Deviations from the Covered Interest Rate Parity

Master's Thesis

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1 Abstract

Within this paper, I study the significance and persistence of the returns from the Covered Interest Rate Parity (CIP) subject to bid/ask spread and transaction costs. Afterwards, two explanations for the existence of deviations from the CIP are presented. I find that the NZD and AUD strategies perform especially poorly. The returns are found to be independent from the measurable risk premiums applied. The disclosure requirements introduced in Jan. 2015 are shown to significantly increase the Cross-Currency Basis for the one-week maturities. Furthermore, there is a correlation between the Cross-Currency Basis and the foreign xIBOR, indicating that a supply and demand mismatch causes the forward rate prices to break from the CIP.

Contents

2 Introduction

The Covered Interest rate Parity (CIP) builds on the no arbitrage condition—the interest rate differential between two currencies should be offset by the forward premium of said currencies. The CIP is used to set the pricing for forward rates and currency swaps. The daily turnover of these instruments was around $800bn in 2016 (Triennial Central Bank Survey, 2016). It is, therefore, easily one of the most important parity conditions in international finance. The parity condition has held reasonably well until the financial crisis in 2007, at which time previous research shows that the deviations dramatically increased for most currencies. This presents a puzzle: how can these deviations exist despite a previously robust no arbitrage condition? As a result, my research question is as follows:

Are there persistent and significant deviations from the Covered Interest rate Parity and if so, what are the reasons or explanations behind those deviations?

The research question immediately begs for an explanation of what constitutes a "persistent and significant" deviation. For the purpose of this paper, those definitions are held to be somewhat subjective. The words "persistent" and "subjective" are included in the research question to allow for ample discussion of all of the viable strategies and the returns they provide, rather than to create strict constraints for what results are allowable. In short, both the presence and absence of significant of persistent data will be discussed, and results that fall short will be shared and examined rather than excluded.

Within this thesis, I often state that the Covered Interest rate Parity "holds" or "does not hold." In the context of this paper, if the CIP "holds" then it is understood to be stable, meaning that any deviations should be small enough to be considered insignificant and remain close to the X-axis.

The purpose of this thesis is to allow me to apply my skills and tools to conduct a large-scale analysis. I wanted an opportunity to draw my own conclusions from quantitative data on a topic which I once found truly puzzling.

There are a few delimitations that must be acknowledged. These delimitations will allow me to narrow down the research question in order to keep the answer as concise as possible. The primary focus of the paper will be on short-term deviations found in the forward rate agreements, as opposed to long-term deviations found the in the cross-currency swaps. Furthermore, I will not look into the single currency Basis of the interest rate swaps between, for example, one-month and three-month interest rates, as described by (Du, Tepper, & Verdelhan, June 2018).

The introduction is followed by a brief literary review, in which I explain the findings of (Du, Tepper, & Verdelhan, June 2018), among others, and how this paper expands upon their findings. In the Methodology section I describe the philosophical ideas behind the thesis, the data used in the analysis, and the data analysis tools. The main tool used is linear regression models using OLS with heteroskedasticity robust standard errors. In the analysis, I will show the deviations from the CIP as the Cross-Currency Basis, which can be extracted from the CIP. The first deviations exist in a stylized world with no market frictions. In order to improve this analysis, I calculate the returns on an arbitrage strategy subject to bid/ask spread and transaction costs. Afterwards, the concept of risk factors is introduced to the analysis. After concluding the analysis of the arbitrage returns, the thesis turns toward finding explanations for the behavior of the Covered Interest rate Parity. Two reinforcing reasons for the deviations will be investigated. Firstly, the effects of banking regulation following the financial crisis is investigated through increased scrutiny on quarterly financial reports. Secondly, the supply and demand imbalances for investments in the US compared to foreign countries are measured through the interest rate differential.

3 Literary review

The Covered Interest rate Parity (CIP) is a well-documented subject. The fact that the CIP held before the 2007 financial crash has been demonstrated in various articles. (Frenkel & Levich, 1975) describe a dense "band" that exists around the neutral CIP, in which possible deviations are prevented from becoming profitable by transaction costs, elasticity in the financial markets, and lags in the execution of the arbitrage strategy. Similarly, (Juhl, Miles, & Weidenmier, 2004) show that the deviations from the CIP have actually significantly decreased from the Gold Standard period until the publication of their article in 2004. They find that the higher deviations typical of an earlier time were the result of less liquid markets because information costs were higher— information travelled slower back then. Contrary to most contemporary research of its time, (Clinton, 1988) states that the transaction costs are often overstated and that there are small deviations to be found in excess of transaction costs. However, the possible arbitrage opportunities found in Clinton's research are not large, nor are they consistent enough to yield serious returns.

After the financial crisis of 2007-2008, research began to emerge which documented larger deviations in the CIP. An example is the article by (Baba & Packer, 2009). The effect of Credit Default Swaps was found to be a statistically significant way to explain the larger deviations, though my own results demonstrated the opposite. The supply and demand imbalances for USD during the crisis are described by (Goldberg, Kennedy, & Miu, 2010) through their analysis of the currency swaps facilitated by the FED in order to alleviate USD funding constraints. The effects of these imbalances on the CIP are explored by (Fong, Giorgio, & Fung, 2010).

On the subject of emerging markets, (Skinner & Mason, 2011) investigate the deviations from 2003 to 2006 for countries such as Brazil, Chile, and Russia. They find that the short-term CIP holds, while the long-term CIP shows deviations that can be attributed to credit risk. Their article expands the scope of the topic by including currencies that are not commonly analyzed. In more recent research, (Su, Wang, Tao, & Lobont, 2019) look at whether or not the CIP works between the US and China because of the difficulties imposed by Chinese-controlled exchange rates[1]. They find that while the CIP is as not stable over long periods, it does have sub-periods where it holds. However, their suggestion is to use the CIP as a stabilizing state and encourage a more open and international RMB.

The most important article that influenced this thesis is "Deviations from Covered Interest Rate Parity" by (Du, Tepper, & Verdelhan, June 2018). They discover consistent and persistent deviations for all of the major currencies that they analyze. The credit worthiness of the xIBOR banks is not found to have an effect on the deviations. Instead, the deviations are determined to be the result of supply and demand imbalances and increased banking oversight.

This paper serves to expand upon the research laid forth in the article by (Du, Tepper, & Verdelhan, June 2018). I commence my analysis by using their research methods as a launchpad, and the data I utilize is expanded forward to August 2019 to capture contemporary changes. In addition, I seek to broaden the framework laid by Du et al. by including additional analyses when appropriate. For example, I develop a method to estimate the bid/ask rates on xIBORs in order to calculate a more accurate return on a Covered Interest rate Parity arbitrage strategy. This allows greater insight into which currencies show persistent and favorable returns over a given time frame. Moreover, each currency is individually

[1] Interestingly, the FED has very recently (13/01/2020) removed China as a designated currency manipulator (Rappeport, 2020). Admittedly, the timing (in regards to trade deals) certainly draws questions concerning the motivation behind this decision.

analyzed. This further develops the analytical points in regards to differences between each currency and the deviations that they exhibit.

4 Methodology

4.1 Philosophy of Science

In order to develop the method applied throughout this thesis, the nature of the research and the generation of knowledge must be considered through the lens of relevant philosophical considerations, i.e. ontology and epistemology. Such considerations are the keystone of this thesis, as they depict how knowledge is both produced and understood within this paper. Firstly, the main methodological traditions will be briefly described in order to place this thesis in a relevant philosophical context.

Contemporary methodology in social sciences can be broadly characterized by a simple dichotomy; naturalism v. constructivism, which together comprise the two main methodological traditions. The core theme of the constructivist paradigm is that there is a gap between the natural and the social worlds, and that this gap consequently underscores the notion of subjectivity (Knutsen, 2012). This means that knowledge is not generated by reality—instead, the subject only has access to the real world through observation, which leads to the creation of systematic knowledge. According to this paradigm, knowledge is thus intrinsically subjective; it cannot be separated from the observer, and it is based on the very perceptions of the observations. Accordingly, there can be no single and universal truth and the meaning of a phenomenon is always embedded in context. Such an assumption does not serve the main purpose of this paper, which is to determine through testing whether there are deviations from the CIP and why—in short, an *objective* analysis of the quantitative data available, not a subjective observation. Constructivist research is, instead, directed towards understanding the action of the subject without disjointing it from its context, which makes it unsuitable for the purposes of this thesis.

The naturalist stream of thought, in contrast, endeavors to uncover and formulate general patterns and laws, which can then be used to predict causality and/or future causal events. This is possible because naturalism assumes a Real World that exists independently from the observer's experience of it. This creates the possibility of objective knowledge. The notion of truth is, therefore, based on correspondence theory, which argues that: "a theory or statement is true, if what it says corresponds to reality" (Knutsen, 2012); (Egholm, 2014). Central to this theory of truth is the belief that research can and should test whether a statement's validity corresponds with the Real World (Egholm, 2014). In order to do so, naturalism relies on the premise of falsification, in which quantitative data is regarded as a distillation of the Real World (Egholm, 2014). Naturalism is an appropriate methodological starting point for my purposes, as searching for patterns within observable data and testing predictions are some of the chief goals of this thesis. The next section will explain the ontological and epistemological implications that a naturalist approach will have on this thesis.

4.1.1 Ontology

Ontology is the study of being and existence, and it considers assumptions about the world (Egholm, 2014). The ontological approach of this thesis is inspired by naturalism, because the thesis aims to explain peculiarities in the form of deviations from the CIP. Naturalism assumes that the world exists independently of the researcher, and that the world contains phenomena that have universal and objective essence (Egholm, 2014). Such an assumption allows this thesis to study the collected data independently from my own understanding of the data. Therefore, this paper takes on a realistic world view, allowing the focal point of the analysis to be the results of the quantitative analysis. Naturalism thus considers these material conditions to exist freely from contextual constraints and influences, which means that phenomena can be universal. The concept of universalism is crucial for this paper because part of the analysis requires retesting previous research with new data. This project thus follows naturalism's universalist assumptions about the independent world, so that it can test the correlations between the Cross-Currency Basis and the explanatory regressors in order to inform the necessary conclusions.

4.1.2 Epistemology

Epistemology concerns the theory of knowledge and how it is generated as well as its origins and the limitations of its applicability (Egholm, 2014). Naturalist epistemology recognizes the opportunity to achieve objective knowledge through nomothetic explanations. Methodological objectivity entails an attempt to eliminate observer bias by considering the data in isolation (Egholm, 2014). As this thesis mostly relies on quantitative data, the objectivity is achieved through careful data handling. Set procedures have been put in place, and I have avoided using values decided by myself as data delimiters. Naturalism heavily relies on quantitative methods because data and numbers are considered to be the best and most neutral reflections of reality. There are different epistemological criteria for how to evaluate the reliability and objectivity of knowledge in Naturalism. Verification or induction, practiced by positivist thinkers, starts with an observation or hypothesis and later verifies whether the observation or hypothesis is actually true. In opposition, Karl Popper (1902-1994) introduced the idea of falsification, arguing that no general statements can be made from only empirical observation. He further argues that all observations rely on theory. Instead, through a constant process of falsification of statements, one can come close enough to the truth to make a general statement, which is true only so long as it is not falsified (Egholm, 2014). The knowledge production of this thesis follows the premise of falsification and therefore takes departure in deduction. My research question is based on existing financial theory, which I want to test and, afterwards, explain. Now that I have presented the philosophical considerations behind my thesis, I can continue by explaining data and the data collection methods used.

4.2 Data

The forward rates, spot rates, and interest rates (xIBOR) have all been gathered from Bloomberg in daily frequency, subject to availability. The daily values are gathered as "px_mid", which is the mid quote for that day. I have collected the data corresponding to maturities of one week, one month, three months, and one year. The xIBORs for CAD and NZD were not available for the one-week maturity. The data collection method used is the inbuilt Bloomberg excel function, which is available on Bloomberg terminals.

For the purpose of this paper, the term xIBOR is defined as a generic way of referring to Inter-Bank Offered Rates from different countries. Generally, the rates can be put into the categories of London Inter-Bank Offered Rate (LIBOR) (USD, GBP, JPY, and CHF) and the rest (see appendix A). The xIBORs are calculated from a panel of contributing banks (see appendix A). Most of the panels use some form of trimming mechanism to trim one to four of the highest and lowest rates. The purpose of the xIBORs are to be used as benchmark or an index for the associated currency.

4.2.1 BID ASK on xIBOR

The xIBORs do not have a bid/ask spread because they are not commodities, but rather informational rates. I will need to approximate the bid/ask spread on the xIBOR in order to calculate the hypothetical arbitrage returns. My approximation of the bid/ask spread involves calculating the daily spread found on interest rate swaps (IRS) for each currency as a percentage of the mid quote. This percentage is then applied to the xIBOR to calculate the approximated bid and ask values. The interest rate swaps are standard one-year swaps between a quarterly floating rate and a semi-annual fixed rate[2] (see Appendix B). I do not take the different day count conventions into account, as I only utilize the percentage spread. My assumption is that the IRS are a similar enough product to xIBORs that I can apply the spread and receive results that are reasonable.

A downside of this method is a significant reduction of the amount of available data points, because the IRS spread is not as reliably available as the xIBOR is. There are still plenty of data points available, however, so the analysis can easily continue. Also, I have found that some of the interest spread calculation was either negative or too large. This could likely be attributed to faulty data from Bloomberg. Outliers are deemed to be any negative values and values above 25%, and are removed from the results[3].

4.2.2 Mean Credit Default Spread for Panel Banks

In order to calculate the average credit default spread for each of the panel banks, I have gathered the spreads for 1-year Credit Default Swaps (CDS) for each of the contributing banks of said panel. The data is gathered from S&P's Capital IQ platform, where it is available from 1/1/2008 until the present. For clarification purposes, it is necessary to note that the price of a CDS is also referred to as its "spread." This is because the "price" refers to how much one would have to pay (in bps) to insure the underlying asset. Therefore, when I refer to the "spread" of a CDS, I am referring to the insurance price of the underlying asset and not the difference between the bid and ask prices.

The mean panel spread is simply calculated as the average credit spread for the banks with available CDSs. The data is not readily available for every panel, so the currencies NZD, DKK, and CAD must be excluded. There is a full table of banks that contribute to the panels and whether or not CDS prices are available through Capital IQ in Appendix A. The average spread used will be an approximation of the true average panel spread for the following reasons: as mentioned, not every bank's CDS prices are available; the banks contributing to the panels today might not have done so historically; and there is no trim which is used to calculate the xIBORs. I am not using a trim method for the panel banks, since the result would still be an estimation due to the fact that CDS spreads are not available for every bank. I find that the end result, however, is still useful for my testing purposes—even as an approximation.

[2] DKK, NOK, SEK fixed leg are all annual.
[3] The spread should always be positive and is a percentage of the mid value. Thus, any values over 25% are extreme.

4.3 Analytical tools

The essential analysis tool for this paper is the linear regression model through Ordinary Least Squares (OLS). This method facilitates testing for correlation between a dependent variable and one or more independent variables (regressors). The OLS method is to fit a model on the data that has the lowest squared sum of model errors terms: $\min \sum\left(Y_i - \hat{Y}_i\right)^2$ (Stock & Watson, 2012). Here Y_i is the actual dependent variable value and $\widehat{Y}_i$ is the model value.

For the purpose of this thesis, I will highlight the model assumptions which I find to be the most important, which I will test in the Discussion section: The first assumption is that the regression is linear in its coefficients and that there is no covariance between $cov(x_i, \epsilon_i) = 0$. This can be tested by plotting the residuals against the either the independent variable or in a time series, against time. The second assumption concerns the error term and the fitted values. The error term should have constant variance (heteroskedasticity), a mean of zero, and no systematic correlation with the fitted values. Lastly, the residuals should be distributed normally.

A note should be made with regard to heteroskedasticity, because a lot of economic data exhibits heteroskedasticity. If the data exhibits heteroskedasticity, the regression OLS estimates are still unbiased and useable. However, the OLS standard errors are no longer unbiased (Stock & Watson, 2012). This is the reason why every regression calculated in this paper will use the "White" heteroskedasticity robust standard errors. The "White" standard errors are also usable if there is homoskedasticity; the result will be slightly more conservative standard errors. A different method of dealing with heteroskedasticity is to use the Generalized Least Squares method (GLS), which produces more heteroskedasticity-efficient estimators. However, to use the GLS I need to accurately estimate the Variance/Covariance matrix for the errors, which can be difficult to accomplish empirically (Stock & Watson, 2012). Therefore, I will employ the OLS with "White" standard errors.

The robustness of the regression estimates is also an important component of model validity. If the variation in the data changes dramatically over the time period, then so can the estimates. I have divided my analysis into three time periods to better understand the separate conditions within each of them. Additionally, this improves the robustness of the regression estimates, as the variations within each of the periods are most similar to each other.

5 Theory of forward rates and CIP

I would like to offer some clarification regarding the use of exchange rates and compounding. Firstly, I will use continuous compounding primarily for the mathematical properties associated with exponents and logarithms. In addition, continuous compounding is the most theoretically accurate method, which is appropriate because my analysis is largely theoretical.

Secondly, for the purpose of this paper, the US Dollar is considered to be the "home" currency—all exchange rates, unless otherwise stated, are against the USD. S_t is the spot exchange rate in USD per foreign currency, so in order to go from a foreign currency to the home currency one would multiply the foreign amount with the exchange rate. This means that an increase in S_t signifies a depreciation in the USD and an appreciation in the foreign currency.

As previously mentioned, the primary focus of the paper is the short-term deviations from the Covered Interest rate Parity[4]. These deviations are present in currency Forward Rate Agreements (FRA). FRAs are over-the-counter products—two parties agree to exchange a notational at a specified future date with a fixed rate. For example, let us imagine that a company that wants to exchange USD for EUR in 3 months' time. That company would need to enter an agreement to sell Dollars and receive Euros. I will define the forward rate ($F_{t,t+1}$) as the times $t + 1$ exchange rate seen from times t.

FRAs are constructed to have a Net Present Value (NPV) of zero at the time of initiation, and no cash is exchanged initially. Therefore, the FRA is simply two known opposing cash flows at a future date. The NPV of a hypothetical FRA to buy $\frac{1}{F_{t,t+1}}$ foreign currencies by selling 1 domestic can be set up as the following by discounting and converting the foreign currency:

$$NPV\ FRA_t = \frac{1}{e^{n*y^{\$}_{t,t+1}}} - S_t * \frac{1}{F_{t,t+1}} * \frac{1}{e^{n*y^{f}_{t,t+1}}}$$

The first term is the PV of the domestic leg and the second term is the second leg. $y^{\$}_{t,t+n}$ and $y^{f}_{t,t+n}$ represent the US rate and foreign xIBORs, respectively, over a given time period in annualized rates. In

[4]Deviations on agreements with maturity of one year or less. I have included a short section on the long-term deviations.

the formula they are used as the risk-free rates to discount the cash flows. n is the fraction of a year given by the length of the forward contract.

With an NPV of zero, I can rearrange the above formula to isolate the forward rate in the below equation[5]:

$$F_{t,t+n} = S_t \frac{e^{n*y^{\$}_{t,t+n}}}{e^{n*y^{f}_{t,t+n}}} \qquad \textit{Eq. 1}$$

From equation 1, the outright forward rate is calculated as the current spot rate times the fraction of the compounded interest rates. The conventional belief behind the CIP is that any gain made by investing in one currency over another will be offset by a depreciation in the forward rate for the higher return currency. If this is not the case, an investor would theoretically be able to guarantee certain future gain without any upfront cost. Under general economic theories, such arbitrage opportunities could not persist for long in liquid markets, as they would be exploited until they evaporate.

5.1 The forward break and cross-currency basis

This paper considers deviations from the Covered Interest rate Parity. The forward "break" is one way to measure deviations from the CIP. The forward break is the difference between the actual forward and the calculated (theoretical) forward from above.

$$Break = F^{*}_{t,t+n} - F_{t,t+n}$$

However, for the purpose of the below calculations, this paper will compare the deviations across several currencies. The above forward break cannot easily be compared across the currencies because the units will be those of the different exchange rates.

Instead I will focus on the continuously compounded Cross-Currency Basis[6] $x_{t,t+n}$ (Du, Tepper, & Verdelhan, June 2018) which is defined as the additional interest added to the foreign interest for the CIP to hold:

[5] If the currency rates were expressed as foreign currency per USD the formula would be $F_{t,t+n} = S_t \frac{e^{n*y^{f}_{t,t+n}}}{e^{n*y^{\$}_{t,t+n}}}$

[6] It will be referred to simply as the Basis

$$F_{t,t+n} = S_t \frac{e^{n*y^{\$}_{t,t+n}}}{e^{n*y^{f}_{t,t+n}+n*x_{t,t+n}}} \qquad \textit{Eq. 2}$$

Before isolating the Cross-Currency Basis, I will define the continuously compounded forward premium $\rho_{t,t+n}$ as the interest rate differential from the following derivation of the CIP in logs. $f_{t,t+n}$ and s_t is the natural log of the forward rate and spot rate, respectively.

$$\rho_{t,t+n} = \frac{1}{n}\left(f_{t,t+n} - s_t\right) = y^{\$}_{t,t+n} - y^{f}_{t,t+n} \qquad \textit{Eq. 3}$$

Returning to the cross-currency basis in logs, we have, similarly:

$$f_{t,t+n} = s_t + n * y^{\$}_{t,t+n} - n * y^{f}_{t,t+n} - n * x_{t,t+n}$$

$$\frac{1}{n}\left(f_{t,t+n} - s_t\right) = y^{\$}_{t,t+n} - y^{f}_{t,t+n} - x_{t,t+n}$$

I can now insert the forward premium and isolate the cross-currency basis:

$$x_{t,t+n} = y^{\$}_{t,t+n} - y^{f}_{t,t+n} - \rho_{t,t+n} \qquad \textit{Eq. 4}$$

The cross-currency basis measures the difference between the interest rates and the implied interest rates from the CIP. The Basis can also be thought of as the difference between the actual dollar LIBOR $y^{\$}_{t,t+1}$ and the synthetic dollar rate, which is achievable by hedging the foreign rate through a forward. If the covered interest rate parity holds, we should naturally see that the cross-currency basis equals zero.

6 Analysis

6.1 Short term deviations from covered interest rate parity

In order to perform calculations, daily observations from the beginning of 2000 to mid-2019 have been collected from Bloomberg. The interest rates are the relevant xIBORs for each country. Figure 1 shows a weekly rolling average of the 3-month deviations from the CIP in basis points[7]. To reiterate, the basis found for each currency is against the USD.

[7] A weekly rolling average is chosen to smooth the curve and make the graph intelligible.
Basis points are $\frac{1}{10000}$: that is, 100 basis points is equal to 1%.

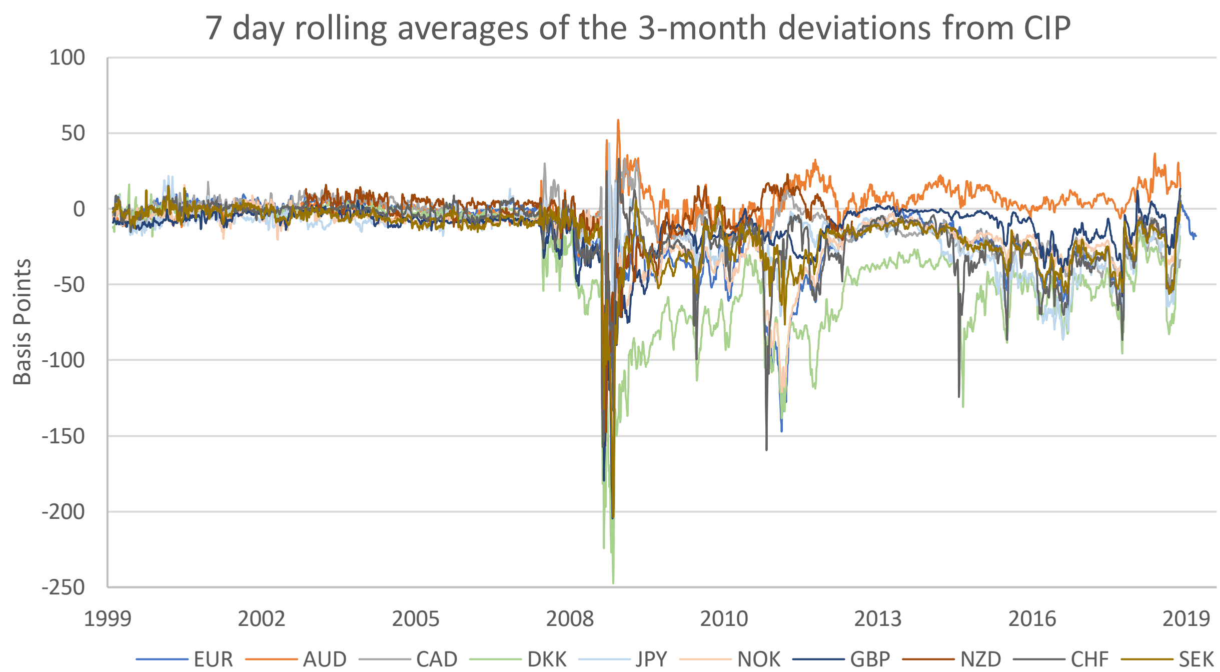

Figure 1: Short term (3m) deviations from the covered interest rate parity. The deviations are the Cross-Currency Basis: $x_{t,t+n} = y^{\$}_{t,t+n} - y^{f}_{t,t+n} - \rho_{t,t+n}$. *Source: Bloomberg*

The results of my analysis will be divided into three time periods. Within the first period (2000-2006), the deviations from the CIP are close to zero. The currencies' average deviation within that time period is between -6 and 2 basis points (see table 1). In the second period, which is when the financial crisis occurred, the Basis significantly increased. The average deviation within this period is between 7 and -63 bpts. Most of the currencies have large Basises over this time period, with the largest deviations occurring around Nov/Dec 2008. Furthermore, the deviations are negatively skewed in comparison to the pre-crisis period. The DKK Basis, for example, has an average deviation of -63 basis points with a high of -319 bpts from 2007 to 2009. To put the significance of these deviations into perspective, it means that the real CIBOR was -3.19% (see equation 2) lower than indicated by the forward rate. Interestingly, the CAD, NZD, and AUD have significantly less deviations and those deviations are more symmetric around zero.

The third period begins after the financial crisis. Here, the deviations have not returned to their pre-crisis lows. There are still persistent and significant deviations in most of the major currencies. Again, the average DKK Basis is the highest in the post crisis years when compared to the other currencies. Similarly, it is the CAD, NZD, and AUD that once again exhibit the lowest deviations. The average deviation for the AUD is only 7 in the post-crisis years.

The Cross-Currency Basis for the 12 month forward rates and interest rates are similar for most currencies and time periods. During the financial crisis only AUD is significantly different, with a mean of 88 bpts (see appendix C).

Overall, the results of the three-month analysis are very similar to those found by (Du, Tepper, & Verdelhan, June 2018) in their summary statistics (see appendix D). There are only slight inconsistencies of a few basis points for the currencies and time periods[8]. One likely reason for these inconsistencies is different and/or updated data sources on Bloomberg. Another source of inconsistency could be due to the way that I created and ordered my data set in Excel as described in the "Data" section. Through the use of "VLOOKUP's" I might have missed some dates for the currencies other than EUR.

This section has shown that there have been significant deviations from the Covered Interest rate Parity. These deviations were the largest during the financial crisis and were still atypically large afterwards.

[8] The last time period shouldn't be identical, as I have included roughly 3 more years of data.

Summary Statistics of the Cross-Currency Basis

	2000 to 2006 (n=1824)	2007 to 2009 (n=784)	2010 to 2019 (n=2521)	Overall (n=5129)
EUR				
Mean (SD)	2.06 (3.76)	-27.6 (32.5)	-31.0 (22.9)	-18.7 (25.7)
Median [Min, Max]	2.17 [-21.3, 35.0]	-24.8 [-257, 25.3]	-25.6 [-157, 10.5]	-12.2 [-257, 35.0]
Missing	61 (3.3%)	27 (3.4%)	86 (3.4%)	174 (3.4%)
GBP				
Mean (SD)	-6.22 (3.96)	-34.8 (36.9)	-11.9 (10.6)	-13.4 (18.9)
Median [Min, Max]	-6.95 [-26.4, 10.6]	-26.4 [-223, 21.8]	-10.2 [-77.5, 14.8]	-8.50 [-223, 21.8]
Missing	57 (3.1%)	24 (3.1%)	80 (3.2%)	161 (3.1%)
AUD				
Mean (SD)	-2.94 (5.12)	-1.40 (20.1)	6.62 (10.2)	2.02 (11.9)
Median [Min, Max]	-3.51 [-28.2, 22.6]	-4.43 [-119, 125]	6.57 [-30.6, 42.3]	0.827 [-119, 125]
Missing	75 (4.1%)	41 (5.2%)	80 (3.2%)	196 (3.8%)
CAD				
Mean (SD)	1.59 (5.15)	-3.84 (16.6)	-20.8 (11.5)	-10.2 (15.1)
Median [Min, Max]	1.77 [-17.3, 26.0]	-5.66 [-105, 44.5]	-19.9 [-65.7, 13.8]	-7.85 [-105, 44.5]
Missing	98 (5.4%)	42 (5.4%)	146 (5.8%)	286 (5.6%)
JPY				
Mean (SD)	-5.52 (6.75)	-16.8 (23.7)	-29.2 (17.8)	-18.9 (19.3)
Median [Min, Max]	-5.91 [-30.5, 37.3]	-14.9 [-240, 64.9]	-26.4 [-90.5, 2.11]	-13.5 [-240, 64.9]
Missing	57 (3.1%)	24 (3.1%)	80 (3.2%)	161 (3.1%)
NZD				
Mean (SD)	-4.09 (7.03)	6.68 (15.3)	13.2 (9.89)	6.23 (12.8)
Median [Min, Max]	-3.96 [-24.0, 45.2]	4.51 [-63.6, 62.8]	11.3 [-10.7, 49.7]	5.43 [-63.6, 62.8]
Missing	136 (7.5%)	31 (4.0%)	83 (3.3%)	250 (4.9%)
CHF				
Mean (SD)	-1.06 (4.69)	-18.3 (27.6)	-28.0 (20.0)	-17.0 (21.7)
Median [Min, Max]	-0.718 [-29.2, 39.8]	-13.7 [-239, 49.8]	-24.2 [-172, 13.1]	-10.5 [-239, 49.8]
Missing	57 (3.1%)	24 (3.1%)	80 (3.2%)	161 (3.1%)
DKK				
Mean (SD)	-1.31 (4.60)	-63.0 (54.6)	-56.6 (22.4)	-37.8 (38.1)
Median [Min, Max]	-1.06 [-34.1, 31.1]	-55.8 [-319, 5.21]	-52.1 [-152, -12.6]	-35.9 [-319, 31.1]
Missing	93 (5.1%)	45 (5.7%)	146 (5.8%)	284 (5.5%)
NOK				
Mean (SD)	-5.12 (6.02)	-29.6 (33.6)	-26.6 (19.0)	-19.4 (21.8)
Median [Min, Max]	-5.57 [-45.6, 33.5]	-14.8 [-184, 11.4]	-22.1 [-135, 0.943]	-12.7 [-184, 33.5]
Missing	93 (5.1%)	37 (4.7%)	128 (5.1%)	258 (5.0%)
SEK				
Mean (SD)	-4.34 (5.75)	-26.7 (33.5)	-24.8 (13.1)	-17.8 (19.2)
Median [Min, Max]	-4.71 [-22.4, 78.3]	-14.7 [-220, 15.8]	-23.3 [-83.0, 11.0]	-12.7 [-220, 78.3]
Missing	95 (5.2%)	41 (5.2%)	133 (5.3%)	269 (5.2%)

Table 1: Summary Statistics of the Cross-Currency Basis against the USD: $x_{t,t+n} = y^{\$}_{t,t+n} - y^{f}_{t,t+n} - \rho_{t,t+n}$. The time periods are as follows: 01/01/2000-31/12/2006, 01/01/2007-31/12/2009, and 01/01/2010-30/08/2019

6.2 Long Term deviations

Forward rates are, for the most part, not available for maturities over one or two years. The main reason for this is that the FRA carries interest rate risk for the parties involved, which is due to the fixed payment at the time of maturity. Intuitively, the interest rate risk increases with the time to maturity as there is a longer period in which the interest rates can change. In order to manage the interest rate risk over, say, a five- or ten-year period, the financial world uses Cross Currency Swaps (CCS) instead.

A CCS swap works by two parties agreeing to swap a principal and interest payments for a given time period. The standard is to use 3M xIBOR as the interest rate (Linderstrøm, 2013). When the CCS reaches maturity, the principals are swapped back. Essentially, the swap works as a synthetic method of taking out a loan in one currency while depositing the money in another currency. The figure below shows the cash flows of a EUR-USD CCS with a €100 notational and a spot exchange rate of $S_t = 1.05\frac{USD}{EUR}$.

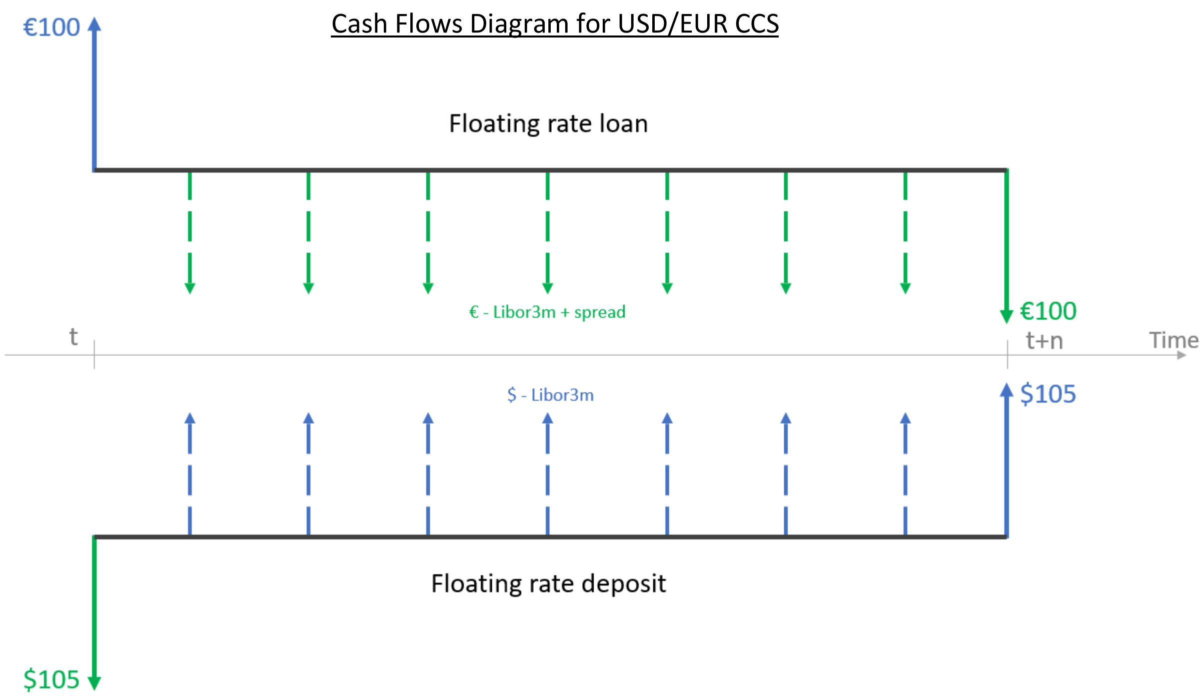

Figure 2: Cash Flows on a €100 notational CCS swap with exchange rate of $S_t = 1.05\frac{USD}{EUR}$. The notational is exchanged and the US LIBOR is received while paying EURIBOR until maturity, when the notational is returned.

As with the FRA, the CCS swap value is zero at initiation. The PV can be calculated by converting the foreign leg to the home currency through the forward rate and discounting it back with $y^{\$}_{t,t+n}$. Alternatively, the PV can be found by using the foreign rate ($y^{f}_{t,t+n}$) to discount the foreign leg back and converting it with the spot rate. Therefore, these two methods should yield the same value if the Covered Interest rate Parity holds. However, as has been shown, the CIP does not always hold and therefore a spread is applied to the non-USD part of the swap. Essentially, the CCS Basis can be thought of as the weighted average of the Basises found in equation 4, over the CCSs maturity (Linderstrøm, 2013).

The long-term deviations are thus readily observable in the market as the quoted basis spread on CCS. The below figure shows the deviations from the CIP in the CCS between USD and EUR for a 3M and 12M basis swap:

As can be seen from figure 4, the deviations from the CIP are comparable with what was found in the short-term Basis. The deviations are especially large during the financial crisis, with deviations as low as --200 basis points. This means that the actual interest rate on the EUR leg is 2% lower than what is dictated by the CIP. Again, these deviations are expected after exploring the short-deviations, as the CCS basis is the weighted average of the short-term deviations over its maturity.

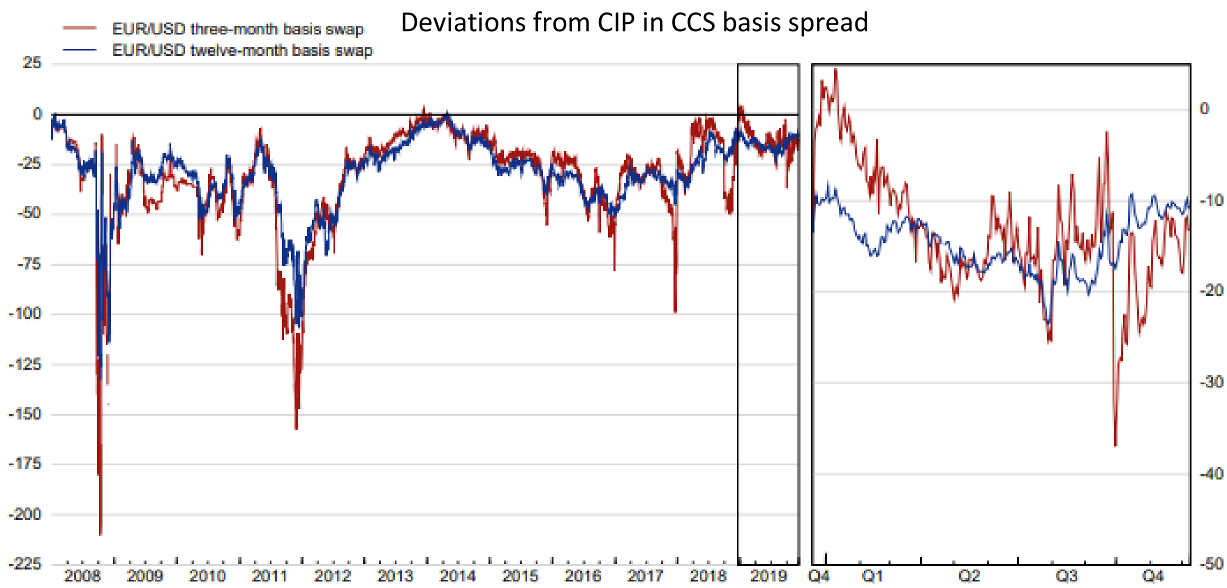

Figure 3: Deviations from the CIP in the 3M and 12M basis CCS. The y-axis is measured in basis points. Large negative deviations are present.
Source: (ECB, 2019). (The data is from Bloomberg).

6.3 Arbitrage strategies

As previously mentioned, the Covered Interest rate Parity is a no arbitrage condition. Therefore, any analysis of deviations from the CIP would logically begin with an analysis of potential arbitrage strategies. In an arbitrage strategy, the arbitrageur will need to lend and borrow in the relevant currencies and engage in forward contracts. A classic arbitrage strategy involves going long in one currency and shorting the other while hedging the exchange rate risks through a forward contract. The following section will evaluate whether or not the CIP deviations present an actual opportunity to implement a true arbitrage strategy. A true arbitrage strategy is understood as a strategy where there is profit despite bid/ask rates and transaction costs, and the profit cannot be explained by risk factors such as credit default risk.

In the below figure, I show the cash flows for an arbitrage strategy in which a negative basis is present between the USD and EUR. This strategy necessitates borrowing USD at the risk-free rate, converting them to EUR, and then investing them in a risk-free asset at time *t*. Simultaneously, the arbitrageur enters a forward deal to sell EUR at time *t*+1. At time *t*+1, the EUR investment is withdrawn and used to pay the FX dealer. Finally, the USD bank loan is repaid and—hopefully—the arbitrageur is left with a profit of $-\mathrm{e}^{y^{\$}_{t,t+1}} + \frac{\mathrm{e}^{y^{f}_{t,t+1}} F_{t,t+1}}{S_t}$, which is equal to $-e^{x_{t,t+1}}$. That is, the returns from the arbitrage strategy are equal to the Cross-Currency Basis. In the case that the Basis is positive, the arbitrage strategy is simply reversed so that the arbitrageur would earn approximately the positive basis. Thus, any deviations from the CIP could represent an opportunity for arbitrage, whether the deviations are positive or negative.

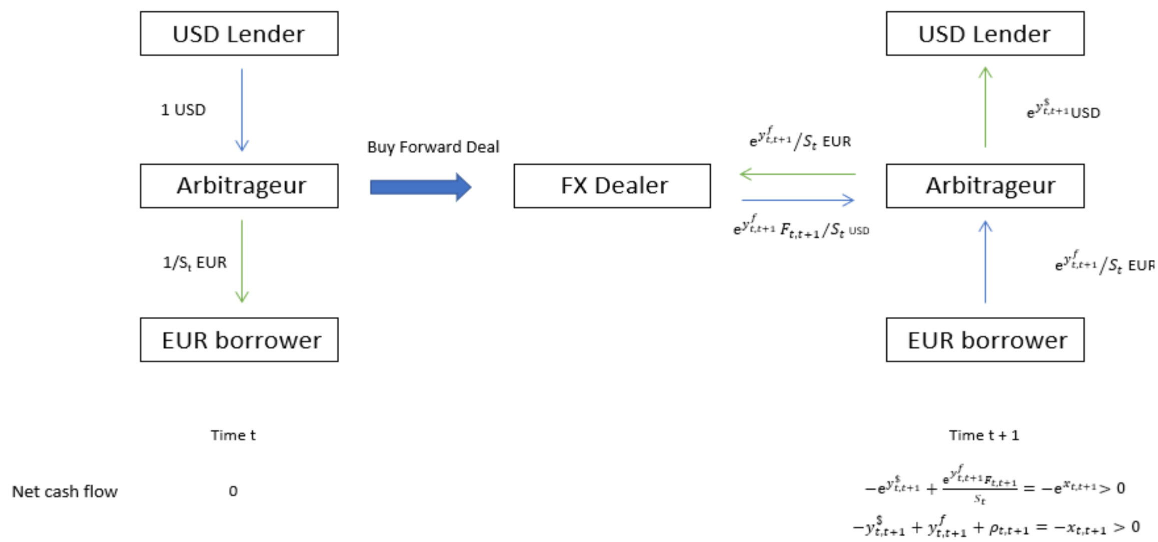

***Figure 4 Cash Flow Diagram of a negative basis arbitrage strategy**:*
The figure shows the Cash Flows regarding an arbitrage strategy for a negative basis between USD and EUR. The arbitrageur borrows 1 USD and converts it to EUR in order to invest it. At time t+1 he unwinds the position and ends up with $-e^{y^{\$}_{t,t+1}} + \frac{e^{y^{f}_{t,t+1}} F_{t,t+1}}{S_t}$.

The returns from an arbitrage strategy are the absolute values of the Basis from equation 4. Therefore, a summary of the returns from the simple arbitrage strategy is available in the previous sections (see table 1). It should be noted that the values in the table are not 100% accurate because the Basis of some of the currencies crosses the X-axis, which distorts the mean. (see appendix E for a summary in absolute values). However, since the Basis is often skewed negatively (aside for a few currencies) the effects are not much different. As expected, the largest changes are for currencies such as AUD and CAD.

It should be emphasized that this is a self-financing strategy, since money is borrowed at the “risk-free” rate. This means that the returns generated are excess returns[9]. Furthermore, as a true arbitrage strategy, a certain return on investment is guaranteed. There is no variation between expected return and realized return, as the investor will be certain of their payoff at time zero. Therefore, the Sharpe ratios of the returns will be infinite as the conditional volatility is zero. This indicates a very lucrative opportunity for any arbitrageur within the FOREX.

This is a very stylized scenario with no bid/ask spreads or transaction costs. These costs will significantly hamper the returns on an arbitrage strategy, as the Basis was often found to be below 1%. Furthermore, as of yet there has been no consideration for risk premiums. In the next section, I will apply a more realistic method of calculating the returns earned on a hypothetical arbitrage strategy.

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[9] Excess of the risk-free rate, either the US rate or the foreign rate.

6.3.1 Arbitrage strategies subject to Bid/Ask spread and transaction costs

This section will attempt to improve the analysis of returns earned on a hypothetical arbitrage strategy by including bid/ask rates and transaction costs. In my analysis, I have included the bid/ask spread of the spot rates, currency rates, and forward rates for each currency. The bid/ask for the xIBORs have been estimated through the spread on Interest rate swaps (see section 4.2 Data). I am going to assume that the transaction costs are fixed. Some examples of potential transaction costs are: a fee incurred with a broker for the spot rate; a fee incurred for the forward rate; or a fee for the bank loans[10]. I will treat such transaction costs as barriers to entering the CIP arbitrage. The larger the fees, the larger the position must be in order to make the transactions yield a profit.

As described earlier, which strategy is necessary depends on the sign of the Basis. In the case of a negative Basis, the strategy follows Figure 4. To summarize, one borrows USD, sells USD, deposits foreign currency, and buys a forward deal. Therefore, the returns at time $t = 1$ can follow equation 4, with bid and ask rates[11]:

$$r_{t,t+1}^{-x} = -{y_{t,t+1}^{\$}}^{ASK} + {y_{t,t+1}^{f}}^{BID} + \frac{1}{n}\left(f_{t,t+1}^{ASK} - s_t^{BID}\right) \qquad \textit{Eq. 5}$$

If the sign of the basis is positive, the formula for the return would simply be reversed:

$$r_{t,t+1}^{+x} = {y_{t,t+1}^{\$}}^{BID} - {y_{t,t+1}^{f}}^{ASK} - \frac{1}{n}\left(f_{t,t+1}^{BID} - s_t^{ASK}\right) \qquad \textit{Eq. 6}$$

The Covered Interest rate Parity with a bid/ask spread can be generalized by these two inequalities: $\frac{F_{t,t+1}^{ASK}}{S_t^{BID}} \geq \frac{e^{n*{y_{t,t+1}^{\$}}^{ASK}}}{e^{n*{y_{t,t+1}^{f}}^{BID}}}$ and $\frac{F_{t,t+1}^{BID}}{S_t^{ASK}} \leq \frac{e^{n*{y_{t,t+1}^{\$}}^{BID}}}{e^{n*{y_{t,t+1}^{f}}^{ASK}}}$ (Du, Tepper, & Verdelhan, June 2018). The first of these prevents arbitrage with a negative Basis, and the latter prevents arbitrage with a positive Basis.

Implementing equation 5 and 6 to calculate the returns of CIP arbitrage would result in a significant reduction of the profits when compared to the absolute value of the Cross-Currency Basis. This is because the CIP arbitrage often produces low returns, especially pre-2007 (see Figure 2). However, it is expected that arbitrage will have an atypically profitable outcome during and after the financial crash because the deviations from the CIP are much higher during these periods. Furthermore, I expect the returns from this analysis to mimic those of the previous analysis, in which certain currencies showed larger returns.

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[10] See section 7.1 Discussion, for reasoning behind the assumption.

[11] I have expanded equation 4 with equation 3 to properly show the correct bid and ask rates.

As I have mentioned before, I assume that transaction costs are fixed costs incurred by the arbitrageur. Because the strategy is self-funding, the actual returns will not be significantly reduced since the positions can simply be increased. Instead, the lower returns become undesirable as the leveraged positions would need to be significantly increased to recoup the transaction costs and break even. Therefore, in order to account for the presence of transaction costs, I will remove the lowest 5% of the returns. Any returns below 5%, therefore, can be deemed inefficient. Most of the inefficient returns will probably occur in the pre-crisis years, as it was the period with the lowest returns.

The below figure shows the number of periods where a CIP arbitrage strategy would be viable for the different currencies over the different time periods. The returns used in the calculations are from equation 5 and 6 with the lowest 5% removed.

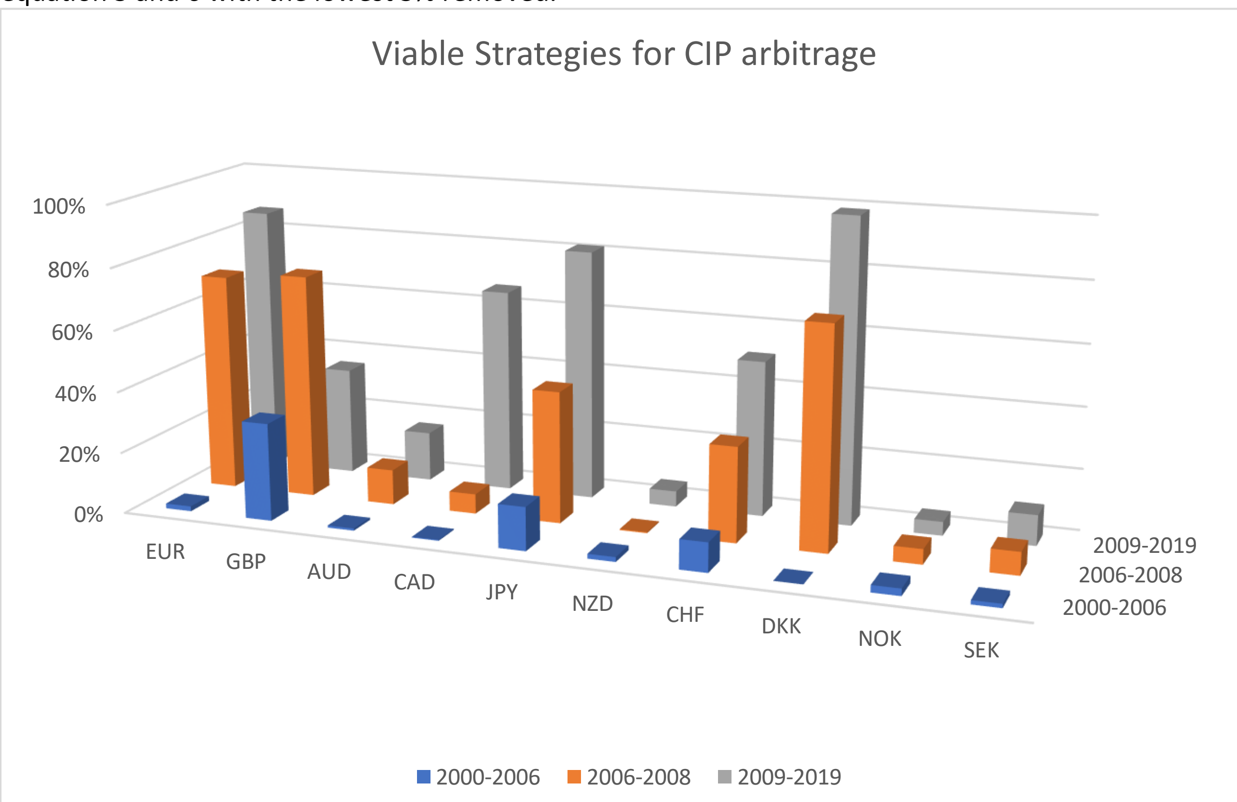

Figure 5: Percentage of viable strategies for each currency against the USD (deviations from CIP including bid/ask). The returns are calculated via equation 5 and 6 on three-month maturities, with only the positive values being viable strategies and the transaction costs removing the lowest 5%.

The results follow the intuition behind the arbitrage strategy. In the first period (2000-2006) the percentages of viable strategies are below 5% for most of the currencies. The only currency with viable strategies in a significant number of periods is GBP, with 36% positive returns. This is due to a high mean return of the Basis (see table 1) and a low spread on the exchange[12]. However, with the sole exception of the Pound, there do not seem to be any significant returns to be had in the years before the financial crisis. The percentage of viable periods increases in periods after the financial crisis for most currencies. These results are comparable with what was found in previous research, as seen in the literary review.

There are some interesting and unexpected points to note from figure 6. Firstly, there are several currencies that do not show any significant amount of positive returns over any of the periods. NOK and NZD are the currencies with the lowest amount of positive returns. They each show around 5% positive returns in the post-crisis years. They are followed closely by SEK and AUD, which have 10% and 17% positive returns, respectively, within the same period. This indicates that the CIP holds, to some degree, for these particular currencies within all of the time periods. This is a significant discovery compared to what was found in the previous section, as there were fairly large deviations for those currencies.

Secondly, for the remaining currencies which show larger returns, the post-crisis years have a much higher percentage of positive returns when compared to the period 2006-2008. This is somewhat surprising based on the initial findings from the previous sections, because the largest deviations occurred during the crisis period. For DKK, the arbitrage strategy generates positive returns for 99% of the data points. Again, the Pound is atypical amongst the currencies evaluated in this analysis in that it sees more consistent positive returns in the second time period.

I will continue the analysis with a summary statistic of the returns subject to bid/ask spread. Figure 7 illustrates the maximum returns for each period and currency (See appendix F for the full table). The maximum returns within the first period are mostly below 20 bpts. The low returns coupled with the low percentage of viable strategies demonstrate conclusivley that reliable CIP arbitrage opportunities are not available from 2000 to the end of 2006, which conforms easily with previous research.

[12] One of the main drivers behind currency spread is volume, and the volume between USD and GBP is obviously much larger than, say, USD and DKK.

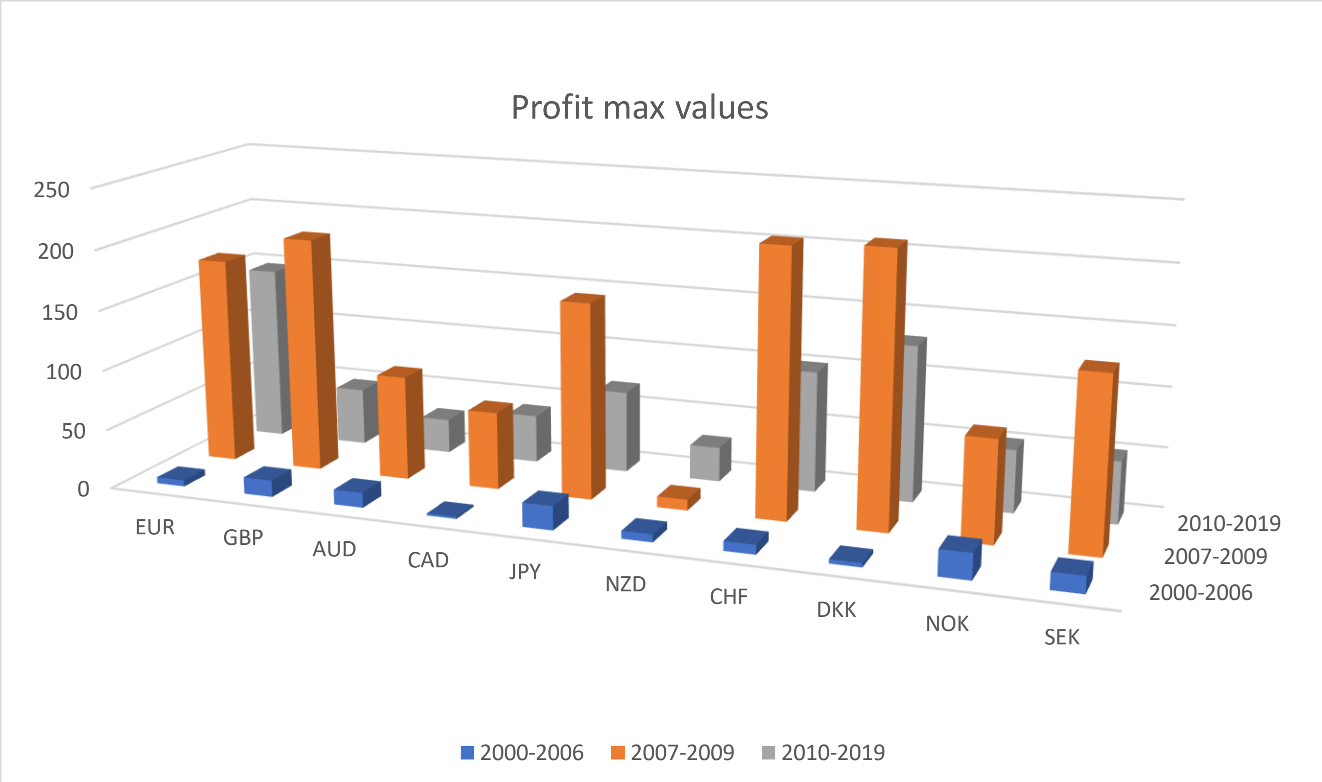

Figure 6: The maximum values of the returns of a CIP arbitrage for each currency against the USD with bid and ask values. The returns are calculated via equations 5 and 6.

The application of the bid/ask spreads has somewhat reduced the returns from 2007 onwards when compared to table 1. The largest returns are still found during the crisis years, as was the case with the Basis. There are excess returns of over 150 bpts for the currencies other than NOK, NZD, CAD, and AUD. The analysis finds that the crisis years exhibit larger but less consistent returns when compared to the years after 2010. I would argue that, based on the low number of viable strategies and low returns, CIP arbitrage from a hypothetical standpoint has been limited for NZD, and to some degree AUD. The average return for those countries is around 1 bpt, which is negligible. The amount of leverage needed in order to make those strategies viable makes them extremely undesirable.

6.3.2 Returns and Risk Premiums

In order to determine whether the deviations and returns from the CIP are true arbitrage opportunities, I want to analyze the performance of the strategies and whether portions of the returns can be classified as risk premiums. If the returns are gained from risk premiums then it is not true arbitrage, but rather adequate compensation for the risks acquired.

6.3.2.1 Model vs Real Returns

At first glance, the returns from the CIP do not look very impressive. The average excess return in the post-crisis years for EUR arbitrage, for example, is 24.1 bpts. The strength of the strategy is that it can be leveraged until a preferable return has been achieved. The conditional variance of the strategy is zero—no matter what the leverage ratio is—because the return is known at the onset of the trade. This explains, in part, why the Sharpe ratios are infinite.

It is important to note that the ability to increase the leverage without increasing the riskiness is only possible because the theoretical conditional variance is equal to zero. In the real world, however, the expected return would not always equal the realized return and thus there would be return variance. In order for the realized returns to equal the model returns, the strategy must be held until maturity and none of the counterparties must default. I will describe some risk factors below:

a) **Time/short squeeze risk**: There is risk associated with whether the arbitrageur is able to hold the position to maturity. If the arbitrageur is forced to unwind before maturity, they would be stuck with the transaction costs and the risk of an unsecured forward agreement. A potential factor that might force an early liquidation could be other pressing liabilities which require payment. There is no currency risk in the trade due to the fact that if the forward position goes out of the money, the loss will be offset by the bank loan and deposit. A second risk factor associated with the trade is the bank loan (bond) losing value because of an interest rate increase. This would cause the position to lose value, since the lost value on the loan is not automatically offset anywhere.
   For the purpose of this paper I am unable to include any of these factors into the modelling, as I cannot predict hypothetical cash squeezes and I assume that the interest rate risks are insignificant over short time periods.
b) **Counterparty risk**: The counterparty risk can be separated into risks associated with either the bank deposit or the forward rate agreement. If the bank that holds the arbitrageurs deposit goes bankrupt, the entire principal and any gains will be lost. Therefore, there should be

significant counterparty risk in regards to the xIBORs. I aim to account for this uncertainty by applying CDS spreads for the xIBOR panel banks.
The counterparty risk regarding the forward rates are less severe. The only result of non-compliance with the agreement is currency risk and the loss of any value that the FRA might have accumulated. However, the forward rate is traded at an NPV of zero, and no money is exchanged. Therefore, I assume that the counterparty risk associated with the forward rates are negligible.

The conclusion must be that from a theoretical perspective, the CIP deviations remain a very lucrative arbitrage opportunity if the arbitrageur can leverage efficiently. In order to bring the theoretical returns into a real-world scenario, I turn to two measurable risk factors.

6.3.3 CIP returns and VIX

The VIX measures the expected volatility of the S&P 500 within the next 30 days, calculated from put/call options (Cboe, 2020). The VIX gauges uncertainty in the US stock market, which I will use as a proxy for general market uncertainty. The VIX is often used as a standard measure of risk (Brunnermeier, Nagel, & Pdersen, 2009).

I want to apply the VIX in order to gain an understanding on whether or not the returns are correlated with my risk measure. My hypothesis is that the returns from the Cross-Currency Basis[13] are positively correlated with the percentage changes in the VIX. That is to say, the large excess returns can be explained in part by general market uncertainty. To test this hypothesis, I have run a linear regression analysis with the returns as the dependent variable and the changes in the VIX as the independent variable:

$$x_{t,t+1}^{abs} = \alpha_t + \Delta VIX_{t,t+1} + \epsilon_t \qquad \textit{Eq. 7}$$

$x_{t,t+1}^{abs}$ indicates that it is the absolute value of the Basis and $\Delta VIX_{t,t+1}$ is the percentage change in the VIX index from the time t and 90 days forward. The reasoning behind using the absolute value of the returns is that I want to investigate the effects of uncertainty on the returns. For purpose of this analysis, I am not concerned with the direction of the Basis. I am using the Cross-Currency Basis instead

[13] Absolute value of Equation 4

of the returns calculated in equation 5+6, because there are more continuous observations to match with the changes in the VIX. The results are posted in table 2 below for the years 2007 and 2010 (see Appendix G for full table)

Table 2: Regression analysis of equation 7. The Cross-Currency Basis regressed on percentage changes in the VIX. The regressions are reported for the financial crisis years (2007-2009). The Confidence Intervals are reported in the parenthesis.

	Dependent Variable: Cross-Currency Basis									
	EUR	GBP	AUD	CAD	JPY	NZD	CHF	DKK	NOK	SEK
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
d.VIX	-21.623***	-29.318***	-8.612***	-8.416***	-3.161*	-11.830***	-0.952	-57.727***	-38.160***	-25.953***
	(-27.136, -16.109)	(-35.989, -22.647)	(-10.878, -6.346)	(-10.215, -6.616)	(-6.863, 0.540)	(-13.867, -9.794)	(-5.227, 3.323)	(-67.758, -47.696)	(-43.904, -32.416)	(-31.585, -20.321)
Constant	28.914***	35.818***	14.529***	13.194***	19.149***	12.485***	20.404***	64.630***	30.891***	27.707***
	(26.677, 31.150)	(33.160, 38.475)	(13.514, 15.544)	(12.410, 13.978)	(17.641, 20.657)	(11.675, 13.295)	(18.583, 22.224)	(60.903, 68.357)	(28.575, 33.207)	(25.266, 30.147)
Observations	712	715	699	702	715	710	715	698	704	700
R^2	0.070	0.092	0.055	0.084	0.003	0.151	0.0002	0.163	0.185	0.089
Note:										*p<0.1; **p<0.05; ***p<0.01

The R^2 for the regressions are negligible. This is perfectly acceptable, as I don't expect that the volatility of the US market should be able to explain all of the variation in the CIP arbitrage returns. During the financial crisis, the coefficients are particularly significant, which is why they are displayed above. All of the coefficients are negative. This indicates that the returns on CIP arbitrage are reduced by market uncertainty. During the period of the largest CIP arbitrage returns,[14] the returns are negatively affected by uncertainty. This inference contradicts my previous thought that the returns could be explained by a risk premium from general market uncertainty.

6.3.4 Credit Risk of xIBOR Panel Banks

This subsection will analyze whether the deviations from the CIP could be explained by the credit worthiness of the panel banks that contribute to the xIBORs. I want to find out if the returns from CIP arbitrage can be attributed to compensation for additional credit risk when investing in one currency compared to another. Rather, the Basis should reflect the differences in the credit riskiness of the panel banks.

To begin the analysis, I will introduce the assumption that the interest of the xIBOR is the sum of the "true risk-free rate" plus the credit spread found from the respective panel banks[15]: $y^{\$}_{t,t+1} = y^{*\$}_{t,t+1} + sp^{\$}$. In this formula, $y^{*\$}_{t,t+1}$ is the "true risk-free rate" and $sp^{\$}$ is the average credit default spread for the

[14] Since I have made the distinction earlier, I shall make it again. These are the theoretical (model) returns that are reduced by increasing market uncertainty. It is not the actual realized returns that are reduced. I do not have a good way to measure realized returns.
[15] See section 4.2.2 data for explanation on calculation of the panel bank spreads.

US panel banks (Du, Tepper, & Verdelhan, June 2018). Obviously, this formula also applies to the foreign rates and panel bank riskiness. I can insert this into equation 4 for the Basis[16]:

$$x_{t,t+n} = (y^{*\$}_{t,t+1} + sp^{\$}_{t}) - (y^{*f}_{t,t+1} + sp^{f}_{t}) - \rho_{t,t+n} \qquad \textit{Eq. 8}$$

I can rearrange Equation 8 to the following:

$$\mathrm{x_{t,t+n}} = (\mathrm{y^{*\$}_{t,t+1}} - \mathrm{y^{*f}_{t,t+1}} - \rho_{\mathrm{t,t+n}}) + (\mathrm{sp^{\$}_{t}} - \mathrm{sp^{f}_{t}})$$

Now, if the assumption is that the Covered Interest rate Parity holds, then the contents of the first set of parentheses should be equal to zero because it is the "true" Cross-Currency Basis. All that we are left with is, therefore:

$$x_{t,t+n} = sp^{\$} - sp^{f} \qquad \textit{Eq. 9}$$

Equation 9 now states that the Basis can be explained by the difference in the credit riskiness of the panel banks. The Basis is negative if the foreign panel is riskier than the US one, and the opposite is true if the Basis is positive. This also makes sense if one returns to the conclusions drawn from the Basis earlier, where a negative Basis indicates that the foreign interest rate is higher than what is indicated by the CIP.

As with the analysis of the VIX, I am going to look at the changes in the Basis compared to the changes in the credit risk differential. The expectation is that the Basis and the credit risk differential will not necessarily be equal, but that the changes in them should be. In addition, the transformation helps prove that the variables are truly correlated and not just spuriously correlated. Once again, I will employ a regression analysis to test my hypothesis that the changes in the Basis can be explained by the changes in the mean credit spread of the panel banks. The regression is run on one-year maturities because the Credit Default Swaps are not available for shorter maturities.

$$\Delta x_{t,t+1} = \alpha_t + \beta\Delta\left(sp^{\$}_{t} - sp^{f}_{t}\right) + \epsilon_t \qquad \textit{Eq. 10}$$

If the hypothesis holds, I should expect an α-value close to zero and a β-value around 1. The results are shown in table 3 below. As mentioned, the CDS spreads are not available for CAD, NZD, and DKK. Therefore, they are obviously not included in table 3.

[16] I am using Equation 4 for simplicity and so that I have a large sample size compared to the returns subject to bid/ask.

Table 3: Regression analysis of the changes in the Cross-Currency Basis on the changes in the mean credit default swap spread on panel banks for the xIBORs. One-year maturities are used for the Basis and Credit Default Swaps.

	Dependent variable Δ(Cross-Currency Basis)							
Currency	EUR		GBP		AUD		JPY	
Year	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019
$\Delta(sp_t^{\$} - sp_t^{f})$	0.122	0.142**	-0.011	0.015	-0.169	-0.464	-0.086	-0.070
CI	(-0.313, 0.556)	(0.028, 0.257)	(-0.577, 0.554)	(-0.92, 0.122)	(-0.471, 0.132)	(-1.087, 0.160)	(-0.548, 0.367)	(-0.222, 0.081)
Observations	492	2,371	495	2,382	145	2,348	495	2,382
R^2	0.001	0.017	0.00001	0.0001	0.03	0.011	0.0003	0.001

	Dependent variable Δ(Cross-Currency Basis)					
Currency	NOK		CHF		SEK	
Year	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019
$\Delta(sp_t^{\$} - sp_t^{f})$	-0.060	-0.033	0.030	0.032	-0.066	-0.265***
CI	(-0.251, 0.130)	(-0.164, 0.098)	(-0.425, 0.485)	(-0.140, 0.204)	(-0.261, 0.128)	(-0.385, -0.145)
Observations	363	953	495	2,382	362	753
R^2	0.001	0.001	0.00004	0.0002	0.002	0.037

* p<0.1; ** p<0.05; *** p<0.01

The results are profound in their rejection of my hypothesis. The three-month deviations from CIP cannot be explained by credit risk differential on the panel banks. None of the slopes are even close to 1 and the R^2 are often close to 0. The highest R^2 is around 2% for the second regression of EUR. Since equation 8/9 was derived mathematically to explain the deviations, I had hoped for a much higher R^2. My results are wildly different from what (Du, Tepper, & Verdelhan, June 2018) found in their analysis, however the final conclusion of the regression is the same in that the Basis cannot be explained by the credit riskiness of the xIBOR panel banks (see appendix H for a copy of their table.)

6.4 Explanations for Deviations from CIP

The previous section found that there are significant deviations from the CIP that cannot be explained by any of the risk premiums. In this section, I will describe and test two hypotheses on why these deviations persist despite transaction costs and risk premiums. One of these hypotheses deals with balance sheet constraints, while the other contends with supply & demand imbalances between currencies (Du, Tepper, & Verdelhan, June 2018). The first topic faces with constraints on the ability to conduct arbitrage strategies to reduce the deviations, while the second focuses on why there might be deviations in the first place.

6.4.1 Balance sheet constraints

One of the underlying assumptions behind the Covered Interest rate Parity is that the deviations will be arbitraged away. If there are limits to the effectiveness of the arbitrage strategies, then it follows that the deviations will persist. The Basel III framework has had significant impacts on the degree to which banks and other institutions can earn a profitable return on CIP arbitrage (Du, Tepper, & Verdelhan, June 2018).

The Basel III framework is a voluntary global regulation to improve the stability of the financial sector hat was created by the Bank for International Settlements (BIS). The members of the BIS are required to implement the provisions of the framework. All of the countries I have included in the analysis are members of BIS. The framework was developed in response to the financial crisis in 2007-2009 (BIS, 2019). Although the financial crisis was more than a decade ago, Basel III still hasn't been fully implemented as of today (FSB, 2019). However, it should be noted many of the important aspects have been implemented. Basel III has three main pillars, and pillar 1 and 3 are especially important in regard to the CIP.

The first pillar concerns improved capital requirements for member banks. The capital requirements were raised on both risk-weighted and non-risk-weighted assets (Du, Tepper, & Verdelhan, June 2018) (Basel Committee, High-level summary of Basel III reforms, 2017). The increase in capital requirements will have a direct effect on the banks' ability to conduct CIP arbitrage. If the leverage ratio increases, it means that the banks need to either expect a lower return or choose not to engage in the arbitrage opportunity for that point.

In order to test whether the new capital requirements have an effect on the banks' ability to arbitrage deviations from the CIP, I will look at the third pillar of Basel III. This pillar aims to improve the requirements for reporting on factors such as leverage ratio and risk-weighted assets (Basel Committee, Pillar 3 disclosure requirements - updated framework, 2018). In essence, Pillar 3 means that the banks are required to prove that they adhere to the first pillar. If the new banking regulations have an effect on the CIP, it should be observable in the deviations for maturities less than three months. The reason that it should be observable in the short-term deviations is because there should be a significant difference based on whether the strategy occurs within or outside of the time frame for quarterly reporting. During the reporting period, the banks will have to show their position on their balance sheets. This means that the banks cannot leverage as aggressively as they might have otherwise. This is due to the constraints presented by the leverage ratios. The effects seen during the reporting period will be present on the longer maturities, regardless the time period, as they will always overlap with a quarterly report. Figure 8 below shows the deviations of the CIP with the maturities of 1 week, 1 month, and 3 months for JPY and EUR.

(1) JPY (2) EUR

Figure 7: Weekly, Monthly and Quarterly deviations from CIP. The deviations are calculated from equation 4. The deviations for the JPY clearly jump 1 week and 1 month before the quarter end for the weekly and monthly maturities respectively. This, however, is not as evident for the EUR.

The deviations for the Yen distinctly increase one week before the quarter close for the weekly (green) maturity. Similar deviations are present for the monthly (red) maturity, where the deviations spike one month before the quarter close. In contrast, these characteristics are not present to nearly the same degree for the second graph, which shows the deviations of the EUR. The marked difference between the behavior of the Yen and the Euro certainly calls for attention as to whether the quarter close dynamics with regards to Basel III impact different currencies in the same manner.

In order to further test whether the increased quarterly oversight has an effect on the Cross-Currency Basis, I once again turn to a regression analysis. For the purpose of brevity, I will stick to a regression of the weekly deviations as they exhibit the largest deviations in figure 8. The purpose is to test whether the fact that the maturity period of the FRA lies within the quarter end has an effect on the Basis. Furthermore, I have included three indicator variables corresponding with whether the date is after three periods: 01-01-2008, 01-01-2015, and 01-03-2017. The first date simply indicates the onset of the financial crisis. The last two correspond to the dates of significant implementation of the Basel III disclosure requirement (Basel Committee, Pillar 3 disclosure requirements - updated framework, 2018). I expect there to be a stronger correlation with the 2015 date compared to the March 2017, as the latter was an update to the framework announced in 2015. My regression analysis will be the following:

$$\begin{aligned} x^{w}_{t,t+1} = \alpha + \beta_1 Q.End_t + \beta_2 Q.End_t * Past.2008_t + \beta_3 Q.End_t * Past.2015 \\ + \beta_4 Q.End_t * Past.2017_t + \beta_5 Past.2008_t + \beta_6 Past.2015_t \\ + \beta_7 Past.2017_t + \epsilon_t \end{aligned} \quad \text{Eq. 11}$$

The indicator variable $Q.End_t$ represents whether the settlement date is within seven days of the end of the quarter. For the purpose of this analysis, the quarters are assumed to end on the last days of March, June, September, and December[17]. The important regressors are the interaction terms between the $Q.End_t$ and those three date variables. These interaction terms will create an inference on whether the quarter end dynamics of the weekly Basis are correlated with the implementation of the third pillar

[17] Some businesses do follow a different fiscal year.

of Basel III. As demonstrated, the Basis is mostly negative, so I expect that the Beta values will have a negative sign. The results of the analysis for each currency are posted below in table 4:

	Dependent Variable: Cross-Currency Basis							
	EUR	GBP	AUD	DKK	JPY	NOK	CHF	SEK
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Q.End	-2.670**	-1.101	-1.960***	-4.538	-4.445**	1.819	-3.744***	-0.485
	(-4.971, -0.370)	(-4.231, 2.029)	(-3.226, -0.693)	(-10.553, 1.477)	(-8.100, -0.789)	(-2.698, 6.336)	(-5.818, -1.671)	(-4.038, 3.069)
Past.2008	-20.357***	-9.536***	-7.531***	-30.586***	-9.856***	-18.143***	-17.423***	-11.292***
	(-21.820, -18.894)	(-10.657, -8.415)	(-8.729, -6.333)	(-32.787, -28.385)	(-11.063, -8.650)	(-19.934, -16.351)	(-19.097, -15.750)	(-13.034, -9.551)
Past.2015	-10.441***	-6.956***	-12.225***	-7.216***	-22.531***	1.942*	-10.551***	-14.015***
	(-13.318, -7.564)	(-9.274, -4.638)	(-14.046, -10.404)	(-10.200, -4.231)	(-27.062, -18.000)	(-0.178, 4.062)	(-14.756, -6.346)	(-17.018, -11.012)
Past.2017	-2.037	-2.063	8.108***	-2.700	1.643	-4.539**	-0.025	-0.552
	(-6.724, 2.651)	(-5.812, 1.685)	(6.450, 9.766)	(-8.013, 2.612)	(-4.784, 8.070)	(-8.152, -0.926)	(-6.212, 6.163)	(-5.697, 4.593)
Q.End:Past.2008	-8.693	-3.657	0.031	-7.467	-7.583**	-3.218	-9.189**	3.687
	(-19.143, 1.757)	(-8.970, 1.656)	(-5.832, 5.894)	(-19.835, 4.902)	(-13.780, -1.386)	(-11.722, 5.287)	(-16.400, -1.978)	(-3.502, 10.876)
Q.End:Past.2015	-41.020**	-36.447***	-13.458*	-34.642**	-93.562***	-15.899*	-55.486***	-44.836**
	(-75.113, -6.927)	(-60.688, -12.206)	(-29.288, 2.373)	(-66.744, -2.541)	(-130.235, -56.890)	(-33.887, 2.088)	(-90.668, -20.305)	(-82.043, -7.628)
Q.End:Past.2017	8.683	6.960	13.019*	9.038	42.930*	-12.224	14.202	8.497
	(-33.092, 50.458)	(-23.979, 37.898)	(-2.189, 28.227)	(-37.125, 55.200)	(-6.388, 92.248)	(-45.351, 20.902)	(-36.840, 65.243)	(-40.111, 57.105)
Constant	1.250***	-1.354***	7.947***	-9.388***	-7.943***	-9.182***	-3.363***	-5.233***
	(0.823, 1.677)	(-2.016, -0.692)	(7.558, 8.336)	(-10.873, -7.903)	(-8.705, -7.181)	(-9.967, -8.396)	(-3.824, -2.902)	(-6.054, -4.412)
Observations	4,954	4,963	4,908	3,547	4,964	4,857	4,966	4,858
R^2	0.205	0.137	0.131	0.141	0.221	0.105	0.146	0.111
Note:								*p<0.1; **p<0.05; ***p<0.01

Table 4: The Cross-Currency Basis from Eq. 4 is regressed on indicator variables representing if the date is within 7 days of the quarter close and if the date is past certain milestones. The interaction terms between $Q.End$ and the years ($e.g.\ Past.2008$) are the important coefficients for my analysis. The numbers in parentheses are the 95% confidence intervals. Unfortunately, data was not available to calculate weekly deviations for NZD and CAD.

The R^2s aren't incredibly high, with the highest value reaching 20%. However, I would not expect the R^2 to be much higher than that, given the type of regression that was used. Unsurprisingly, the coefficients $\beta_5\ and\ \beta_6$ are negatively correlated with the Basis, as it is seen in figure 8 that the Basis seems to increase (negatively) at the beginning of 2008 and 2015. Interestingly, I observe that half of the currencies have small but statistically significant quarter end dynamics before the financial crisis for the one-week deviations. This indicates that there could have been some incentive to reduce the arbitrage positions during the last week of the quarter. However, those incentives became much greater after Basel III, as shown by the regression results.

The results of the regression analysis show that there is a strong negative correlation between the Basis and the interaction term (of the quarter end indicator, and the indicator that the date is past January 2015.) β_3 is significant across all currencies–although only at the 10% significance level for AUD and NOK. This means that the deviations from the CIP sharply increased during the last week of the reporting periods after January 2015, even though this increase might not be visible on the second graph in figure 8. For Japanese Yen, the quarter close dynamics increased (negatively) the Cross-Currency Basis by an average of -94 bpts after the implementation of the Basel III requirements in

January 2015. Furthermore, I do not find that the interaction between the quarter end indicator and the indicator that the date is past January 2008 is a significant regressor to explain the Basis. This supports the general assumption that the quarter end dynamics only significantly increased after the implementation of the reporting requirements, and not earlier, despite the large deviations that occurred during the financial crisis.

My hypothesis that the March 2017 adjustments to the disclosure requirement had a significant effect on the deviations from the CIP has been disproved beyond a doubt. The coefficient of β_4 is not significant for most of the currencies and the sign is positive, which indicates that quarter end dynamics decreased after March 2017. However, it should not be inferred that the announcement reduced the quarterly oversight of international banks.

The analysis led to the discovery of a new phenomenon with regards to deviations to the CIP. The sharp increase in the deviations over the quarter close days shows that banks and other actors are incentivized to reduce their leveraged positions significantly at those times. We can infer that deviations from the CIP dramatically increase when the leverage ratios are more stringent.

6.4.2 Supply & Demand Imbalances

The second explanation for the deviations from the CIP concerns the supply and demand for high interest rate currencies. There will naturally be a higher demand for investments in currencies with higher interest rates, and the supply will come from low interest rate currencies. The reason for this can mainly be attributed to investors from low interest rate countries being attracted to the higher yield of other currencies (Du, Tepper, & Verdelhan, June 2018). In many cases, these investments would be hedged by selling the investment currency forward through either FRA or CCS, depending on the maturity and form. This in order to avoid currency risk. A large demand to sell these currencies will naturally push the price of the FRAs in an unfavorable direction for the investors. Thus, the investors are willing to accept a rate outside what is determined by the CIP in order to hedge their investment.

In addition, the lopsided demand means that the market makers supplying the FRAs cannot offset the currency exposure with FRAs going in the opposite direction. This means that they will have to hedge their currency exposure by investing in the low interest currency while shorting the high interest currency. This trade is shown in figure 5 and the profit (the Basis) can be seen as the compensation to the market maker for any direct or balance sheet costs incurred by taking the position. The introduction of Basel III has been shown to increase these costs by increasing capital requirements. These costs are obviously much higher than they would be if the intermediary had been able to offset the exposure with an opposite FRA.

The hypothesis that I want to test is that the Cross-Currency Basis increases (negatively) as the foreign xIBOR decreases in relation to the US rate. If the Basis is negative with a large positive interest rate differential, an increase in said interest rate differential would further encourage the imbalance of investment supply towards the USD, and therefore the Basis should increase negatively.

For the analysis, I will mostly disregard the first period before the recession because I have found the deviations within this period to be almost negligible. I will investigate the hypothesis within each currency and as a cross-sectional analysis across all of the currencies. I expect the hypothesis to fit better across the different currencies, as I suspect that it is more reasonable that if pension funds are searching for high yield returns it is attempted within general appeal of each country/currency, as opposed to daily changes between the returns of two separate countries.

I will begin by looking at the daily changes in the Cross-Currency Basis relative to the daily changes in the interest rate differential between the USD and foreign currency. The following regression analysis is tested:

$$\Delta x_{t,t+1} = \alpha_t + \beta\Delta\left(y^{\$}_{t,t+1} - y^{f}_{t,t+1}\right) + \epsilon_t \qquad \textit{Eq. 12}$$

The results for equation 12 on the three-month maturity deviations are shown below in table 5.

Table 5: Regression analysis of equation 9. The daily changes in the Cross-Currency Basis are regressed against the daily changes in the interest rate differential. The regression is run on the period during and after the financial crisis. The deviations are on three month forward/xIBORs.

	Dependent variable Δ(Cross-Currency Basis)									
Currency	EUR		GBP		AUD		CAD		JPY	
Year	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019
$\Delta(y^{\$} - y^{f})$	0.376***	0.485***	0.703***	0.393***	0.509***	0.508***	0.459***	0.198***	0.152	-0.250***
CI	(0.199, 0.553)	(0.302, 0.668)	(0.580, 0.825)	(0.262, 0.523)	(0.401, 0.617)	(0.438, 0.579)	(0.310, 0.608)	(0.199, 0.276)	(-0.061, 0.365)	(-0.473, -0.027)
Constant	0.033	-0.072	0.015	-0.038	0.331	-0.105	-0.018	0.006	0.050	0.015
Observations	737	2,371	742	2,382	711	2,382	706	2,250	742	2,382
R^2	0.023	0.011	0.146	0.014	0.108	0.077	0.049	0.011	0.003	0.002

	Dependent variable Δ(Cross-Currency Basis)									
Currency	NZD		CHF		DKK		NOK		SEK	
Year	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019	2007-2009	2010-2019
$\Delta(y^{\$} - y^{f})$	0.218***	0.608***	0.307***	-0.720***	0.059***	0.342***	0.431***	0.601***	0.496***	-0.035
CI	(0.199, 0.317)	(0.546, 0.670)	(0.125, 0.489)	(-0.948, -0.491)	(0.432, 0.748)	(0.192, 0.492)	(0.360, 0.502)	(0.552, 0.650)	(-0.599, 0.719)	(-0.151, 0.081)
Constant	0.040	-0.088	0.096	0.062	0.062	-0.037	0.185	-0.046	0.060	-0.002
Observations	731	2,377	742	2,382	712	2,286	723	2,305	715	2,290
R^2	0.025	0.135	0.015	0.016	0.070	0.009	0.165	0.202	0.128	0.0002

* p<0.1; ** p<0.05; *** p<0.01

The R^2 values are mostly very small—the largest is 20%, but many are near 1%. However, I did not expect a large overall fit, so it is acceptable. The results of the regression, for the most part, disprove my hypothesis that increasing changes in the interest rate differential have a negative effect on the Basis. The β-values are almost all positive, indicating the opposite effect.

I would like to highlight the two currencies that seem to follow my hypothesis. The currencies JPY and CHF both have a negative coefficient for the changes in interest rate differential in the period from 2010 onwards. Throughout the past 20 years, these two currencies have been classic low interest rate currencies. My hypothesis was that the Basis is increasing (negatively) in interest rate differential, and so it makes sense that low interest currencies would show a stronger effect. Low interest currencies are a prime location to fund investment into USD denominated assets, and so the Basis reacts more strongly to changes in the interest rate differential for these currencies. JPY and CHF were also the currencies that exhibited the largest quarter close effects on the weekly deviations both before the financial crisis and after implementation of Basel III.

I continue the analysis with a cross-sectional graph of the average Basis compared to the average foreign interest rate. The below figures show the relationship between the Basis and the foreign interest rate for each currency in the recession years and post-crisis years.

(1) 2007-2009 (2) 2010-2019

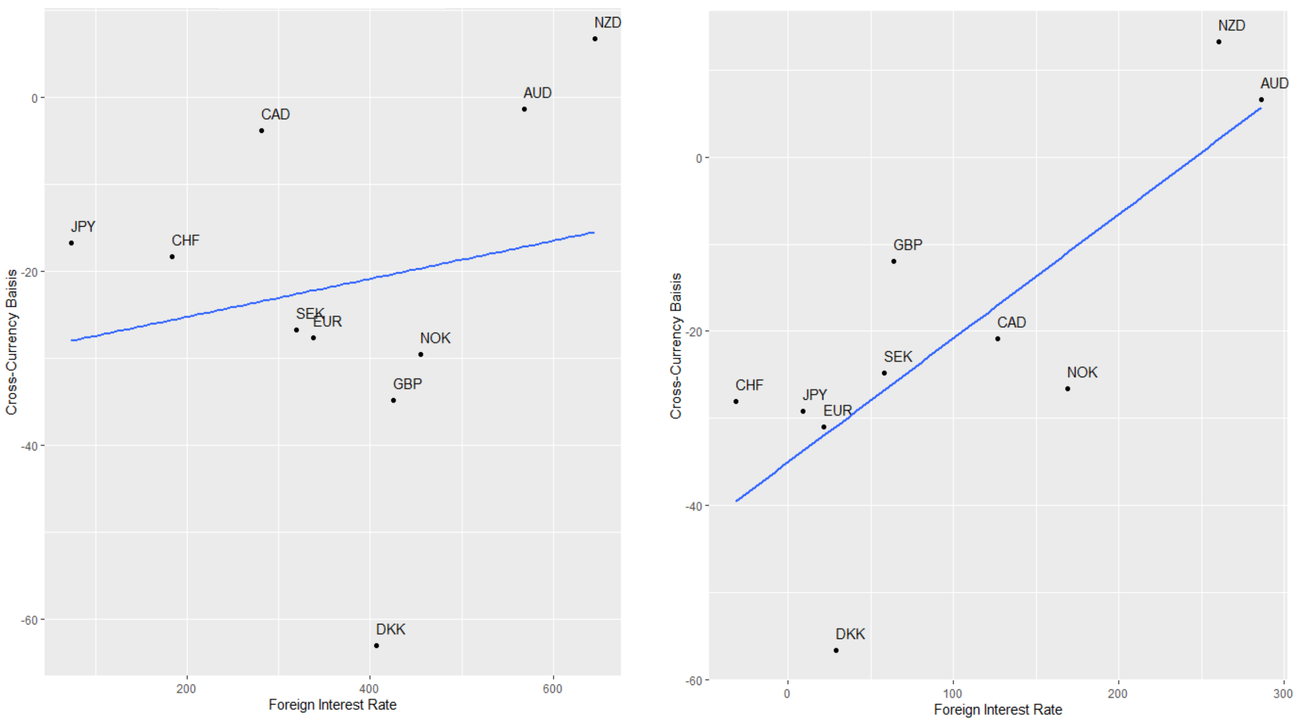

Figure 8: The figure shows the Cross-Currency Basis against the USD relative to the foreign Interest Rate (the currencies shown). For comparison, the average US rate is 290 bps and 80 bps respectively for the two periods.

The second graph shows a strong relationship between the foreign xIBOR and the Basis. The positive slope-coefficient of the fitted line indicates that as the foreign interest increases, so does the Basis. This is in line with my hypothesis; however, it is not an exact match in the sense that a positive interest rate differential $(y^{\$} - y^{f})$ equals a negative basis, but a negative interest rate differential does not necessarily equal a positive basis. The average US LIBOR in the post-crisis years is at 80 bps. Both CAD and NOK have a higher average interest rate than the USD and also have a negative average Basis. The NZD and AUD are the only currencies with a positive mean Basis, and their interest rates are twice as large as the interest rate of the USD.

The first graph in figure 9 and table 5 indicates that my hypothesis is not sufficient to explain the Cross-Currency basis during the financial crisis. In the post-crisis years, the correlation between the Basis and foreign interest rate is 0.78 compared to only 0.19 during the recession. The results for the years from

2010 and onwards, however, conform more closely (though not perfectly) with my hypothesis that the interest rate differential causes investment and hedging imbalances between the USD and the foreign currencies, which influences the deviations from the CIP. Of the currencies that were analysed, it appears that only Japanese Yen and Swiss Francs lend evidence to that hypothesis.

6.4.2.1 Supply and Demand for USD during the financial crisis

Clearly, the above analysis does not fully explain why the deviations were so much larger during the financial crisis as shown in figure 9 and table 5. The correlation between the Basis and foreign interest rate is much smaller during the financial crisis period. I will attempt to explain why the deviations were so high during this period.

First, I will focus briefly on the role of Asset-Backed Commercial Paper (ABCP) in the financial crisis. An ABCP is a financial instrument to cover short term liabilities for corporations or institutions. ABCPs differ from regular Commercial Papers in the sense that they are backed by underlying assets. In theory, this should reduce the riskiness of the papers by providing them with collateral. However, the ABCP's market is now tied to the market of the underlying asset. If large negative disruptions occur in underlying asset, investors may lose faith in the yield and balk at the riskiness of the ABCP. This is precisely what happened during the financial crisis when the subprime mortgages began to collapse. In effect, the ABCP yields increased dramatically to compensate for lost faith, and the total outstanding value dropped by 20% in August 2007 alone (Covitz, Liang, & Suarez, 2009). This severely hampered the short-term financing availability in the US. Another effect was that the banks who had sponsored the ABCPs came under suspicion of being unable to meet their obligations, and therefore the banks began to hoard cash (Covitz, Liang, & Suarez, 2009). This further constrained the supply of funding in the US financial market.

The foreign banks and institutions with US-based assets also began to lose money on said assets. They needed USD to cover their losses and refinance their debt (Linderstrøm, 2013). They were unable to raise money in the US market, as the market was effectively shuttered. The remaining option was to raise money in the native currency and convert it to USD. However, this would require them to hedge their purchases in order to avoid currency risk. This could be done either through FRAs or CCSs. The increased demand and urgency for these products would drive the prices or spreads away from the no arbitrage position.

The extreme liquidity constraints and USD shortage during the financial crisis resulted in foreign based institutions and entities accepting FRAs and CCSs at a significantly lower rate in order to obtain the USD funding that they needed. Therefore, the primary driver during the financial crisis was not necessarily the interest rate differential, but rather the severity of the USD shortage that the financial entities of those countries faced. On the other hand, the liquidity constraint does appear to have a greater impact on currencies with a larger (positive) interest rate differential, as this would lead to a greater need for USD to cover investments. This can be seen in table 1, for example. This explanation also serves to show why it might be difficult for arbitrageurs to take advantage of the large deviations from the CIP. A negative return requires a strategy where one borrows USD, and as explained previously, the short-term USD funding market had functionally ceased operation during the financial crisis. This would significantly hamper the feasibility of this strategy, and thus its implementation.

7 Discussion: Reliability of Analysis

I would like to use the following section to evaluate the validity and consistency of my results in the previous sections. The shortcomings of my data selection, methods, and assumptions will be reviewed. I will go through the sections in a chronological manner and perform the evaluations when necessary. Furthermore, the important validation checks for selected regression models will be revised.

7.1 Returns subject to bid/ask spread

In the 4.2.1 Data section, a description of the bid and ask estimation for the xIBORs was given. As this is an estimation, it should certainly raise some concerns. The method employed, however, was intended to be as objective and unbiased as possible. Furthermore, I had extreme outliers when calculating the interest spread between the bid and ask for the interest rate swaps. The solution to that problem was less objective; I had to choose a way to discern what is or is not an outlier, and decided that spread values are deemed outliers if above 25%. This is a place where my human input was necessary to create a cohesive data set, which unfortunately decreases objectivity.

I encountered a similar problem in the calculations for the returns with equation 5 and 6. I found one instance where the calculation returned a higher return than what was calculated in the Basis (Eq. 4). This should be impossible, as the bid/ask spread should always reduce the return. Again, I attribute this to faulty data from Bloomberg on the bid/ask rates for the FRA. This presents a greater concern for the validity of the analysis. The solution employed was to remove the entire row from the data sheet, since the problem was discovered late in the process. There is no visible result in the mean returns, but it does reduce the maximum returns found. The methodological problem arises because this was done post-analysis as a quick fix for an impossible value. I certainly recognize the bias it introduces. These shortcomings are also the reason why I resort to using the Basis (Eq. 4) in further analysis.

7.2 Credit Risk Regression

In order to estimate the impact of the credit worthiness of the xIBOR panel banks, I had to estimate an average panel bank credit spread. The method used was the simplest, as it was just an average of the spread from the banks available. The simplification of the estimation certainly reduces the accuracy of the calculations. I chose to accept the estimation because the results conformed with previous research. Had the conclusion to the analysis been in contrast to what was found by (Du, Tepper, & Verdelhan, June 2018), it would have warranted a more careful review.

7.3 Day counting

There are two points from separate parts of the analysis to be made here. Firstly, the time period n from equation 3 is a simplification in that it is a fixed value depending on the maturity (e.g. 1 month maturity $n = 1/12$). The method is certainly not biased towards any specific result. Furthermore, I find that the calculations yield usable results which are not affected by the simplification in a discernable manner.

Secondly, the method for calculating $Q.End_t$ for equation 11 is, again, a simplification. The indicator variable indicates whether the start date of the forward falls within seven days of a closing day for the quarter. This ignores contracts that might end on a weekend or bank holiday. Furthermore, it ignores the fact that the final payment of forward agreements is usually made two days after the contract ends unless that date is bank holiday (Linderstrøm, 2013). Due to the difficulties posed by determining and applying all of the relevant bank holidays for all of the different currencies, I opted for a simple but consistent method. The results are not found to be significantly impacted by this choice—the regression analysis gave results consistent with my hypothesis.

7.4 Regression Model Validation

The model validation highlighted here is the regression analysis from equation 11. I find this regression to be the most important for the conclusions of the thesis. The below graphs in figure 10 shows the residuals of the model and allow for evaluation of the linear regression model assumptions. JPY has been chosen as the model due to the fact that the JPY had the most statistically significant model.

<u>Residual plots equation 11 using one-week maturities for JPY</u>

(1) Residuals against time (2) Residuals against $\hat{y}$ (3) probability plot

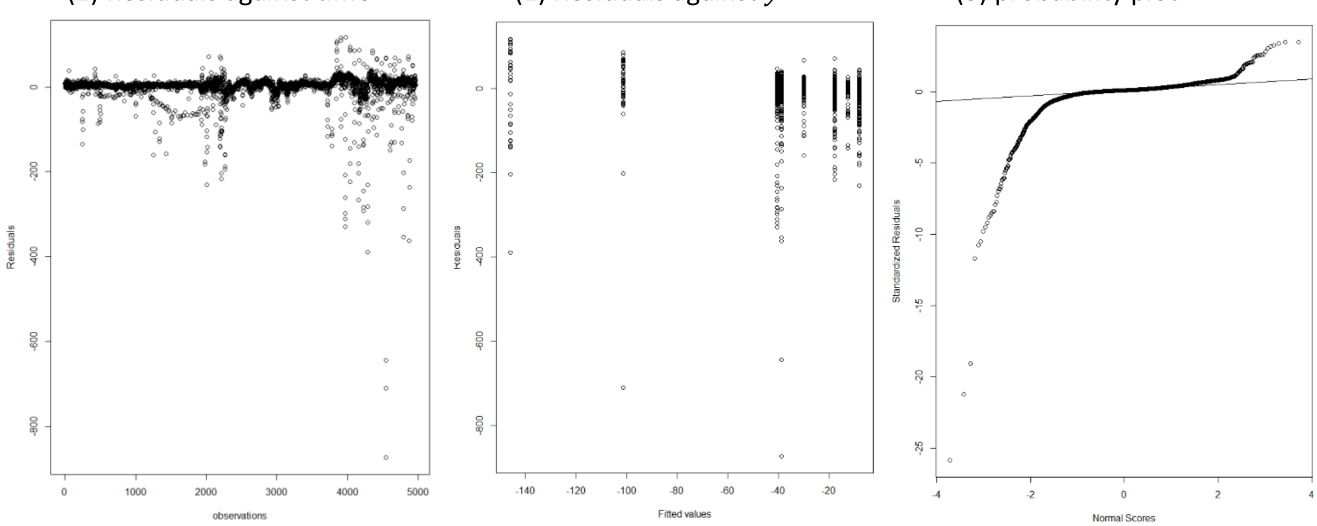

Figure 9: Graphs of the residuals from equation 11. (1) plots the residuals against the observations (time), (2) plots the residuals against the fitted value from the model, and (3) uses the standardized residuals in a probability plot to test the distribution of the residuals.

The first graph shows that it is correct to use a linear regression model; the error terms would not suggest a different model. Furthermore, it allows discussion of whether the error term is independently distributed. A large portion the errors seem to be randomly distributed. However, there seems to be some systemic variation in the residuals, especially around the financial crisis (observation 2000) and within the latest four years. This shows that there is some variation that is not captured by the model.

The second graph is used to check the assumptions that $E[\epsilon_t] = 0$, $Cov(\epsilon_t, \epsilon_t) = 0$, and $var(\ \epsilon_t) = \sigma^2$. Essentially, graph 2 should show that the residuals have an expected value of zero, no systemic errors, and the variance should be constant (heteroskedasticity). It does seem that the errors have a mean mostly around zero; however, the residuals do seem to be negatively skewed. The skewness comes from the model's inability to predict some of the large negative Cross-Currency Basis'. There isn't any particular pattern, but the variance of the residuals does seem to be greater for some fitted values. The absence of constant variance of the error term is not overly important, as I have assumed heteroskedasticity and used appropriate standard errors.

The last graph clearly shows that the residuals are not normally distributed, which violates one of my weaker assumptions and I will not place too much weight on it. The other currencies all follow the points made for JPY. Despite the shortcomings of some of the assumptions, I still believe that some of the most important inferences of the model are possible. For example, it is still possible to infer that the Basis increases dramatically over the quarter close dates.

The regression model from equation 12 follows the same points as the previous model (see appendix I). There seems to be to some unexplained systemic variation around certain time spots; the residuals are not completely independent. There also seems to be no serial correlation between the residuals, and they have a mean of zero with close to constant variation.

The conclusion for this section is up to the reader to infer; whether the analysis still holds water or not. I will make the inference that my assumptions and analysis are robust enough, despite their shortcomings, to inform the overall conclusion of my thesis.

8 Conclusion

This thesis set out to investigate the deviations from the CIP and the reasons that they exist. The returns of an arbitrage strategy subject to bid & ask rates and transaction costs is significant and persistent for eight of the currencies, excluding NZD and AUD. These two currencies exhibit the worst performance with less than 5% viable strategies with a mean return around 1bpt. Furthermore, neither the VIX nor the changes in the credit differential of the panel banks are found to properly explain the deviations from CIP. The analysis concludes that there are arbitrage returns to be earned in excess of any measurable risk premium for most of the currencies. However, it has been shown that there are other risk factors not included in the calculations.

I test two hypotheses in order to explain the deviations from CIP. The first concerns the effects of new banking regulation that increased the disclosure requirements for quarterly reporting. I find that the interaction term between a dummy variable for the last seven days of the quarter and a dummy variable for the date (Jan. 2015) of the implementation of the regulation is highly correlated across all currencies. This leads me to infer that the new banking regulation in the form of Basel III reduces the banks' ability to conduct profitable CIP arbitrage, which in turn increases the CIP deviations.

There is a strong correlation between the Basis and the foreign interest rate after 2010 on a currency-wide analysis. This supports the hypothesis that the Basis is caused by a supply and demand imbalance for forward contracts that results from the interest rate differential. The Basis for the two low interest rate currencies (JPY and CHF) becomes increasingly negative as the interest rate differential increases. However, the other currencies exhibit the opposite effect, which limits how valuable any inference based on these two currencies can possibly be. My conclusion is that the interest rate differential causes some deviations, and that the causation becomes much stronger as the interest rate differential increases.

8.1 Epilogue

In the epilogue, I will discuss two of the significant consequences of deviations from the CIP. Firstly, the most impactful consequence of deviations from the CIP is that it is more expensive for companies to hedge their cash flows in a foreign currency if there is a negative Basis. It should be noted that it is more expensive in relation to what should be the neutral no arbitrage price. The main reason that companies hedge their cash flows is to remove the currency risk, which is achieved with a more expensive contract. A question that could be interesting to examine in future research is whether the deviations significantly reduce companies' desire to invest into certain currencies, and if so, what the effects of this incentive (or lack of incentive) are.

The second significant consequence concerns the ability to earn money. An interesting question, (which I have fielded many times during the development of this thesis,) is whether my friends and family can earn money off of the deviations from the CIP. To answer the question, I make the following quick assumptions: with the current low interest rates, any returns earned on a bank deposit or short-term bond are negated by transaction costs, and it would be too expensive to partner with a US bank to take a loan in USD. These two assumptions leave the only one option for trading on the CIP, which is to invest in the forward premium between DKK and USD. Unfortunately, the forward premium has to be negative if Danes want to earn a positive return, and between USD and DKK the forward premium is almost never negative. Therefore, the answer to the question is; no, you most likely cannot earn money on CIP deviations.

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