations, which in the case of the one month maturity means that we are left with one observation for each month. We do this for all regression tests, both when testing the unbiasedness hypothesis and when we look for variables that affect the unbiasedness.

Similarly to the zero conditional mean assumption we can test for autocorrelation both visually and more formally. The formal Durbin-Watson test revealed that most currency pairs had a test-statistic close to 2, which indicates no autocorrelation, although some had indications of positive or negative autocorrelation. The one month maturity had the largest outliers in terms of test-statistic, especially CHF with 2.25, AUD with 1.78 and CAD with 1.79.

The visual test of the presence of autocorrelation is conducted by plotting the residuals from the strong form regression test against its own lag and look at their distribution. We have included such graphs for each currency pair and maturity in the appendix. For the one month maturities we see that the residuals for CHF, AUD and CAD are somewhat correlated, but the rest of the currency pairs seems to be quite uncorrelated for most currency pairs. Similar tests of the one week and overnight maturities has less indication of autocorrelation.

4. Data description

4.1. Part 1: Testing The Unbiasedness Hypothesis

To be able to conduct an empirical analysis of the unbiasedness hypothesis we need to collect time series data on the spot foreign exchange rate and the forward foreign exchange rate on several currency pairs. We are also interested in collecting data on different maturity lengths to see if there is any variation in the deviation from the unbiasedness hypothesis and its predictability due to differences in maturity.

Our data set consist of 9 currency pairs from the G10 currencies, which includes USD/AUD, USD/EUR, JPY/USD, USD/GBP, NOK/USD, CAD/USD, SEK/USD, USD/NZD and CHF/USD. We chose these currency pairs because they are the most liquid and actively traded in the foreign exchange market, which should mean that these currencies are the most likely to be priced correctly and should have the smallest bid-ask spreads. Since these currency pairs are thought to be more correctly priced, the deviation from unbiasedness is likely to be smaller than if we had chosen currency pairs based on the interest rate differential.

Through Thomson Reuters Datastream we retrieved all of our exchange rate data from WM/Reuters which has become an industry wide standard. WM/Reuters has daily observations (excluding weekends) on bid, ask and middle rates for closing spot rates and closing forward contracts with many different maturity lengths. Also, note that exchange rates from Datastream are padded, meaning that the exchange rate for the preceding trading day are ascribed to non-trading days, such as holidays.

The exchange rates from WM/Reuters are sourced from the Thomson Reuters Market Data System which collects data from multi-contributor sources. A number of snapshots are taken from the Reuters system at 16:00 (London time) and median rates are then selected for each currency. London time was selected as the middle of the 'global day' and the time of highest liquidity in the global foreign exchange market (Thomson Reuters, 2017).

In our analysis we include the spot rate, the overnight forward, the one week forward and the one month forward closing rates. Since taking the bid-ask spread into account would overcomplicate our analysis, we chose to use the middle rate for our tests of the unbiasedness hypothesis. We chose the overnight, one week and one month maturity lengths since arbitrage

opportunities often exists on a very short horizon (Du et al., 2018), and the monthly maturity has become the conventional way to test the unbiasedness hypothesis. Another benefit of having short maturities is that it offers a large number of observations and thus yields great statistical power. We chose to exclude longer maturities because longer maturities means that we are left with a smaller sample size after removing overlapping data.

In order to be able to compare the results of the analyses of the currency pairs to each other we have chosen to use the same time-period across all pairs, as far as possible. While WM/Reuters started to collect data on closing spot rates in 1994, they only offer data on forwards from 31.12.1996 for most currencies (notably except the Euro which starts on 31.12.1998). Thus, we chose to start the time-period of our analysis from this date and to end the period on 25.04.18. After removing overlapping data we have 222 observations for the monthly maturities, 1.070 for the weekly maturities and 5.347 for the overnight maturities, with the exception of the Euro which has 212, 1.008 and 5.038 respectively.

We compile all of our data in one Excel-file, with different sheets for different maturities. Each sheet has 18 currency variables (one spot rate and one forward rate for each currency), plus a date-variable and the explanatory variables for part two. Any necessary transformation of the data is then done in Stata through a series of interconnected do-files in order to ensure all three maturity lengths are treated equally in terms of testing. Some currencies are quoted as domestic currency per foreign currency for the spot rate and the inverse for the forward rate, from the source. We correct for this by dividing 1 by the forward rate for USD/AUD, USD/GBP, USD/NZD and USD/EUR, which gives us the inverse quotes, AUD/USD, GBP/USD, NZD/USD and EUR/USD. This ensures that all currency pairs are quoted against the dollar, which enables us to run the necessary analyses and simplifies the comparison between currency pairs.

For the one month and one week maturity we chose to use Tuesdays as the starting date for every forward contract. This means that time of maturity falls on a Thursday for the 30-day forward and Tuesday for the one week forward, and most importantly not in a weekend. For the one month maturity the next forward contract has to start on the following Tuesday to avoid any overlap, meaning that we have 35-day gaps between observations. For the one week and overnight maturity this is not an issue. The overnight maturity however has a different kind of issue which is the fact that we do not have any data during weekends. To

solve the issue with irregular gaps between our observations we utilize a business calendar i Stata.

4.2. Part 2: Predicting Deviations From The Unbiasedness Hypothesis

To conduct tests for the prediction of the deviation from the unbiasedness hypothesis we collect different variables that might have an effect on the deviation. We attain historical data for the following factors; bid-ask spread for the spot foreign exchange rates, LIBOR, the Baltic Dry Index, VIX-index, S&P 500-index and the price of brent crude oil. The specific VIX-index we use is the CBOE Volatility Index. It calculates the implied volatility of call and put options on the S&P 500 Index. The specific LIBOR is denominated in USD with one month maturity.

All data are retrieved through Thomson Reuters Datastream except the Baltic Dry Index, which is retrieved from Bloomberg. The time period is the same as for the currencies, starting at 31.12.1996 and ending at 25.04.2018. To be able to run reasonable regression models we have limited our variables to those that are recorded in daily intervals. This is because a quarterly variable, for instance, will not have the same direct and sudden response to market fluctuations and thus not a significant contributor to the deviation from the unbiasedness hypothesis.

Similar to the exchange rate data our explanatory variables are also padded. As most of the variables are asset prices, or highly related to asset prices, they are most likely subject to autocorrelation. To account for this we structure the dataset in the same way as the currencies, meaning that we remove all overlapping data.

5. Empirical Results

5.1. Part 1: Testing The Unbiasedness Hypothesis

In this chapter we will present the results of the tests described in the methodology chapter. First we will look at the weak test to get an indication of how the unbiasedness hypothesis holds on average and then we will continue on to the stronger form time series regression tests.

5.1.1. Mean Comparison Test Results

All our currency pairs are plotted on graph 4 through 6, each with their individual maturity length, where the X-axis represents the average ex-post change in spot rate and the Y-axis represents the average forward premium. Additionally we have superimposed a fitted line and a 45-degree line, representing the interest rate parity line. The fitted line is generated by calculating the prediction for the ex-post change in spot rate from a linear regression of ex-post change in spot rate on the forward premium.

While this graphical illustration is useful for getting a visual indication of whether or not the unbiasedness hypothesis holds, we also conducted a formal mean comparison t-test. This test is able to tell us if the difference between the mean forward premium and the mean ex-post change in the spot rate is significantly different from zero, for any currency pairs.

The results from the mean comparison t-test are presented in table 1 through 3 below, which contains information on the mean rate of appreciation, the mean forward premium, the difference between the two and its P-value for being different from zero for all currency pairs. None of the differences for any currency pairs are significantly different from zero for any maturity, which means that we cannot put too much confidence in the magnitude or direction of the difference. For each maturity length we have marked the currency pair with the lowest P-value in green.

5.1.1.1. One Month Maturity
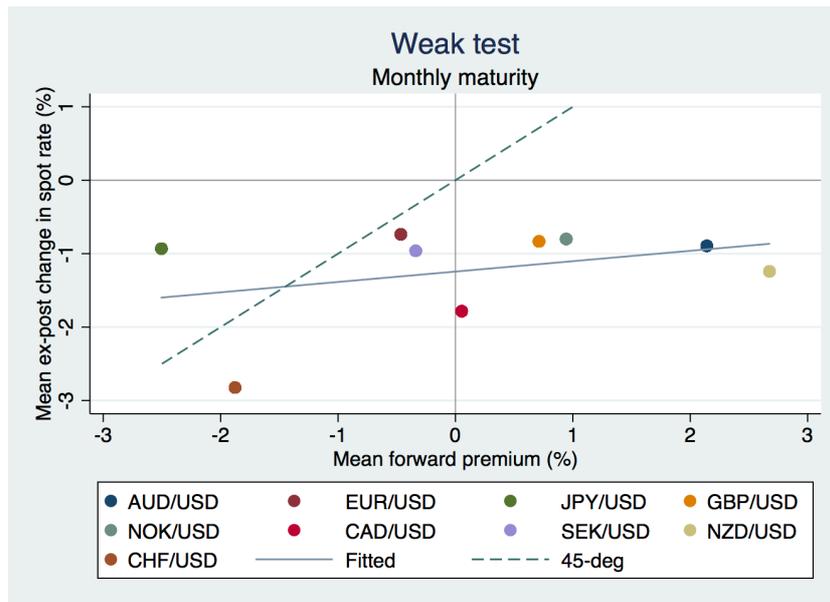
Figure 4: Mean comparison plot using one month forward rates. Annualized percentage rates.

As discussed in the methodology section, we expected the currencies to be randomly scattered around the 45-degree line if the unbiasedness hypothesis holds. As we can see from figure 4 this does not seem to be the case for the one month maturity. Only one currency pair is above the interest rate parity line and all currency pairs have a negative mean ex-post change in the spot rate, meaning that the USD has depreciated against all other currencies on average. The fitted line has a slope of 0.1415 which is a lot less than unity, but not an indication of the forward premium puzzle.

When looking at the weak form graphs there are two areas which are interesting to note. The first one is the area in the top left of the origin, where the mean forward premium is negative and the mean rate of appreciation is positive. This is ideal conditions for carry trade because the investors can buy the forward at a discount as well as receive capital return by ex-post changes in the spot rate. From the graph we can see that none of the currency pairs are in this area for the one month maturity.

The other interesting field, is the one in the bottom right of the origin, where we can see a total of five currency pairs. Currencies in this area have a positive forward premium on average and a mean decline in the ex-post spot rate. In other words, one would have a

negative return from carry trades using these currency pairs, by going long in USD. However, if we invert the exchange rates, the return from carry trade would have the opposite sign. If we were to invert all the exchange rates, the scatter plots would have flipped horizontally as well as vertically, which would change the sign of both the mean forward premium and the mean rate of appreciation for all currency pairs.

Although obvious, the two other areas of the graph, the bottom left and top right, are not strictly interesting because the forward premium and ex-post change in the spot rate have opposite signs and thus affects the difference from both directions. The closer the currency pairs are to the interest rate parity line, the closer the rate of appreciation and the forward premium are to cancel each other out. By inverting the currency rates the forward premium and ex-post change in spot rate would switch signs, but they would still be opposite to each other.

Currency Pair	Mean Rate of Appreciation ($\bar{s}$)	Mean Forward Premium ($\overline{fp}$)	Difference ($\bar{s} - \overline{fp}$)	P-value ($D = 0$)
AUD/USD	−0,90%	2,15%	−3,05%	0,3092
EUR/USD	−0,87%	−0,45%	−0,42%	0,8775
JPY/USD	−0,93%	−2,50%	1,57%	0,5512
GBP/USD	−0,84%	0,72%	−1,56%	0,4942
NOK/USD	−0,80%	0,95%	−1,75%	0,5244
CAD/USD	−1,79%	0,06%	−1,84%	0,3189
SEK/USD	−0,96%	−0,33%	−0,63%	0,8163
NZD/USD	−1,25%	2,69%	−3,93%	0,2138
CHF/USD	−2,82%	−1,87%	−0,95%	0,7077

Table 1: Mean comparison test results using one month forward rates. Annualized percentage rates.

Table 1 tells us that NZD/USD is the closest currency pair to being significant with a P-value equal to 0.21, for the one month maturity. NZD/USD has an average annualized ex-post change in the spot rate of -1.25% and a negative average forward premium of 2.62%, giving it the highest difference of all currencies with monthly maturity in absolute terms of -3.93%.

From the graph we can see that NZD/USD is the most extreme outlier from the interest parity line. Since the difference is negative we would lose money by going long in USD and short in NZD in the forward market, but as mentioned we would earn money by doing the exact opposite, i.e. going long in NZD and short in USD. While this currency pair is not commonly used in carry trade, investors often go long in NZD due to its relatively high interest rate.

We also see that the AUD/USD has the second largest difference for the monthly maturities, in absolute terms, with -3.05%. AUD/USD is also the second closest to being significant, although the P-value is 0.3. Similarly to NZD/USD, the AUD/USD currency pair also has a negative difference and we can thus use the same strategy as for the NZD/USD, by going long in AUD. AUD has also been a common currency for carry trade investors to go long in, traditionally.

The only currency pair with a positive difference is JPY/USD with 1.57%. This finding is not unexpected, since JPY has had a consistently low interest rate compared to USD during the period of our analysis. We would also expect CHF to have a positive difference, since it also has had a low interest rate compared to USD, in the same period, but this is apparently not the case according to our results. However, the difference for CHF/USD has the third highest P-value for all currency pairs with one month maturity, at 0.7. The other currency pairs also have such a large P-value that they are practically meaningless to discuss in any useful manner.

5.1.1.2. One Week Maturity
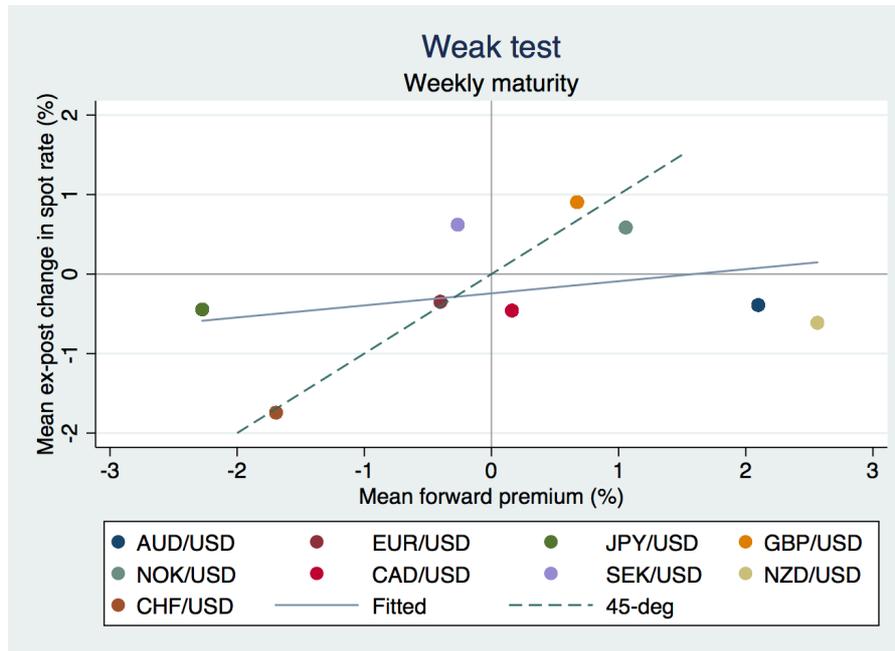
Figure 5: Mean comparison plot using one week forward rates. Annualized percentage rates.

In the case of the one week maturity we can see from figure 5 that the currency pairs seems to be more randomly dispersed around the interest rate parity line, compared to the one month maturity. However, the fitted line has a slope of 0.1519 and is therefore not much different from the monthly maturity. The slope is still far from unity, meaning that the ex-post depreciation of currencies that were initially trading at a discount is not sufficient to regain equilibrium in accordance with interest rate parity.

For the one week maturity we can see that a total of four currencies fall in the two interesting areas. SEK/USD, which was below the interest rate parity line for the one month maturity is now in the top left, while CAD/USD, AUD/USD and NZD/USD are in the bottom right as for the one month maturity. GBP/USD and NOK/USD have both moved out from the bottom right area and closer to the interest rate parity line.

Currency Pair	Mean Rate of Appreciation ($\bar{s}$)	Mean Forward Premium ($\overline{fp}$)	Difference ($\bar{s} - \overline{fp}$)	P-value ($D = 0$)
AUD/USD	−0,39%	2,10%	−2,49%	0,3661
EUR/USD	−0,19%	−0,40%	0,21%	0,9244
JPY/USD	−0,44%	−2,27%	1,83%	0,4150
GBP/USD	0,91%	0,67%	0,23%	0,9117
NOK/USD	0,59%	1,06%	−0,47%	0,8555
CAD/USD	−0,46%	0,16%	−0,62%	0,7579
SEK/USD	0,62%	−0,26%	0,88%	0,7252
NZD/USD	−0,62%	2,57%	−3,19%	0,2858
CHF/USD	−1,76%	−1,71%	−0,05%	0,9832

Table 2: Mean comparison test results using one week forward rates. Annualized percentage rates.

From table 2 we see that NZD/USD and AUD/USD are the largest differences for the weekly maturity as well. USD/NZD is also the closest to being significant at the one week maturity with a P-value of 0.28 as well as having the largest difference between the mean rate of appreciation and mean forward premium in absolute terms at -3,19%. Again NZD/USD is followed by AUD/USD in terms of both significance and difference.

We also see that JPY/USD, which was the only currency pair to have a positive difference for the one month maturity, has the largest positive difference for the weekly maturity. Again CHF/USD does still not have a positive difference as we initially expected, but the P-value is extremely large at 0.98. It is also interesting to note that the P-value has also increased for the other 8 pairs, with the exception of SEK/USD and JPY/USD. Since the number of observations has increased, the increase in P-values is likely to be due to increased volatility in the difference.

5.1.1.3. Overnight Maturity
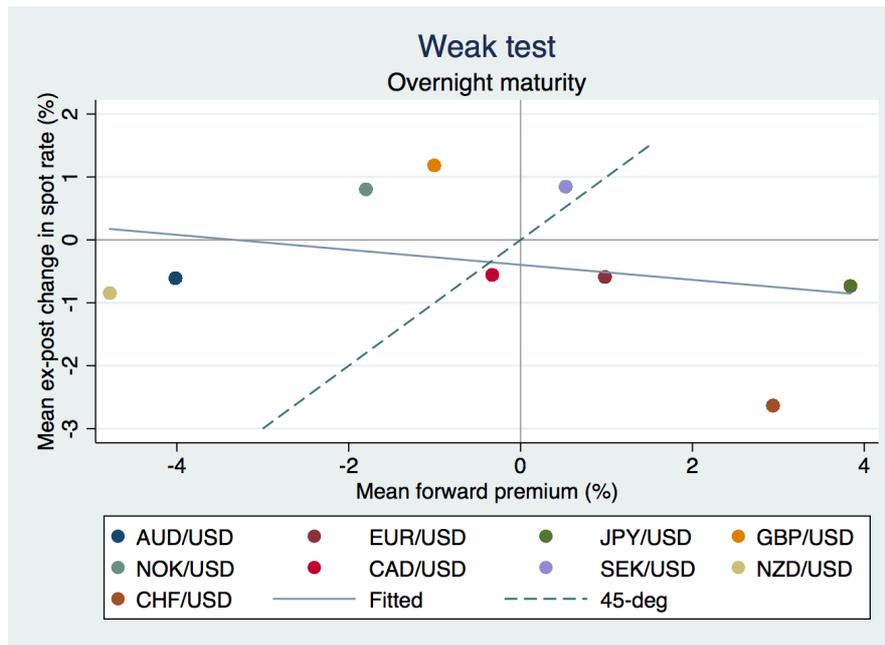
Figure 6: Mean comparison plot using overnight forward rates. Annualized percentage rates.

When we compare figure 6, which depicts the weak test graph for overnight maturities, to the graphs for the one month and one week maturities, we see that the overnight maturity currency pairs are more widely dispersed. Most notably the overnight maturity has currency pairs with both positive and negative mean forward premium of around 4%, where the most extreme outliers for the two longer maturities were at about 3%.

In contrast to the monthly and weekly maturity, figure 6, reveals a fitted line with a negative slope of -0.119. Since a negative slope means that a low forward premium (or a high forward discount) is associated with a high ex-post appreciation of the spot rate, we can interpret the slope as an indication of the presence of the forward premium puzzle for the overnight maturity forwards quoted against the US dollar.

For the overnight maturity we can see that NOK/USD and GBP/USD fall in the top left area, while EUR/USD, CHF/USD and JPY/USD are in the bottom right area. The only two currencies that has fallen in either of these areas for the other two maturities are GBP/USD and NOK/USD, which was on the opposite side of the interest rate parity line when we looked at the one month maturity. Thus, they have gone from a negative difference for the one month maturity, to a positive difference for the overnight maturity.

Currency Pair	Mean Rate of Appreciation ($\bar{s}$)	Mean Forward Premium ($\overline{fp}$)	Difference ($\bar{s} - \overline{fp}$)	P-value ($D = 0$)
AUD/USD	−0,62%	−3,94%	3,32%	0,3806
EUR/USD	−0,26%	0,98%	−1,24%	0,6943
JPY/USD	−0,73%	3,83%	−4,56%	0,1834
GBP/USD	1,19%	−1,02%	2,20%	0,4485
NOK/USD	0,80%	−1,81%	2,61%	0,4780
CAD/USD	−0,55%	−0,33%	−0,21%	0,9346
SEK/USD	0,85%	0,52%	0,32%	0,9299
NZD/USD	−0,84%	−4,63%	3,80%	0,3281
CHF/USD	−2,63%	2,94%	−5,57%	0,1011

Table 3: Mean comparison test results using overnight forward rates. Annualized percentage rates.

Both from the graph and the table we can see that the overnight maturity seems to be quite different from both the monthly and weekly maturity. For instance, both NZD/USD and AUD/USD, which had negative differences for both one month and one week maturity, now has a positive difference. From table 3 we see that both currency pairs have a negative mean rate of appreciation as well as a negative forward premium. The large average forward discounts relative to the negative rate of appreciation reveals that going long in USD overnight forward and simultaneously shorting NZD or AUD would yield a positive return according to our data. This is contradictory to what we found for the two longer maturities and what we would expect.

Perhaps the largest surprise is the results for CHF/USD. While we expected the CHF/USD to have a positive difference, it has the largest difference in absolute terms out of all currencies with overnight maturity and across all maturities, with -5.57%. The P-value for this difference is 0.101, which is also the closest to being significant out of all currency pairs regardless of maturity length. The second largest difference in absolute terms for the overnight maturities, and across the board is JPY/USD with a difference of -4.56%, which is also the second closest to being significant.

The results from the overnight maturity are very interesting, since they seem to contradict the results for the other maturities and the conventional carry trade has been conducted. CHF, JPY, AUD and NZD are all currencies commonly used in carry trade, but not in the way that our data for the overnight rate would suggest. Due to their relatively low interest rate investors often borrow CHF and JPY in the spot market or short them in the forward market to finance long positions in higher yielding currencies. However, our results for the overnight maturity reveals that both CHF/USD and JPY/USD has had a negative return from carry trade on average. While going long in CHF and JPY, and simultaneously short in USD, is contradictory to the way carry trade has been conducted historically, this would have been profitable on average according to our results. This is especially surprising given the large negative difference for CHF/USD which is close to being significant at the 10-percent level. As discussed earlier, AUD and NZD are popular currencies for investors to go long in, but our results show that they have had a negative return on average, relative to USD, for the overnight maturity.

While the deviation from the unbiasedness for the overnight maturity can seem large in table 3, keep in mind that these are annualized, meaning that even small absolute deviations can appear large. Hence, a possible reason for the surprising results from the overnight maturity is that the return from an overnight carry trade is quite small compared to the transaction costs. Even though Bekaert and Hodrick (1993) found that accounting for the bid-ask spread did not affect the beta estimates significantly for the one month maturity, this is not necessarily the case for overnight maturities.

We also note that this is in line with the theory of a nonlinear relationship between the change in spot rate and the forward discount, proposed by Baillie and Bollerslev (2000). As discussed in the literature review, they argue that the forward discount is likely to point in the wrong direction of the ex-post rate of appreciation when the forward discount is small in absolute value, perhaps due to large transaction costs relative to the potential gains (Chinn, 2007).

5.1.2. Times Series Regression Test Results

According to the weak test none of the currency pairs significantly deviate from the unbiasedness hypothesis, but as discussed this test does not detect all inefficiencies. Now we will take a look at the strong form time series regression results. Table 4 through 6 has information on the beta coefficients for the ex-post changes in spot rates regressed on the forward premiums, the constants, the beta coefficients' P-value for being significantly different from 1 and the R^2. For each maturity length we have marked the currency pair with the lowest P-value in green. Note that none of the constant terms are significantly different from zero.

When comparing the results from the strong test to the weak test it is useful to keep the interpretations of the different test results in mind. While the weak test looks for a statistically significant average deviation from interest rate parity for the overall time period, the strong test looks for a relationship between the forward premium and the ex-post rate of appreciation that is significantly different from unity. This means that currency pairs which consistently exhibits opposite signs for the ex-post rate of appreciation and the forward premium through the time period should have a negative beta coefficient for the forward premium. Hence, comparing the results of the different tests could be interpreted as a robustness check of our results.

5.1.2.1 One Month Maturity

Currency Pair	Constant	Forward Premium Beta	P-value ($\beta = 1$)	R^2
AUD/USD	0,0017	−1,3885	0,1952	0,0032
EUR/USD	−0,0015	−2,1652	0,1426	0,0060
JPY/USD	0,0015	1,0946	0,9406	0,0036
GBP/USD	−0,0009	0,2872	0,7217	0,0001
NOK/USD	0,0005	−1,4410	0,0690	0,0051
CAD/USD	−0,0015	−0,6018	0,3546	0,0005
SEK/USD	−0,0013	−2,0030	0,0452	0,0076
NZD/USD	−0,0015	0,2010	0,6647	0,0001
CHF/USD	−0,0056	−2,0699	0,0658	0,0069

Table 4: Time series regression test results for one month forward rates.

For the one month maturity length, our results show that 6 out of 9 currency pairs have a negative beta-coefficient and 8 out of 9 has a beta-value less than one. However, we see that only one currency has a significant beta value at the 5-percent level, which is SEK/USD. We also note that the beta is extremely negative at -2.00. In fact, out of all the maturities, the one month maturity has the highest number of beta estimates with a value less than -1. This is a clear indication of the forward premium puzzle, since a negative beta implies that a one percentage point decrease in the forward premium is associated with an increase of two percentage points in the ex-post rate of appreciation. Additionally, both NOK/USD and CHF/USD have negative beta estimates which are significant at the 10-percent level (and close to the 5-percent level).

If we compare the strong test results for the one month maturity to the weak test results for the same maturity, we see that five currency pairs have a beta estimate that is in line with what we would expect from the sign of the mean rate of appreciation and mean forward premium. This is true for AUD/USD, JPY/USD, NOK/USD, CAD/USD and CHF/USD. However, since none of the beta estimates from the strong form test (with the exception of the beta for SEK/USD) and the differences from the weak form test are significant, we cannot put too much emphasis on this comparison.

The strong form regression test using one month maturity forwards has been the most frequently used test of the unbiasedness hypothesis within academia. Nevertheless, few test results from previous research are strictly comparable due to differences in choice of currency pairs, time periods and the treatment of data such as annualization. Bekaert and Hodrick (2013) ran a similar regression test on data from 1976 to 2010 on three of the same currency pairs which is included in our analysis. Out of these three the forward premium beta for GBP/USD has the same sign, while JPY/USD and EUR/USD does not. There are a number of different reasons why the signs and magnitude of the beta estimates differ from our analysis to theirs. For instance, the difference in time period and the fact that they have used the Euro as a replacement Deutsche mark from 1999 onwards.

It's also important to note that the one month forward premiums for all currencies exhibited indications of a unit-root, with the exception of CAD/USD. This means that the P-values might be too optimistic.

5.1.2.2 One Week Maturity

Currency Pair	Constant	Forward Premium Beta	P-value ($\beta = 1$)	R^2
AUD/USD	0,0006	−1,8061	0,0973	0,0012
EUR/USD	−0,0001	−1,3337	0,2082	0,0006
JPY/USD	0,0001	0,3601	0,5644	0,0001
GBP/USD	0,0001	0,6653	0,8475	0,0001
NOK/USD	0,0002	−0,1981	0,3082	0,0000
CAD/USD	−0,0002	2,1135	0,6068	0,0007
SEK/USD	0,0001	−0,7088	0,2301	0,0002
NZD/USD	−0,0004	0,5961	0,8342	0,0001
CHF/USD	−0,0011	−2,2034	0,0445	0,0018

Table 5: Time series regression test results for one week forward rates.

For the one week maturity length our results show that 4 out of 9 currencies have a negative beta, while 8 out of 9 currencies have a beta less than 1.

The most interesting result from the strong from test of the one week maturity is the CHF/USD which has a negative beta of -2.2, which is significant at the 5-percent level and has the highest R^2 for all currencies in the one week maturity category. USD/AUD has the second largest beta-value in absolute terms which is equal to -1.8 and significant at the 10-percent level.

By comparing the strong test results for the one week maturity to the weak test results for the same maturity we find that AUD/USD, JPY/USD, GBP/USD and SEK/USD has matching forward premium beta estimates to what we would expect from the signs of the mean rate of appreciation and the mean forward premium. But again, comparing two sets of insignificant results is not reliable.

5.1.2.3 Overnight Maturity

Currency Pair	Constant	Forward Premium Beta	P-value ($\beta = 1$)	R^2
AUD/USD	0,0001	0,9700	0,9645	0,0003
EUR/USD	−0,0001	1,8135	0,2742	0,0019
JPY/USD	−0,0001	0,5479	0,4871	0,0001
GBP/USD	0,0000	−0,6888	0,1172	0,0001
NOK/USD	0,0000	0,1222	0,1417	0,0000
CAD/USD	0,0000	0,5110	0,0000	0,0004
SEK/USD	0,0000	−0,2759	0,2822	0,0001
NZD/USD	0,0000	−0,0941	0,1150	0,0000
CHF/USD	−0,0001	0,8813	0,7356	0,0006

Table 6: Strong form regression test results for overnight forward rates.

The regression analysis of the overnight maturities yields merely 3 negative beta coefficients, none of which are significant at any reasonable level nor particularly large. However, 8 out of 9 currencies has a beta below unity. One of these is CAD/USD with a beta of 0.51 which is significant at the one percent level. This is interesting since it's in contrast to all other currency pairs across all maturities. One might think that the low P-value could be caused by persistent co-movements in the spot and overnight forward, but the Dickey-Fuller test firmly rejects any unit root, and with a Durbin Watson test-statistic of 1.99 we do not have any noteworthy issue with autocorrelation.

If we compare the weak test results to the strong test results for the overnight maturities we find that four currency pairs have a beta estimate with a sign corresponding to what we would expect from the sign of the mean rate of appreciation and the mean forward premium. These currency pairs are AUD/USD, GBP/USD, CAD/USD and CHF/USD.

In summary, the results from our tests of the unbiasedness hypothesis revealed that the hypothesis does not seem to hold for most of the currency pairs regardless of maturity length, and there are some evidence indicating the presence of the forward premium puzzle.

5.2. Part 2: Predicting Deviations From The Unbiasedness Hypothesis

In this chapter we will present and discuss all the results from our regression tests of the relationship between the deviations from unbiasedness and our explanatory variables, as well as the direction of change-tests. We limit our discussion to cases where the beta estimates of the explanatory variable affect all currency pairs similarly and will not discuss individual relationships unless they stand out as particularly interesting. We apply the same principle to discussions regarding the constant terms, as these tends to be small and positive. In addition, we seek to find relationships that can predict changes in the deviation from unbiasedness, the constant terms will therefore not alter any conclusions from our analysis. For a discussion on the interpretation of these constant terms see chapter 3.2.1. The results from the direction of change-tests can be found in appendix IV.

5.2.1. LIBOR

Lagged log-difference of the LIBOR regressed on the deviation from unbiasedness									
	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Maturity lagged changes									
1M	-0.026	-0.027	-0.002	-0.016	-0.033**	-0.004	-0.019	-0.021	-0.029
1W	-0.011	-0.006	-0.002	0.028*	0.000	-0.000	-0.006	0.009	-0.029*
Daily lagged changes									
1M	-0.245	-0.015	0.102	0.073	-0.266	0.072	-0.126	0.179	-0.048
1W	0.140	0.105*	-0.060	0.220***	0.121**	0.099	0.127*	0.187	-0.020
ON	0.022	0.009	-0.004	0.011	0.023	0.006	0.016	0.019	0.009

Table 7: Shows the beta coefficients from the time series regression tests, indicating the relationship between the LIBOR and the deviation from unbiasedness. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 1M = One month maturity, 1W = One week maturity, ON = Overnight maturity.

For the one month maturity, all coefficients are negative for monthly lagged changes in LIBOR as a regressor. This is an indication that there exists a negative relationship between the monthly changes in the LIBOR rate and the deviations from unbiasedness for monthly forward prices. This result is supported by the results from the direction of change-test, which also indicates a negative relationship for all currency pairs, except for the AUD, EUR and GBP. However, none of these DoC-values are significantly different from 0.5. The lacking significance is also an issue in the regression tests, where the NOK/USD is the only currency pair with a significant coefficient. It is therefore uncertain whether we would get the same negative relationship out of sample.

For daily lags there is no statistically significant relationships for any currency pairs, and with 5 negative beta coefficients and 4 positive there is not a clear one-way relationship either. A daily change in LIBOR seems therefore, on average, not to affect the deviation from unbiasedness in any particular direction. The results from the direction of change-test gives indications of a negative relationship for the daily lags, suggesting that there is a negative relationship between the LIBOR and the deviation from unbiasedness for one month maturity contracts.

The findings for the monthly changes in LIBOR are stronger than for the daily changes, but both lag structures have indications pointing in the same direction. Based on these results it therefore seems like there is a negative relationship between the changes in LIBOR and the following deviations from unbiasedness. Knowing that a decrease in the deviation from unbiasedness happens through a relative depreciation in the USD spot rate, an investor will be able to extract a carry trade profit by going short in a USD monthly forward following an increase in LIBOR. Despite the negative relationship indicated by the DoC-test for the daily lagged changes, this would not have yielded a carry trade profit across all currencies, since the beta coefficients varies in signs among the currencies. This strategy would therefore only have been profitable using monthly lags, for all currency pairs except for the JPY/USD.

For the one week maturity, with daily lagged changes in the explanatory variable, we find positive coefficients for every currency pair, except the CHF and JPY. The EUR, NOK, SEK and GBP are positive and significantly different from 0 at the 10-percent level or lower. The deviations from unbiasedness on one week forward contracts thus seems to increase when the LIBOR increases one day prior. However, from the DoC-test we see that none of the mean values are significantly different from 0.5, and overall the results tends to be lower than 0.5. This indicates that the robustness of the positive beta is rather weak and again invokes questions on whether we would find the same coefficients out of sample.

The contradictory results from the time series regression test and the DoC-test implies that although the signs of the changes are more often opposites than not, the magnitude of the relationship is greater when the signs are equal. An investor who is exploiting the positive relationship would therefore make a profit according to our data, but it is unclear whether the profit would be the same out of sample since the DoC-test shows that the relationship appears not to be robust.

For daily lags in the overnight maturity we find no significant beta coefficients, though all are positive except for the JPY. This result is not supported by the DoC values, which finds that none of the means are even close to larger than 0.5. The only significant result from the DoC-test is CAD, which has a mean significantly smaller than 0.5. These results are therefore not robust.

To summarize, we see that LIBOR has some significance as a predictor of future deviations. However, the coefficients have different signs depending on the length of maturity. For the one month maturity our results indicate a negative relationship for all currencies quoted per dollar, while they indicate a positive relationship at the one week and overnight maturity. The weekly results are more significant but was not supported by the DoC-test results. The test results are therefore not robust enough to provide any strong interpretations towards exploitation of the bias through carry trade.

5.2.2. S&P 500 Index

Lagged log-difference of the S&P Index regressed on the deviations from unbiasedness								
	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Maturity lagged changes								
1M	-0.022	-0.027	-0.081*	0.091	-0.033	0.012	-0.036	-0.022	-0.053
1W	0.025	-0.008	0.001	0.002	-0.017	0.009	-0.019	0.014	-0.001
Daily lagged changes								
1M	-0.556**	-0.233	0.243	-0.384	-0.422	-0.404***	-0.395	-0.614**	-0.047
1W	-0.102	-0.102**	0.005	-0.082*	-0.146**	-0.074	-0.172***	-0.151**	-0.040
ON	-0.015	0.000	0.017*	0.005	-0.019	-0.009	-0.002	-0.011	0.008

Table 8: Shows the beta coefficients from the time series regression tests, indicating the relationship between the S&P 500 Index and the deviation from unbiasedness. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 1M = One month maturity, 1W = One week maturity, ON = Overnight maturity.

For the S&P 500 Index we find that most coefficients for the one month maturity, using monthly lagged changes of the index, are negative although few are significant. For daily lags we have a significantly negative relationship for the AUD, CAD and NZD at the 1-percent level. The relationship also appears to be negative for the other currency pairs, except for the JPY/USD. This is however not supported by the DoC-test, which on the contrary indicates a positive relationship for all currency pairs, again with the exception of JPY/USD, although with little significance.

Due to the contradictory results it is hard to draw clear conclusions as to the nature of the relationship between the S&P 500 and the deviations from unbiasedness for monthly maturities. The robustness of these results is therefore not strong enough to provide any confident predictions of future deviations from the unbiasedness hypothesis.

The results for the one month maturity forward contracts are quite similar to the results for the one week maturity, where the weekly lagged changes have little to no significance, while the daily lagged changes are more significant. The signs of the beta coefficients indicate a negative relationship for all currency pairs, except the JPY, while the DoC-test results indicates 5 negative relationships and 4 positive ones, where one of the positives is the JPY. The result from the regression test is therefore stronger than for the one month maturity. Hence, there appears to be a negative relationship between the daily changes in the S&P 500 Index and the deviations from unbiasedness on one week maturity contracts.

An investor should in other words be able to extract a carry trade profit by going short in the USD one week forward the day after an increase in the S&P 500 index. This is a strange relationship as one might think that an increase in the S&P should be positive news for the USD. It is traditionally accepted that US stock prices drops when the USD appreciates, since a stronger dollar means less international revenue for multinational companies, but the inverse relationship is harder to explain. The nature of the negative relationship might however be that an increase in the S&P indicates good times ahead, prompting investors to sell off their safe US Dollars and stocks in favor of riskier currencies and stock markets abroad.

As for the overnight maturity we find little evidence of a clear relationship between the S&P and the deviation. This is reasonable as we expected short term stock market fluctuations to have little effect on such short contracts, particularly during normal market situations. The only significant beta estimate is the JPY, which is positive. The DoC-test also has little significance, but supports the positive relationship found in the regression for JPY/USD, which indicates that an increase in the S&P 500 Index should be followed by a short position in the JPY overnight forward against the USD.

From these results it seems that the S&P 500 Index has some predictive power over the deviations when using daily lagged changes of the index. The signs of the coefficients for the

monthly and the weekly maturities are more robust on the negative side than for LIBOR, but there is still not much support from the DoC-test.

Although we have limited our discussion to look for overall relationships, there are several reasons for why individual differences between the different currency pairs should lead to different signs of the coefficients. For example, JPY has the opposite sign in almost every regression compared to the other currencies. A drop in the S&P 500 is positively correlated with the deviations from unbiasedness for the JPY/USD. A decline in the S&P will therefore lead to a decrease in the deviations, implying that the JPY strengthens relative to the USD in times of declining stock prices. This might be because the JPY is considered a safe haven and investors seeks refuge in the JPY when the stock indices fall. The JPY will then strengthen compared to the other currencies in our tests and as we show, the forward prices does not succeed in eliminating this bias, making it possible to exploit this relationship through carry trade.

5.2.3. Baltic Dry Index

Lagged log-difference of the Baltic Dry Index regressed on the deviations from unbiasedness								
AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Maturity lagged changes								
1M	0.010	-0.000	-0.018*	0.019	0.011	0.013	0.009	0.022	-0.011
1W	0.004	0.003	-0.015**	0.005	0.000	0.004	0.004	-0.001	-0.002
Daily lagged changes								
1M	0.293	0.256	-0.271	0.460	0.262	0.286**	0.285	0.407*	0.188
1W	0.022	0.027	-0.061*	0.035	0.027	0.033	0.032	0.003	0.026
ON	0.008	0.006	-0.002	0.005	0.014**	0.006	0.007	0.004	0.010

Table 9: Shows the beta coefficients from the time series regression tests, indicating the relationship between the Baltic Dry Index and the deviation from unbiasedness. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 1M = One month maturity, 1W = One week maturity, ON = Overnight maturity.

The Baltic Dry Index has proven to be an interesting explanatory variable when looking at the results. All coefficients for daily lagged changes in the index points in the same direction for all currency pairs and maturities, except for the JPY/USD. These results indicate that an increase in the Baltic Dry Index, from one day to the next, is followed by an increase in the difference between the rate of appreciation and the forward premium during the following three maturity lengths. This result is supported by the DoC-test which shows a positive relationship for all currency pairs, except for the JPY, both in the one month and one week

maturity. However, they are positive for all currencies, including JPY, for the overnight contracts. The practical interpretation of this result is that a high relative change in Baltic Dry Index increases the future deviation from the unbiasedness hypothesis, meaning that investors could increase carry trade profits by going long in USD in the forward market the day following an increase in the Baltic Dry Index. Most beta coefficients are not statistically significant, however. We can therefore not reject our null hypothesis of no relationship at any reasonable confidence level. Although they are not significant, the similar results from the two different tests does indicate that there is a relationship, and the coefficients prove that trading on this strategy would have yielded a carry trade profit in the period of our analysis.

This finding is in line with Ready et. al (2017), who showed that carry trade profits increased as the Baltic Dry Index increased. The result implies that the bias in forward prices increase when transportation costs are high. As we expect transportation costs to be positively correlated with the level of global trade, our finding therefore implies that the deviations are indirectly positively correlated with the global goods market. This can be true if the arguments of Hummels (2007), of a higher relative increase in transportation costs compared to increases in global trade, are true. Another possibility is that the increased liquidity we would expect in the foreign exchange market during periods of high global trade levels, is positively correlated with the deviations from unbiasedness. This could therefore argue for the rationality in the forward rates, as increased liquidity should lead to more correct pricing of foreign currencies. On the other hand, the high levels of global trade could mean that the market participant care more about the products they buy than the efficiency of the currencies they use to buy them with. This is a complex issue that lies outside the scope of this thesis, but an interesting one nonetheless.

5.2.4. VIX-Index

Lagged log-difference of the CBOE Volatility Index (VIX) regressed on the deviations from unbiasedness								
	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Maturity lagged changes								
1M	-0.010	-0.013	0.011	-0.024*	-0.013	-0.016*	-0.015	-0.007	-0.000
1W	-0.003	0.000	0.003	0.003	-0.000	0.002	0.002	0.001	-0.000
Daily lagged changes								
1M	-0.013	-0.040	-0.020	0.002	-0.027	-0.004	-0.044	0.002	-0.054*
1W	0.012	0.014**	0.003	0.015**	0.011	0.008	0.017**	0.016	0.008
ON	-0.001	0.001	-0.001	-0.000	0.003	0.000	0.001	0.001	0.000

Table 10: Shows the beta coefficients from the time series regression tests, indicating the relationship between the CBOE Volatility Index and the deviation from unbiasedness. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 1M = One month maturity, 1W = One week maturity, ON = Overnight maturity.

The regressions that used VIX as an explanatory variable revealed a few significant results across the three maturities. The results from the regression tests for the one month maturity with monthly lagged changes have negative coefficients for all currencies, except the JPY, though with little significance. The means of the DoC-tests shows significantly negative relationships for all currencies but the JPY. This supports the coefficients' signs found in the regression test and thus indicates a robust finding, despite the low level of significance in the regression test.

The regression tests on weekly maturities with daily lagged changes is significant at the 5-percent level, or below, for three currency pairs: the EUR, GBP and SEK, against the USD. All the beta coefficients across all currencies for the one week maturity, with daily lagged changes, have the same positive sign of the coefficients when the currencies are quoted against the dollar. This means that when the VIX increases from one day to the next, the difference between the rate of appreciation and the forward premium increases the following week. The DoC-test shows 8 positive relationships and 1 negative for the weekly maturity with daily lagged changes, where the negative one is the Japanese Yen, thus supporting the signs of regression coefficients.

For the overnight maturity we have no significant coefficients, and signs varies among the currencies. The DoC-test also has high p-values, although most values indicate a negative relationship. There is in other words little evidence for a relationship between the VIX index and the deviations from unbiasedness in overnight forward contracts.

One reason for the relationship between the VIX and the USD can be because the VIX measures the implied future volatility in the S&P 500, which in turn is connected to the rate of appreciation of the USD. For instance, a higher expected volatility could lead investors to traditional safe havens, such as the USD and the JPY, which should increase the rate of appreciation in the USD and JPY. This relationship seems to switch from positive to negative at longer maturities, as a month long decline in the VIX tends to lead to a decrease in the deviation for currencies quoted per USD. The reason might be that longer period changes in the VIX are more market specific, as international stock indices tends to covary in the short term, while industry specific factors dominates in the longer-term development of the indices (Cavaglia et al., 2000). A monthly increase in the VIX should therefore lead to investors selling the USD, fleeing the high expected volatility.

5.2.4. Brent Crude Oil

Lagged log-difference of the Brent oil price regressed on the deviations from unbiasedness									
	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Maturity lagged changes									
1M	0.041	0.020	-0.009	0.045**	0.025	0.034**	0.026	0.033	0.008
1W	-0.018	-0.010	0.011	-0.005	-0.011	-0.005	-0.014	-0.016	-0.010
Daily lagged changes									
1M	0.058	0.051	-0.051	0.034	-0.022	0.064	-0.044	-0.055	-0.052
1W	-0.023	-0.005	0.008	-0.020	-0.022	-0.013	-0.032	-0.035	0.013
ON	-0.001	0.001	0.001	0.003	-0.001	0.002	0.003	-0.003	-0.001

Table 11: Shows the beta coefficients from the time series regression tests, indicating the relationship between the Brent oil price and the deviation from unbiasedness. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 1M = One month maturity, 1W = One week maturity, ON = Overnight maturity.

Of all the regressions we ran with the percentage change in the brent crude oil price as an explanatory variable, only a few currencies at the one month maturity with maturity lagged changes were significant at the 10-percent level or below. While we expected the oil price to have an impact on the NOK especially, our results show that the beta coefficient related to the NOK does not stand out from the other currencies.

From these results we find no evidence indicating a relationship between the changes in the Brent crude price and the deviations from unbiasedness. Hence, according to our data, there is no reason to believe that the Brent crude price causes any bias in the foreign exchange market. This might be because the demand for oil is fairly constant despite changes in foreign exchange rates. Though this is not the same as saying that foreign exchange rates should not

be affected by changes in demand for oil, the size of the Brent oil market compared to the foreign exchange market might make this true after all.

5.2.5. Bid-Ask Spread

Lagged log-difference in the bid-ask spread regressed on the deviation from unbiasedness								
	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Maturity lagged changes								
1M	-0.008	-0.001	0.003	-0.003	0.001	-0.001	0.005	-0.005	-0.005
1W	-0.003*	0.003*	0.001	0.000	0.001	-0.000	0.004	0.001	0.001
Daily lagged changes								
1M	-0.001	0.004	-0.009	-0.009**	-0.006	0.000	0.005	0.015*	0.005
1W	0.000	0.000	-0.001	-0.000	0.000	0.001	-0.001	0.003**	-0.002
ON	-0.000	-0.000	-0.001*	0.000	-0.000*	-0.000	-0.000	-0.000	-0.000

Table 12: Shows the beta coefficients from the time series regression tests, indicating the relationship between the bid-ask spread of the given currency pair's spot rate and the deviation from unbiasedness. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 1M = One month maturity, 1W = One week maturity, ON = Overnight maturity.

Our regression tests show little indication of a relationship between changes in the bid-ask spread of the spot rate and the deviation from unbiasedness. We have very few significant results, with no clear directional relationship. In the direction of change-test there are some indications of a negative relationship between the bid-ask spread and the deviations. This is particularly true for the AUD/USD, which is significantly negative for the monthly and weekly maturities. However, there are not many other currencies portraying a similar relationship. It therefore does not seem to be a relationship between liquidity and the deviations from unbiasedness, based on the bid-ask spread. This must not be interpreted as anything but a test of the bid-ask spread's effect on the deviations, and not by any means as a full test of liquidity.

6. Conclusion

The results from our tests of the unbiasedness hypothesis revealed that the hypothesis does not seem to hold for most of the currency pairs regardless of maturity length. There are also some evidence indicating the presence of the forward premium puzzle for several currency pairs across all maturity lengths, especially for the one month and overnight maturities.

The weak form mean comparison t-test showed that there are large differences between the mean ex-post rate of appreciation and mean forward premium for many currency pairs across all maturities, but none are significantly different from zero below the 10-percent level. The

most interesting results from the mean comparison test are the results for the overnight maturity. This was the only maturity length with a negative fitted slope when regressing the means of the rate of appreciation on the means of the forward premium, which is an indication of the presence of the forward premium puzzle. Under this maturity some of the most commonly used carry trade currencies, AUD, NZD, CHF and JPY, exhibited large deviations from the unbiasedness hypothesis in the opposite direction of what we would expect according to their interest differential compared to USD. These results also contradicted the results from the one month and one week maturity. These results could be explained by Baillie and Bollerslev (2000) who argue that there is a nonlinearity between the rate of appreciation and forward discount, making a small forward discount is less likely to point in the right direction, perhaps due to large transaction costs relative to the potential gains.

The time series regression test revealed 14 negative forward premium betas and 24 beta coefficients below unity, out of a total of 27. Some currency pairs, especially with one month forward maturity, displayed large negative forward premium beta estimates, which indicates that there is a potential forward premium puzzle. However, across all the maturities only three beta coefficients were significant at the 5-percent level and six at the 10-percent level. Additionally, by comparing the regression test results against the mean comparison test results we found that about half the currency pairs had matching results. Thus, we cannot interpret the results from either test as particularly robust.

After finding evidence indicating the presence of a bias in the pricing of forward contracts, we went on to examine the relationships between the bias and different explanatory variables. Although we found some clear relationships for various explanatory variables most results were not statistically significant. One of the most notable results we found, was an indication of a positive relationship between the bias and the Baltic Dry Index. This suggests that when transportation costs increase, deviations from the unbiasedness hypothesis also increases. This relationship can be exploited via carry trade by going long in the USD forward against all other G10 currencies, following a positive change in the Baltic Dry Index.

We also found indications of a positive relationship between the USD and the VIX-index, at one week maturity forward contracts. However, the relationship is negative at the one month maturity, indicating that the relationship varies with the length of maturity.

For the S&P 500 index we found some evidence indicating a negative relationship for all currency pairs, with the exception of the JPY/USD, for both the one month and one week maturity. These results were however not supported by our direction of change-robustness test. When it comes to LIBOR, we did find some patterns indicating a relationship, but these were contradicted by our DoC-test, therefore failing to provide sufficient confidence. For the Brent oil price and the Bid-ask spread we found no evidence of them having an influence on the bias in currency forwards.

7. Suggestions on Further Research

For further research into the unbiasedness and the forward premium puzzle we have a number of suggestions that might be helpful in expanding researcher's knowledge of the failure of the unbiasedness hypothesis.

We would be interested in seeing a study of the forward premium puzzle which takes actual transaction costs, such as fees and credit risk, into account. Such an analysis might show that the profitability of carry trade is altered significantly, especially for overnight maturities. Transaction costs and credit risk might reveal that the unbiasedness hypothesis does in fact hold for overnight maturities.

Additionally, it would be interesting to conduct a comparative analysis of regressions on the interest rate differentials to regressions on the forward premium. While the two should be more or less equal according to interest rate parity, but due to differences in liquidity and transaction costs we do not know whether the empirical research would back this up. We might see that the two ways of testing the unbiasedness yields surprisingly different results.

Our results show indications of a relationship between the Baltic Dry Index and the deviations from unbiasedness, but we cannot conclude on the rationale behind this results. In this thesis we have mentioned several possible reasons, spanning from increased segmentation in global trade to the irrational global trade market participants. A study looking into these possible explanations would therefore be interesting to see. This can for example be done by including variables that affect the Baltic Dry Index as explanatory variables in the regressions on the deviation from unbiasedness, thereby isolating the indirect effects that are channeled through the Baltic Dry Index.

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Appendices

I. List of Abbreviations

USD	United States Dollar
AUD	Australian Dollar
EUR	Euro
JPY	Japanese Yen
GBP	Pound Sterling
NOK	Norwegian Krone
CAD	Canadian Dollar
SEK	Swedish Krona
NZD	New Zealand Dollar
CHF	Swiss Franc
FX	Foreign Exchange
CIP	Covered Interest Rate Parity
UIP	Uncovered Interest Rate Parity
CAPM	Capital Asset Pricing Model

II. List of Data Collected From Datastream

Foreign exchange spot rates:

AUSTRALIAN $ TO US $ (WMR&DS) - Time Series Data

CANADIAN $ TO US $ (WMR) - Time Series Data

SWISS FRANC TO US $ (WMR) - Time Series Data

EURO TO US $ (WMR&DS) - Time Series Data

UK £ TO US $ (WMR) - Time Series Data

JAPANESE YEN TO US $ (WMR) - Time Series Data

NORWEGIAN KRONE TO US $ (WMR) - Time Series Data

NEW ZEALAND $ TO US $ (WMR&DS) - Time Series Data

SWEDISH KRONA TO US $ (WMR) - Time Series Data

Foreign exchange forward rates:

US $ TO AUSTRALIAN $ 1M FWD (WMR) - Time Series Data

US $ TO AUSTRALIAN $ 1W FWD (WMR) - Time Series Data

US $ TO AUSTRALIAN $ ON FWD (WMR) - Time Series Data

CANADIAN $ TO US $ 1M FWD (WMR) - Time Series Data

CANADIAN $ TO US $ 1W FWD (WMR) - Time Series Data

CANADIAN $ TO US $ ON FWD (WMR) - Time Series Data

SWISS FRANC TO US $ 1M FWD (WMR) - Time Series Data

SWISS FRANC TO US $ 1W FWD (WMR) - Time Series Data

SWISS FRANC TO US $ ON FWD (WMR) - Time Series Data

US $ TO EURO 1M FWD (WMR) - Time Series Data

US $ TO EURO 1W FWD (WMR) - Time Series Data

US $ TO EURO ON FWD (WMR) - Time Series Data

US $ TO UK £ 1M FWD (WMR) - Time Series Data

US $ TO UK £ 1W FWD (WMR) - Time Series Data

US $ TO UK £ ON FWD (WMR) - Time Series Data

JAPANESE YEN TO US $ 1M FWD (WMR) - Time Series Data

JAPANESE YEN TO US $ 1W FWD (WMR) - Time Series Data

JAPANESE YEN TO US $ ON FWD (WMR) - Time Series Data

NORWEGIAN KRONE TO US $ 1M FWD(WMR) - Time Series Data

NORWEGIAN KRONE TO US $ 1W FWD(WMR) - Time Series Data

NORWEGIAN KRONE TO US $ ON FWD(WMR) - Time Series Data

US $ TO NEW ZEALAND $ 1M FWD (WMR) - Time Series Data

US $ TO NEW ZEALAND $ 1W FWD (WMR) - Time Series Data

US $ TO NEW ZEALAND $ ON FWD (WMR) - Time Series Data

SWEDISH KRONA TO US $ 1M FWD (WMR) - Time Series Data

SWEDISH KRONA TO US $ 1W FWD (WMR) - Time Series Data

SWEDISH KRONA TO US $ ON FWD (WMR) - Time Series Data

Explanatory variables:

Baltic Exchange Dry Index (BDI) - Time Series Data

CBOE SPX VOLATILITY VIX (NEW) - Time Series Data

Crude Oil Dated Brent U$BBL - Time Series Data

IBA USD IBK LIBOR 1M DELAYED - Time Series Data

S&P 500 COMPOSITE - Time Series Data

Bid and offer rates for the spot rate for all currency pairs

III. Econometric Test Results

All values represent the P-value for the specific test, except for Durbin Watson where we have used the Durbin Watson-test statistic.
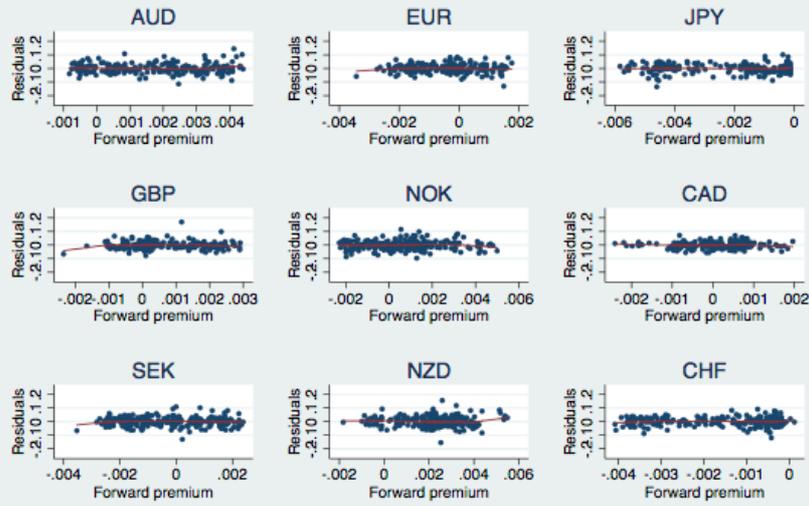
1M	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Dickey Fuller Spot Level	0,6101	0,5134	0,2701	0,4378	0,5251	0,6866	0,3740	0,6124	0,7230
Dickey Fuller Forward Level	0,6090	0,5789	0,2672	0,4321	0,5240	0,6882	0,3726	0,6113	0,7235
Dickey Fuller Rate of Appreciation	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Dickey Fuller Forward Premium	0,5641	0,2570	0,3944	0,4867	0,3175	0,0455	0,3775	0,3848	0,2287
Ramsey RESET	0,0709	0,3248	0,1953	0,1300	0,3606	0,4138	0,2284	0,0899	0,3757
Breusch Pagan	0,0033	0,0182	0,1298	0,4802	0,7765	0,2368	0,2813	0,0230	0,2639
White	0,0098	0,0535	0,5048	0,8274	0,9429	0,3458	0,5396	0,2452	0,5902
Durbin Watson	1,7895	2,0077	1,8854	2,0808	1,8647	1,7942	1,9500	1,9863	2,2566

1W	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Dickey Fuller Spot Level	0,5774	0,5366	0,3472	0,4293	0,5342	0,5760	0,4008	0,5947	0,7101
Dickey Fuller Forward Level	0,5771	0,5727	0,3463	0,4279	0,5340	0,5765	0,4005	0,5944	0,7101
DF Rate of Appreciation	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
DF Forward Premium	0,0201	0,0000	0,0000	0,0000	0,0002	0,0000	0,0000	0,0015	0,0000
Ramsey RESET	0,1338	0,3840	0,8551	0,6509	0,5265	0,6627	0,2618	0,1170	0,4619
Breusch Pagan	0,0000	0,0000	0,0064	0,2107	0,0015	0,0028	0,0000	0,0002	0,0000
White	0,0053	0,0000	0,2323	0,7714	0,0011	0,1285	0,0037	0,0113	0,1057
Durbin Watson	2,0964	1,9986	1,9372	2,0691	2,1518	2,1719	2,1018	2,1387	2,0163

ON	AUD/USD	EUR/USD	JPY/USD	GBP/USD	NOK/USD	CAD/USD	SEK/USD	NZD/USD	CHF/USD
Dickey Fuller Spot Level	0,5348	0,5219	0,2821	0,4223	0,5149	0,5940	0,3766	0,5837	0,6670
Dickey Fuller Forward Level	0,5351	0,5679	0,2826	0,4226	0,5150	0,5945	0,3765	0,5837	0,6672
DF Rate of Appreciation	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
DF Forward Premium	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Ramsey RESET	0,1615	0,0479	0,8065	0,3410	0,0092	0,9259	0,0000	0,5020	0,0358
Breusch Pagan	0,0015	0,0000	0,0287	0,6450	0,0698	0,2298	0,3897	0,7801	0,0003
White	0,2680	0,0000	0,3103	0,9829	0,4627	0,0000	0,0000	0,9865	0,1715
Durbin Watson	2,0352	1,9811	1,9964	1,9083	1,9963	1,9928	2,0059	1,9771	1,9550

Residuals and Explanatory Variable Scatter Plot

Red line: LOWESS (locally weighted scatterplot smoothing)

Residuals and Lagged Residuals Scatter Plot

One month maturity

One week maturity

Overnight maturity

Red line: Fitted line

IV. Direction of Change-Test Results

Each table shows the average of the DoC-variable for each explanatory variable across each maturity and lag structure. A mean less than 0.5 indicates a negative rel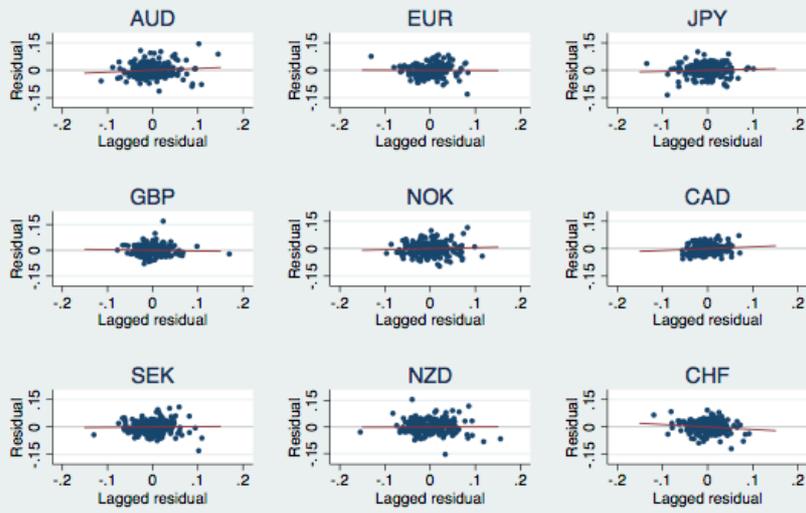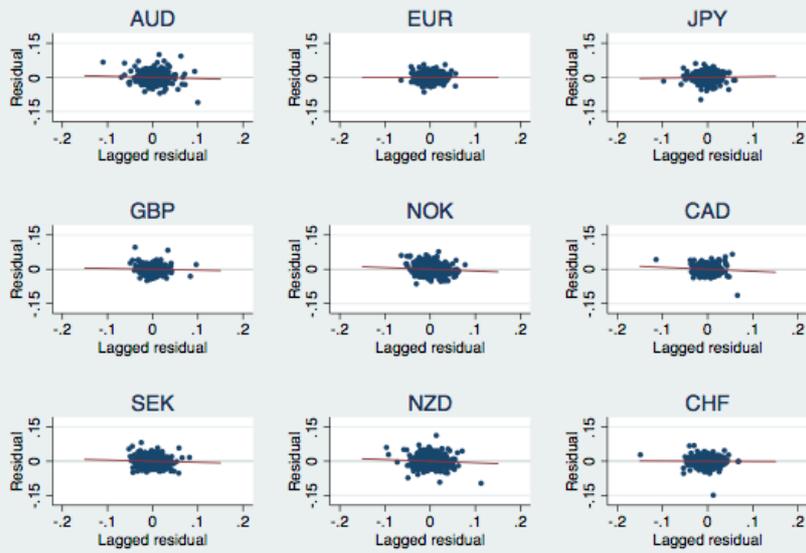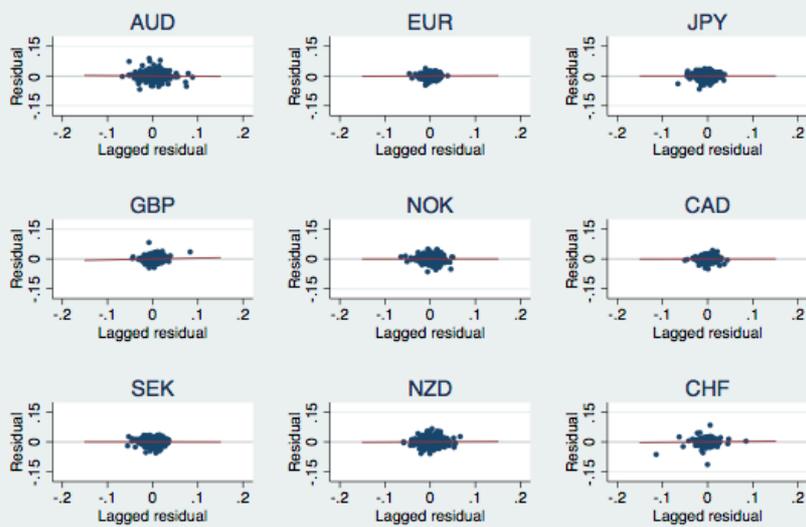ationship, and a mean over 0.5 indicates a positive relationship. The column for p=0.5 is the P-value, i.e. the probability of the sample mean occurring given that the true mean is equal to 0.5. The average can be viewed as the average DoC for the USD, we see here that most explanatory variables has an average close to 0.5, indicating the overall average for the USD is fairly close to 0.5, thus leaving little room for arbitrage if doing so through every currency pair in the G10 against the USD at the same time.

LIBOR	One month				One Week				Overnight	
	Monthly lags		Daily Lags		Weekly lags		Daily Lags		Daily Lags	
	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5
AUD/USD	0,500	1,000	0,477	0,503	0,499	0,951	0,507	0,625	0,500	0,967
EUR/USD	0,514	0,688	0,491	0,789	0,500	1,000	0,493	0,669	0,507	0,292
JPY/USD	0,464	0,284	0,450	0,140	0,473	0,076	0,496	0,807	0,501	0,880
GBP/USD	0,514	0,688	0,545	0,180	0,491	0,542	0,514	0,360	0,492	0,256
NOK/USD	0,464	0,284	0,495	0,894	0,511	0,464	0,495	0,760	0,491	0,213
CAD/USD	0,473	0,422	0,550	0,140	0,501	0,951	0,500	1,000	0,483	0,015
SEK/USD	0,495	0,894	0,446	0,107	0,498	0,903	0,490	0,502	0,494	0,404
NZD/USD	0,482	0,592	0,495	0,894	0,507	0,625	0,499	0,951	0,502	0,774
CHF/USD	0,468	0,349	0,455	0,180	0,475	0,099	0,476	0,112	0,494	0,360
Average	0,486	0,578	0,489	0,425	0,495	0,624	0,497	0,643	0,496	0,463

Direction of Change. Mean is the mean of the DoC-variable. Mean = 0.5 indicates no relationship between the signs of the explanatory variable and the deviation. Mean > 0.5 indicates a positive relationship, and a Mean < 0.5 indicates a negative relationship. P=0.5 is the p-value from the t-test of whether the mean of the DOC-variable is equal to 0.5. "lags" is the lagged change in the explanatory variable.

S&P 500	One month				One Week				Overnight	
	Monthly lags		Daily Lags		Weekly lags		Daily Lags		Daily Lags	
	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5
AUD/USD	0,545	0,180	0,545	0,180	0,551	0,001	0,501	0,951	0,510	0,159
EUR/USD	0,604	0,002	0,550	0,140	0,521	0,179	0,498	0,903	0,519	0,006
JPY/USD	0,446	0,107	0,491	0,789	0,479	0,160	0,507	0,669	0,515	0,030
GBP/USD	0,568	0,044	0,595	0,005	0,498	0,903	0,481	0,222	0,498	0,753
NOK/USD	0,527	0,422	0,509	0,789	0,515	0,329	0,496	0,807	0,502	0,816
CAD/USD	0,518	0,592	0,545	0,180	0,495	0,760	0,518	0,246	0,498	0,732
SEK/USD	0,568	0,044	0,514	0,688	0,515	0,329	0,472	0,067	0,510	0,159
NZD/USD	0,554	0,107	0,527	0,422	0,517	0,272	0,509	0,542	0,497	0,712
CHF/USD	0,523	0,503	0,550	0,140	0,493	0,669	0,484	0,299	0,510	0,151
Average	0,539	0,222	0,536	0,370	0,509	0,400	0,496	0,523	0,506	0,391

Direction of Change. Mean is the mean of the DoC-variable. Mean = 0.5 indicates no relationship between the signs of the explanatory variable and the deviation. Mean > 0.5 indicates a positive relationship, and a Mean < 0.5 indicates a negative relationship. P=0.5 is the p-value from the t-test of whether the mean of the DOC-variable is equal to 0.5. "lags" is the lagged change in the explanatory variable.

BALTIC	One month				One Week				Overnight	
	Monthly lags		Daily Lags		Weekly lags		Daily Lags		Daily Lags	
	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5
AUD/USD	0,554	0,107	0,563	0,060	0,508	0,583	0,517	0,272	0,514	0,034
EUR/USD	0,523	0,503	0,532	0,349	0,530	0,051	0,538	0,012	0,504	0,538
JPY/USD	0,500	1,000	0,482	0,592	0,497	0,855	0,485	0,329	0,510	0,129
GBP/USD	0,523	0,503	0,532	0,349	0,522	0,143	0,516	0,299	0,512	0,087
NOK/USD	0,563	0,060	0,545	0,180	0,513	0,393	0,538	0,012	0,512	0,069
CAD/USD	0,599	0,003	0,554	0,107	0,518	0,246	0,530	0,051	0,501	0,924
SEK/USD	0,532	0,349	0,514	0,688	0,537	0,014	0,548	0,002	0,509	0,176
NZD/USD	0,536	0,284	0,518	0,592	0,524	0,112	0,514	0,360	0,502	0,732
CHF/USD	0,514	0,688	0,541	0,228	0,544	0,004	0,528	0,067	0,506	0,374
Average	0,538	0,389	0,531	0,350	0,522	0,267	0,524	0,156	0,508	0,340

Direction of Change. Mean is the mean of the DoC-variable. Mean = 0.5 indicates no relationship between the signs of the explanatory variable and the deviation. Mean > 0.5 indicates a positive relationship, and a Mean < 0.5 indicates a negative relationship. P=0.5 is the p-value from the t-test of whether the mean of the DOC-variable is equal to 0.5. "lags" is the lagged change in the explanatory variable.

VIX	One month				One Week				Overnight	
	Monthly lags		Daily Lags		Weekly lags		Daily Lags		Daily Lags	
	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5
AUD/USD	0,432	0,044	0,536	0,284	0,451	0,001	0,521	0,160	0,484	0,022
EUR/USD	0,392	0,001	0,523	0,503	0,488	0,427	0,522	0,143	0,492	0,268
JPY/USD	0,523	0,503	0,446	0,107	0,513	0,393	0,484	0,299	0,483	0,012
GBP/USD	0,437	0,060	0,450	0,140	0,505	0,760	0,524	0,112	0,500	0,989
NOK/USD	0,414	0,010	0,473	0,422	0,479	0,160	0,528	0,067	0,500	0,945
CAD/USD	0,414	0,010	0,500	1,000	0,485	0,329	0,507	0,669	0,497	0,632
SEK/USD	0,392	0,001	0,495	0,894	0,473	0,076	0,519	0,222	0,498	0,753
NZD/USD	0,405	0,005	0,518	0,592	0,473	0,076	0,511	0,464	0,493	0,292
CHF/USD	0,437	0,060	0,486	0,688	0,522	0,143	0,512	0,427	0,494	0,345
Average	0,427	0,077	0,492	0,515	0,488	0,263	0,514	0,285	0,493	0,473

Direction of Change. Mean is the mean of the DoC-variable. Mean = 0.5 indicates no relationship between the signs of the explanatory variable and the deviation. Mean > 0.5 indicates a positive relationship, and a Mean < 0.5 indicates a negative relationship. P=0.5 is the p-value from the t-test of whether the mean of the DOC-variable is equal to 0.5. "lags" is the lagged change in the explanatory variable.

BRENT	One month				One Week				Overnight	
	Monthly lags		Daily Lags		Weekly lags		Daily Lags		Daily Lags	
	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5
AUD/USD	0,563	0,060	0,495	0,894	0,511	0,464	0,482	0,246	0,500	0,989
EUR/USD	0,532	0,349	0,500	1,000	0,507	0,669	0,507	0,625	0,500	0,989
JPY/USD	0,536	0,284	0,505	0,894	0,509	0,542	0,493	0,669	0,510	0,136
GBP/USD	0,486	0,688	0,554	0,107	0,486	0,360	0,511	0,464	0,510	0,143
NOK/USD	0,545	0,180	0,459	0,228	0,503	0,855	0,515	0,329	0,501	0,880
CAD/USD	0,563	0,060	0,559	0,081	0,500	1,000	0,521	0,160	0,508	0,268
SEK/USD	0,595	0,005	0,473	0,422	0,507	0,669	0,517	0,272	0,506	0,374
NZD/USD	0,509	0,789	0,505	0,894	0,503	0,855	0,506	0,714	0,505	0,486
CHF/USD	0,550	0,140	0,500	1,000	0,485	0,329	0,514	0,360	0,500	0,967
Average	0,542	0,284	0,506	0,613	0,501	0,638	0,507	0,427	0,504	0,581

Direction of Change. Mean is the mean of the DoC-variable. Mean = 0.5 indicates no relationship between the signs of the explanatory variable and the deviation. Mean > 0.5 indicates a positive relationship, and a Mean < 0.5 indicates a negative relationship. P=0.5 is the p-value from the t-test of whether the mean of the DOC-variable is equal to 0.5. "lags" is the lagged change in the explanatory variable.

BID-ASK	One Month				One Week				Overnight	
	Monthly lags		Daily Lags		Weekly lags		Daily Lags		Daily Lags	
	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5	Mean	p=0.5
AUD/USD	0,432	0,044	0,432	0,044	0,470	0,051	0,470	0,051	0,496	0,520
EUR/USD	0,545	0,180	0,446	0,107	0,544	0,004	0,467	0,032	0,470	0,000
JPY/USD	0,523	0,503	0,550	0,140	0,490	0,502	0,522	0,143	0,498	0,753
GBP/USD	0,541	0,228	0,464	0,284	0,499	0,951	0,499	0,951	0,499	0,859
NOK/USD	0,437	0,060	0,486	0,688	0,519	0,222	0,486	0,360	0,502	0,795
CAD/USD	0,509	0,789	0,459	0,228	0,520	0,200	0,491	0,542	0,504	0,575
SEK/USD	0,500	1,000	0,473	0,422	0,508	0,583	0,492	0,583	0,501	0,859
NZD/USD	0,464	0,284	0,459	0,228	0,508	0,583	0,465	0,024	0,502	0,795
CHF/USD	0,450	0,140	0,491	0,789	0,495	0,760	0,521	0,179	0,502	0,795
Average	0,489	0,359	0,473	0,326	0,506	0,428	0,490	0,318	0,497	0,661

Direction of Change. Mean is the mean of the DoC-variable. Mean = 0.5 indicates no relationship between the signs of the explanatory variable and the deviation. Mean > 0.5 indicates a positive relationship, and a Mean < 0.5 indicates a negative relationship. P=0.5 is the p-value from the t-test of whether the mean of the DOC-variable is equal to 0.5. "lags" is the lagged change in the explanatory variable.