Quarter-end Anomalies in Deviations from Covered Interest Parity

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1 Introduction

Interest rate parity is one of the most basic no-arbitrage conditions in financial economics and international finance. Accordingly, a substantial body of research has formed, focusing on the puzzle resulting from deviations from covered interest rate parity, which is closely related but burdened with fewer assumptions about underlying risk profile of economic agents. The aforementioned no-arbitrage condition can easily be envisaged by an U.S. based investor equipped with the ability to observe and trade in domestic and foreign financial markets. Considering short tenure and low risk money market investment opportunities, the investor may seek for a foreign currency with a higher interest rate, borrow U.S. dollars, and then exchange U.S. dollars for the spot rate S_t. Simultaneously, the investor could enter into a forward contract allowing her to exchange the foreign currency back to dollar at the forward rate $F_{t,t+n}$, which is determined at the inception of the trade. Consequently, when assuming no differences in credit risk among the two currencies, and no counter-party risk regarding the forward contract, the investor is able to accrue risk-less profits that do not require her to tie up her own capital at either leg of the trade. This of course, is only the case if FX forward markets fail to incorporate differences in interest via a premium paid upon entering into the forward contract (Wang, 2019). Above mentioned deviations from CIP (Covered Interest Parity), thus do not only imply the violation of CIP itself but also represent a violation of the law of one price (Rime, Schrimpf, & Syrstad, 2017). This stems from the fact that a difference in direct domestic and indirect domestic rate [1] also represent a difference in funding costs among currencies.

Looking at the vast amount of implications and sub-fields of finance and economics that are affected by this puzzle, the theoretical and empirical investigation in this thesis is prefaced by a concise summary of the relevant current literature. The third section, concerning the theory behind the CIP, consists of a derivation of the underlying parity

[1] The indirect domestic rate is the foreign rate converted to the domestic currency either by an FX swap or an FX forward contract.

condition including the definition of the cross-currency basis, which will be denoted in accordance with Du, Tepper, and Verdelhan (2018). Additionally, the theoretical investigation will entail a short theoretical section on transaction costs. The fourth section is supposed to depict the deviations from CIP that were calculated by obtaining the required data from the Bloomberg Professional service. Besides a reconstruction of the CIP deviations similarly to Du et al. (2018), the focus of this empirical work shifts away from the panel of cross-currency basis for available Repo rates for G10 currencies and focuses on three individual time-series instead. This allows a closer examination of the quite heterogeneous cross-currency basis, regarding the magnitude, as well as the variance of the deviations. As in the paper by Du et al. (2018), the difference-in-difference estimator will be applied to test for quarter-end dynamics linked to rising balance sheet costs, which coincide with a change in reporting standards in January 2015. Then, section five offers final conclusive thoughts on the differences in obtained results and existing literature, and their potential causes.

2 Related Literature

The Literature regarding covered interest parity can essentially be split into three different categories, the first being the literature that was published prior to the global financial crisis in 2008. An example for this pre-crisis literature would be Takezawa (1995), who found that negligible deviations from CIP exist when using FX swap contracts to hedge the currency exchange risk. However, he concludes that said deviations were few and far between and limited to the 1980's.

The second wave of research was triggered by the turbulences on financial markets during the global financial crisis. Those papers mostly focus on the effect of dollar funding shortages during the crisis. Baba, Packer, and Nagano (2008) conclude that the turmoil in the money market did not only spill over to the short term FX forward and the mostly longer term FX swap markets but also to the cross-currency basis swap [2] market. This may sound trivial to deviations from CIP, however the dollar funding shortages during the crisis forced financial institutions into FX swap and forward markets and hence caused a severe impairment of liquidity. Consequently, this resulted in deviations from covered interest parity, since the currency market risk in CIP arbitrage is hedged by the same financial instruments and the inflow of demand for currency-market-risk hedging shifted the forward premium away from the differences in interest. Those deviations, however, were not expected to be persistent and hence from the second group of literature, it seems like there was a consensus about deviations being exclusive for the time of the crisis and were expected to return back to normal levels after the financial crisis. This was especially convincing since U.S. dollar swap lines between the Federal Reserve, the European central bank and other major central banks proved to be efficient in alleviating the dollar funding shortage pressure on FX swap and forward markets (Rime et al., 2017). Other examples for literature that contributed to this consensus are papers such as but not limited to Goldberg, Kennedy, and Miu (2011) and Griffoli and Ranaldo (2010).

The third sub-body of literature consists of contributions that seek to explain the persistent deviations from CIP after the crisis, in absence of turbulences on financial markets. Rime et al. (2017) focus their investigation on the challenges that an FX market maker has to face, when balancing customer order flows. According to them, the combination of increased heterogeneity in U.S. dollar funding costs, with a compression of liquidity premia due to quantitative easing, creates the impossibility for a single price to satisfy the conditions of CIP or even the less restrictive assumption of the law of one price[3].

[2]A cross-currency basis swap agreement is a contract involving two parties, which exchange two currencies at the spot rate S_0 in $t = 0$, then the parties exchange floating or fixed interest rates over a previously agreed period of time and usually bound to an index like the Libor. The contract ends with the parties swapping back the principal amount of the contract at $t = 1$ for the original spot rate S_0 (Baba et al., 2008).

[3]The law of one price only calls for equality among funding costs across currencies, meaning that the indirect domestic interest rate is equal to the direct domestic interest rate. CIP, however, requires the agent to go through a so called round-trip, unlike in the law of one price an agent is not only

What they refer to when writing about heterogeneity in direct U.S. dollar funding costs, is the difference in funding costs between top-tier banks which have low direct U.S. dollar funding costs and lower-tier banks which have high direct U.S. dollar funding costs. An FX market maker therefore needs to balance a quote that incentivizes high-tier banks to swap out of the U.S dollar to build the supply for the lower-tier banks which want to swap into the U.S. dollar[4].

In contrast to Rime et al. (2017), Du et al. (2018) and Kohler and Müller (2019) shift their focus away from the place of origin of deviations from CIP and investigate the reason behind economic agents inability to exploit available arbitrage opportunities. Would big banks and high net-worth funds be able to engage in CIP arbitrage, then the resulting demand and supply pressure they would exert on forward and spot rates would eliminate the existing arbitrage opportunities. Accordingly, the above mentioned papers try to identify the restrictions that potential arbitrageurs face. Both papers manage to identify quarter-end increases in deviations from CIP, however with a significant difference in magnitude. Du et al. (2018) report significantly higher deviations than Kohler and Müller (2019). Said effects are almost entirely attributed to non-risk-weighted capital requirements, which are enforced by observing quarter-end balance sheet reports. Those are of particular relevance because CIP arbitrage trades exhibit minimal market risk. Even though both papers are quite similar in the methods applied, they vary in one important aspect which is the re-usability of collateral on both sides of the trade. In the case of Du et al. (2018), the rates used to replicate CIP arbitrage opportunities are General Collateral Repurchase Agreement Rates, which are quoted by the currencies corresponding central bank. Accordingly the basket of accepted collateral is not identical on the borrowing and lending side of the trade. Essentially, this has two effects. Firstly, it makes the CIP trade asymmetrical and hence forces the introduction of an assumption. Arbitrageurs that are not able to re-use the collateral obtained from the

interested in the cheapest funding or borrowing rate available but has to borrow and lend in different currencies as well as cover the currency exchange risk.

[4] A sound description of order flow balancing can be found in Evans and Lyons (2002).

reverse-repo contract that they entered by lending fully collateralized, have to either purchase the required collateral for the repo contract that the arbitrageur is engaged in on the borrowing side or have the required assets readily available on the balance sheet. Secondly, when considering the purchase of collateral to satisfy repo basket requirements, one is coerced to assume an equivalent level of quality in the purchased securities and the assets obtained from the reverse-repo contract, otherwise the trade exhibits difference in risk for the two parties involved and hence could cause a risk premium paid to the low quality asset holder to be misidentified as deviations from CIP. Kohler and Müller (2019), found an elegant solution to this problem by using try-party settled repurchase agreement rates provided by a specialized Swiss exchange operated by the SIX Repo AG. In contrast to the GC repo rates used by Du et al. (2018), the SIX repo rates are derived from cross-currency repos. Those contracts enable arbitrageurs to use collateral denominated in a different currency which they lent or borrowed in and in turn allows the re-use of the collateral obtained from a reverse-repo to borrow via a repo contract. Even though, this does make the arbitrage trade symmetric and also removes the potential funding premium that is often associated with the U.S. dollar (Kohler & Müller, 2019), it also comes at a cost. The collateral basket created by the third party that settles the repo contracts, in the case of Kohler and Müller (2019) the SIX Repo AG, is assumed to be able to create a basket of equally risk bearing assets.

The contribution of this thesis can be attributed to the third wave of literature concerning CIP. The calculation of the deviations from CIP are calculated using the same approach as Du et al. (2018), and the subsequent investigation of quarter-end dynamics are most fittingly interpreted as an in part replication and extension of the work by Du et al. (2018).

3 Theory

This section consists of a derivation of the CIP condition and a definition of the cross-currency basis, followed by a discussion on transaction costs and corresponding assumptions.

3.1 Covered Interest Parity

Covered Interest Parity represents a no-arbitrage condition that calls for the equality of the differences in interest rates and the forward premium, among two currencies. Deviations from CIP therefore imply, existing and potentially exploitable risk-free arbitrage opportunities that do not require capital.

$$(1+r_h)S_0 = F_{0,1}(1+r_f) \tag{3.1}$$

$$1+r_h = \frac{F_{0,1}}{S_0}(1+r_f) \tag{3.2}$$

$$\frac{1+r_h}{1+r_f} - 1 = \frac{F_{0,1}}{S_0} - 1 \tag{3.3}$$

$$\frac{1+r_h}{1+r_f} - \frac{1+r_f}{1+r_f} = \frac{F_{0,1}}{S_0} - \frac{S_0}{S_0} \tag{3.4}$$

$$\frac{r_h - r_f}{1+r_f} = \frac{F_{0,1} - S_0}{S_0} \tag{3.5}$$

$$r_h - r_f \approx \frac{F_{0,1} - S_0}{S_0} \tag{3.6}$$

Equation (3.1) represents what is referred to as the standard one-year textbook CIP arbitrage. An investor may borrow the desired amount of domestic currency and pay the interest r_h. The obtained money can then be exchanged for a currency which offers a higher interest rate r_f, for the spot rate S_0. The spot rate in this case is quoted indirectly, meaning that it is expressed as the amount of foreign currency obtainable for one unit of domestic currency. After having exchanged the money into the foreign currency, the investor may lend the money for r_f and simultaneously enter into a forward

contract $F_{0,1}$. Assuming default-risk symmetry[5] in interest rates and no counter-party risk associated with the forward contract, the two legs of the trade should be identical and hence should not allow an investor to accrue profits.
Using basic algebra to rearrange the condition one can obtain equation (3.5), which equates the forward premium to the differences in interest rates among the two currencies, with an adjustment by dividing the difference in interest rates by one plus the foreign interest rate. This adjustment will disappear when deriving the cross-currency basis for continuously compounded interest. For now, one may accept the approximation (3.6) as sufficiently accurate for small interest rates. The approximation gives a good basis for an intuitive interpretation. A forward premium suggests a situation, in which the future price of a currency is expected to increase relative to the current price. The exact opposite is called a forward discount and suggests a decrease in future price. Consequently, in order for CIP to hold the forward premium/discount has to equal the difference in interest rates (Wang, 2019).

3.2 Cross-Currency Basis

In accordance with Du et al. (2018), the continuously compound cross-currency basis will be defined as additional accruable interest and will be denoted as $x_{t,t+n}$.

$$e^{ny^{\$}_{t,t+n}} = e^{ny_{t,t+n}+nx_{t,t+n}} \frac{S_t}{F_{t,t+n}} \tag{3.7}$$

$$nx_{t,t+n} + ny_{t,t+n} - ny^{\$}_{t,t+n} = ln(F_{t,t+n}) - ln(S_t) \tag{3.8}$$

$$nx_{t,t+n} + ny_{t,t+n} - ny^{\$}_{t,t+n} = f_{t,t+n} - s_t \tag{3.9}$$

$$x_{t,t+n} + y_{t,t+n} - y^{\$}_{t,t+n} = \frac{1}{n}(f_{t,t+n} - s_t) \tag{3.10}$$

$$x_{t,t+n} \equiv y^{\$}_{t,t+n} - (y_{t,t+n} - \epsilon_{t,t+n}) \tag{3.11}$$

[5] Or negligible default risk.

Equation (3.7) represents the standard CIP with two differences to the previous definition. Firstly, in order to achieve greater accuracy the compounding frequency is assumed to be continuous and secondly the domestic currency is changed to dollar since the U.S. dollar is the currency that will be considered the domestic currency throughout this thesis. Accordingly, $y^{\$}_{t,t+n}$ denotes the U.S. based interest rate and $y_{t,t+n}$ represents the foreign interest rate, which in the case of this paper will either be the pound sterling, the Japanese yen or the euro. In contrast to the previous derivation, the definition of the forward premium is obtained as a difference in natural logarithm of the forward and spot rate and then annualized. It is represented by $\epsilon_{t,t+n}$, in the final equation (3.11). The remaining notational elements share their interpretation with the definitions in the prior subsection, with the slight difference that they are now generalized for varying time-spans and not specific for one year. The corresponding years of the trade are therefore denoted as n.

Even though quite similar in approach, the obtained final definition allows for an additional interpretation and for the explanation of two frequently used terms in the literature. Should the basis be zero and therefore no exploitable arbitrage opportunities available, one can rearrange the condition as follows:

$$y^{\$}_{t,t+n} = y_{t,t+n} - \epsilon_{t,t+n} \tag{3.12}$$

$$y^{\$,direct}_{t,t+n} = y^{\$,synthetic}_{t,t+n}, \tag{3.13}$$

which essentially represents the equality of direct domestic interest rate $y^{\$}_{t,t+n}$ and the synthetic[6] domestic interest rate $y^{\$,synthetic}_{t,t+n}$. The latter can be obtained using FX forward or swap contracts to convert the interest rate to a dollar equivalent. From (3.12) follows that if CIP is not violated one can automatically tell that the slightly less restrictive condition of the law of one price is simultaneously fulfilled as mentioned in section 1.

[6]Besides synthetic, this foreign interest rate swapped into the domestic currency is also sometimes referred to as implied or indirect domestic interest rate.

3.2.1 Transaction Costs in Theory

Since demand and supply in financial markets are rarely synchronous, almost every trade needs to be intermediated by a third party which is often referred to as market maker. Said intermediary faces major challenges when balancing order flows. Firstly, there is an inherent information asymmetry that is associated with supplying liquidity. A market maker that deals in multiple markets and cannot apply the required amount of resources to obtain the maximum amount of possible information, will on average lose money when dealing with better informed counter-parties. Additionally, as mentioned above, buyers and sellers rarely appear simultaneously to be matched at the same time. Hence, market makers need to be compensated for holding assets for an unknown amount of time, which not only binds capital but also causes an inventory that is not optimal in terms of diversifying risk (Bessembinder & Venkataraman, 2009).

Consequently, market makers recover costs by purchasing at a lower price called "bid" and offer at a higher price called "ask". Because CIP requires no owned capital and entails a full circle of buying and selling in different currencies, it is also referred to as round-trip arbitrage. Meaning that an investor may borrow U.S. dollars for $y^{\$,bid}_{t,t+n}$ and then exchange the obtained funds for S^{ask}_t. Foreign currency in hand, the investor is then able to lend for $y^{ask}_{t,t+n}$ and simultaneously enter into a forward contract $F^{bid}_{t,t+n}$. The exact opposite strategy can be constructed by reversing the trade and swapping "bid" and "ask" for each leg of the trade. This results in two inequalities that need to hold in order for a profitable arbitrage opportunity to exist:

$$\frac{F^{bid}_{t,t+n}}{S^{ask}_t} \leq \frac{e^{ny^{ask}_{t,t+n}}}{e^{ny^{\$,bid}_{t,t+n}}} \tag{3.14}$$

$$\frac{F^{ask}_{t,t+n}}{S^{bid}_t} \geq \frac{e^{ny^{bid}_{t,t+n}}}{e^{ny^{\$,ask}_{t,t+n}}}, \tag{3.15}$$

where (3.14) corresponds to the arbitrage trade explained above and (3.15) represents the reversed trade (Bekaert & Hodrick, 2017; Du et al., 2018).

4 Empirical Investigation

This section will be initiated with a description of the hypothesis of this paper. Following that, a brief summary of the available interest rates most fitting to calculate deviations from CIP is included. As well as that, transaction costs will be re-visited, differently to the previous subsection on transaction costs, the focus now lies on the calculation of CIP and the difficulties that are inherent in correctly accounting for transaction costs. The remaining subsections are used to describe the data, explain the methods and check if the required assumptions are fulfilled. In the end, the final model and the corresponding results will be presented.

4.1 Hypothesis

Prior to the global financial crisis in 2008, CIP held quite consistently, with a few minor exceptions (Takezawa, 1995). One important reason was that banks and big funds were able to enforce the CIP condition via arbitrage trading. Following the crisis, a wide variety of regulations were established which restrict banks in their every-day business. Said restrictions can be split into two main categories, risk weighted and non-risk weighted capital requirements. Risk weighted capital requirements under the Basel III framework are of little importance for an on balance sheet CIP trade. The reason behind this is that at the center of risk assessment for a regular CIP trade is the 99% value at risk (VaR) measurement, which is based on a ten day holding period for the weekly trade relevant for this paper (Basel Comitee on Banking Supervision, 2014; European Comission, 2015). Consequently, since CIP arbitrage trades only exhibit cash flows that are determined at the inception of the trade $t = 0$, VaR calculations are rendered irrelevant (Du et al., 2018). This, of course, is only valid if one assumes no credit default risk associated with lending and no counter-party risk concerning the forward contract.

Non-risk weighted capital requirements, however, are of major importance when considering banks' balance sheet costs when engaging in risk-less arbitrage. Even though CIP arbitrage entails negligible market risk, it still requires balance sheet space. Consequently, regulation that requires banks to hold a minimum amount of capital against on balance sheet assets, probably has an effect on banks' willingness to provide liquidity as market maker or engage in arbitrage themselves[7]. This relationship is one of the main hypotheses of Du et al. (2018) and will in part be replicated in this paper with differences that will be explained in later subsections. To be exact, Du et al. (2018) test for quarter-end dynamics caused by the "European Leverage Ratio Delegation Act" which was implemented in January of 2015 (Basel Comitee on Banking Supervision, 2014; European Comission, 2015).

This piece of legislation calls for mandatory quarter-end reports of banks' balance sheets. In the case of EU based banks, the newly passed act coerces them to report a snapshot of their balance sheet on the last day of each quarter. Differently, U.S. banks have to report the average of the month ends, also at the end of each quarter. This imaginably could result in EU banks preparing their balance sheets for reporting dates which is also referred to as "window-dressing". Consequently, banks that usually engage in CIP arbitrage might abandon arbitrage trades that cross quarter-end reporting dates and would have to appear on the balance sheet. In contrast, U.S. banks who already have information on the previous month-ends might realise that they need to either decrease the amount of on balance sheet assets and hence reduce their arbitrage activities or they might realize the exact opposite and increase balance sheet exposure towards quarter ends. Independently from the direction in which U.S. banks might be pushed to either increase or decrease arbitrage activity, there is a clear implication for EU based banks. Accordingly, the hypothesis for the one-week CIP arbitrage is:

[7] Fleckenstein and Longstaff (2018) provide interesting insights in banks behaviour, when facing increased balance sheet costs.

Hypothesis 1 *One-week, GC Repo rate based CIP arbitrage trades between 01/01/2013 and 07/01/2017 that cross quarter-end reporting dates after the implementation of the "European Leverage Ratio Delegation Act" exhibit larger deviations from CIP than quarter-end crossing CIP trades before the implementation of the above mentioned reporting standard.*

4.2 Interest Rates and Residual Risk

When calculating the cross-currency basis, one is faced with a major question. Is it possible to create a CIP arbitrage trade that is truly risk-free or at least symmetric in risk over both legs of the trade? Firstly, one may realize that two above mentioned statements are the same regarding the desired outcome, however, only concerning the interest rate. Should the lending side exhibit default risk but exactly identical to the risk associated with the borrowing side, the compensation that an arbitrageur would get for the increased default risk would be perfectly balanced by the risk that she herself defaults on her borrowed funds. Although quite interesting in theory, assuming that this perfectly fitting offset will be given over a prolonged period of time is nonsensical. As a result, it is much more feasible to create a CIP arbitrage trade that exhibits the least amount of risk at each leg of the trade, to the point where it can be declared risk-free. Following that logic, let the first investigated aspect of the CIP trade be the interest rate. Most of the literature, especially textbooks, rely on Libor[8] rates to calculate CIP arbitrage trades. Generally, there seem to be a variety of reasons why especially early research like Takezawa (1995) used Libor rates. Firstly, Libor rates are easily accessible and available for almost every currency. Additionally, Libor rates with their general definition avoid barriers like domestic interest rate regulations, tax treatments and reserve regulations. At the same time, however, using Libor rates does not allow for a realistic modeling of exploitable CIP arbitrage opportunities.

[8] "Libor" stands for London Interbank Offered Rate.

The root of the problem with Libor rates lies in the procedure that is applied to calculate them. Since the rate is supposed to reflect the average rate at which banks borrow unsecured funds from each other, it is most easily obtained by constructing a panel of the systematically most important banks and then calculated as truncated average of borrowing costs via reported rates. At the time of introduction of the Libor in 1986, this was a sound procedure that had no inherent flaws, simply due to the fact that banks had no incentive to miss-report their borrowing costs. However, since 1986 the Libor has established itself, not only as an important proxy for borrowing costs but also as an index for loans and swaps, as well as an indicator for the risk and health associated with the reporting banks of a panel.

Consequently, banks in recent times have a variety of reasons to report rates that deviate from their actual funding costs. Snider and Youle (2010) provide two reasons why banks' borrowing costs may not be reflected by the Libor. Firstly, they show that banks' borrowing costs and the associated risk are only very weakly correlated with other proxies for banks' borrowing costs or riskiness, one excellent example is derived from the price of default insurance. Additionally, they make use of the fact that many of the 16 reporting banks issue quotes in different currencies. One may therefore assume that the default risk associated with a bank in two different currencies should be identical. Snider and Youle (2010) show that banks do in fact issue deviating quotes across different currencies. The authors suspect that such miss-quotings are based on a bank's portfolio and the resulting benefits from quoting higher or lower borrowing costs.

After establishing that Libor rates are most likely not a good measure for banks' borrowing costs, there are a variety of different other possible rates to choose from. However, since this paper is limited to one-week CIP calculations most potential financial instruments fall flat. Therefore, as pointed out in section 1 on page 2, this paper will make use of General Collateral Repurchase Agreements to replicate historical CIP deviations. A GC Repo contract is quite similar to a normal loan with the difference that it is fully collateralized, meaning that the money received by the borrower is at the same time exchanged for previously agreed assets that are agreed to be bought back at the settlement date of the contract. The same contract from the perspective of the cash lender and collateral receiver is called a reverse-Repo. Even though, Repo contracts do not represent banks' borrowing costs but rather their cost to exchange high quality assets for liquidity, one may assume that sufficiently large banks that are interested in engaging in CIP arbitrage may use available assets to obtain funding at GC REPO rates. Especially since mentioned assets are bought back at the end of the short term Repo contract (Baklanova, Copeland, & McCaughrin, 2015).

The remaining risk, that has not been discussed so far, is the potential counter-party risk from the forward contract. Considering the high collateralization via variation margins[9] in cash, which are equal to the market-to-market value of the forward, one may declare the resulting risk as negligible (Du et al., 2018).

4.3 Data, CIP Calculation and Descriptive Statistics

The entirety of the data, the GC Repo rates, the spot rates and the forward rates were obtained from the Bloomberg professional service. Bloomberg quotes forward contracts as forward points, outright forward rates can then be calculated by scaling the forward points according to the decimals of the spot rate and then adding the forward points to the spot rate. The remaining data was fed into the calculations as obtained from Bloomberg[10].

[9]Information on margin requirements can be found in the Credit Support Annex of the International Swap and Derivatives Association (International Swaps and Derivatives Associaton, Inc., 1995).

[10]"***" representing the country tag JPY, EUR and GBP respectively. Daily spot rates from Bloomberg can be found via the ticker "USD*** CURNCY". One-week forward points can be found at "***1W CURNCY" and one-week GC Repo contracts are obtainable via "JYRP1Z CURNCY" for the Japanese yen, "DMRGCG1Z CURNCY" for the euro, "BPRP1Z CURNCY" for the British pound and "USRGCY1Z CURNCY" for the U.S. dollar.

4.3.1 Transaction Costs when Calculating the CCY-Basis

The one-week, GC Repo cross-currency basis is calculated using equation (3.11) with the slight difference that transaction costs are now included. Depending on the day-count convention[11] of each currency the variable $DayC$ is equal to 360 in the case of the Japanese yen and the British pound and equal to 365 in the case of the euro. Since the transaction costs are also dependent on the currencies lending or borrowing side, the resulting problem is circular. Meaning that one needs to know if the basis is negative or positive in order to correctly choose bid or ask rates for each transaction of the trade. This can be more easily envisaged when recalling the original options of an investor. She can borrow for USD^{ask} exchange for S_0^{bid}, enter a forward contract $F_{0,1w}^{ask}$ and then, assuming GBP as an example, lend for GBP^{bid}, which is represented by equation (4.1). Alternatively, the reversed trade just results in a swap in bid and ask in each leg of the trade and is represented by (4.2).

$$x_{0,1w} = y_{0,1w}^{\$,ask} - (y_{0,1w}^{bid} - \frac{DayC}{7}(f_{0,1w}^{ask} - s_0^{bid})) \tag{4.1}$$

$$x_{0,1w} = y_{0,1w}^{\$,bid} - (y_{0,1w}^{ask} - \frac{DayC}{7}(f_{0,1w}^{bid} - s_0^{ask})) \tag{4.2}$$

This, unfortunately, results in the circular problem mentioned above. It is impossible to decide which trades to calculate without knowing if the basis will be negative or positive and at the same time, the basis cannot be calculated correctly without taking transaction costs into account. Consequently, as in Du et al. (2018) and Kohler and Müller (2019) the basis will be calculated using the midpoint of each step of the arbitrage strategy. This imaginably results in a basis whose absolute value is greater than in reality. However, one can be assured that the magnitude of the basis calculated is far from being eliminated by transaction bid-ask spreads (Du et al., 2018) for the vast majority of the trades. To

[11] The day-count convention is the system applied when calculating accrued interest over a period of time that is less than a full coupon period long. The U.S. dollar and the Euro are both part of the ACT/360 convention, whereas the Japanese yen and the British pound are part of the ACT/365 convention. Where ACT stands for actual and represents actual days.

mitigate this inaccuracy this paper will provide descriptive statistics on the profitability of CIP arbitrage in presence of transaction costs. When only reporting the profitability, one also has to ensure that transaction costs do not exhibit similar quarter-end increases as suspected in the cross-currency basis. Otherwise, quarter-end increases in transaction costs that are not accounted for could be mistaken for deviations from CIP. This potential increase in transaction costs at quarter-ends is especially relevant for the forward bid-ask spread, since banks also take positions as counter-parties in such contracts. In order to make sure that forward contract transaction costs are not a driver in quarter-end deviations, a similar difference-in-difference approach will be applied for the currencies time-series that exhibit the suspected quarter-end effects in the ccy-basis. The equation that is used for the calculation of the ccy-basis is therefore:

$$x_{0,1w} = y_{0,1w}^{\$,qmid} - (y_{0,1w}^{qmid} - \frac{DayC}{7}(f_{0,1w}^{qmid} - s_0^{qmid})). \tag{4.3}$$

This expression does not only offer a way of calibrating the sign and the profitability of CIP deviations, additionally, one can envisage an imaginary world in which every market participating agent only uses limit orders[12] to purchase and sell financial instruments. It follows that, when imagining a market where limit orders on the demand and supply side offer enough liquidity, there is no need for a third party intermediating trades. In this scenario one might beg the question what the “true” price of an financial instrument in that market would be. The simple answer, which is widely agreed on in the literature, is that the price that most accurately represents the value of a security is the midpoint and fittingly that is the price at which limit orders of supply and demand would intersect (Bessembinder & Venkataraman, 2009).

[12] A Limit order is a way of selling or purchasing assets, in which a market participating agent agrees to sell or buy for pre-set price (or more favourable for the trader) and time-span.

4.3.2 Description of the CCY-Basis

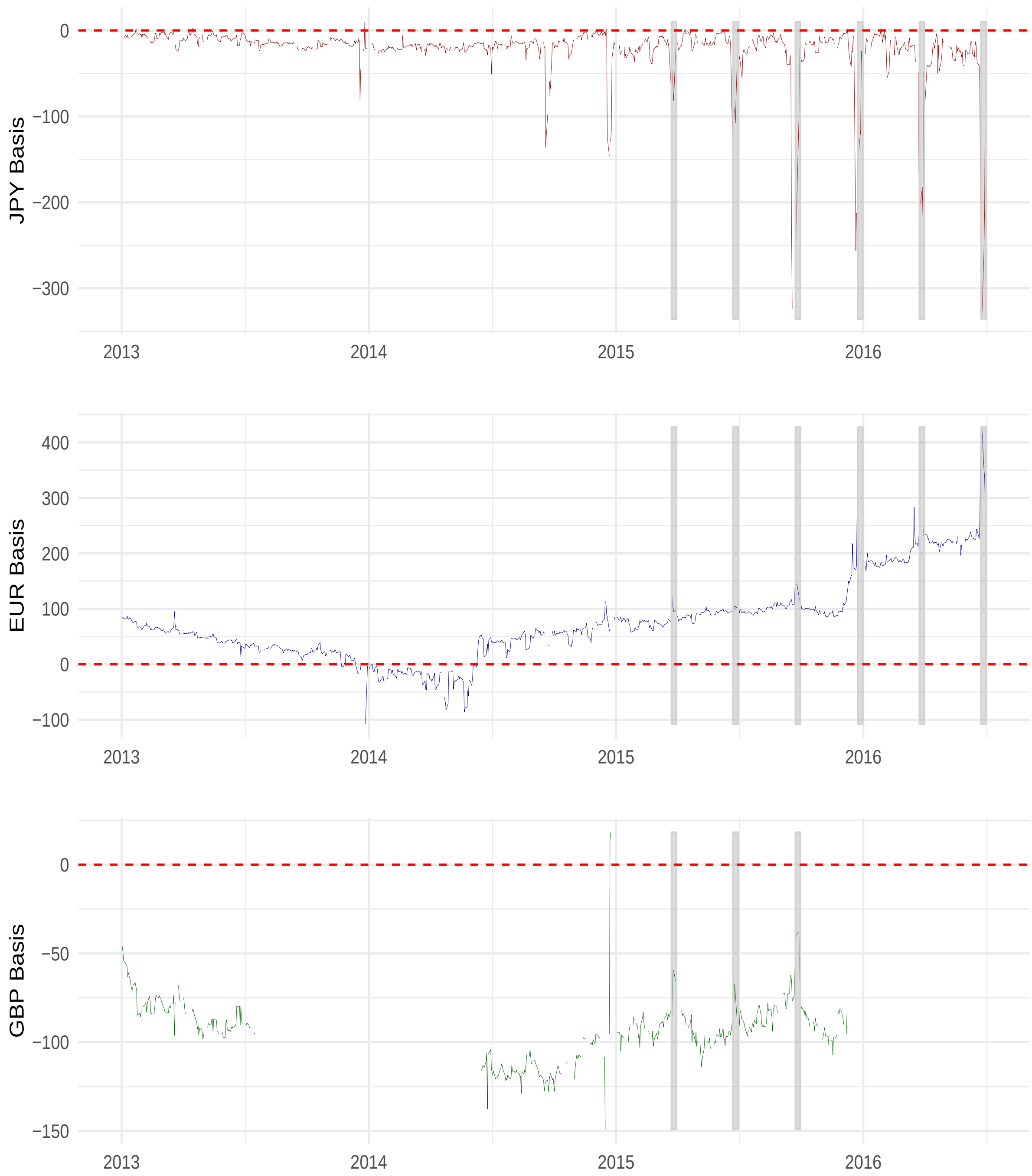

Figure 1: Cross-Currency Basis

Table 1: Cross-Currency Basis Summary Table

Statistic	N	Mean	St. Dev.	Min	Max	NA	% Profitable
JPY	856	−22.5	34.6	−335.6	9.7	58	89 %
EUR	874	75.3	74.2	−107.7	427.2	40	77 %
GBP	450	−92.4	18.1	−149.1	18.1	464	81 %

Figure 1 and table 1[13] offer a visual representation as well as the most important descriptive statistics for the cross-currency basis. The repo-basis for the Japanese yen is negative for 98.5% of the trades examined in the period between 01/01/2013 and 07/01/2016. Compared to its mean, the repo-basis exhibits the highest standard deviation and visually, as can be seen in figure 1, seems to display strong absolute increases for CIP trades crossing quarter-end reporting dates. Besides, it is important to mention that the time-series of the JPY-Basis offers exploitable arbitrage opportunities 89% of the time, when incorporating all round-trip transaction costs. Also relevant is that, even though Du et al. (2018) obtained their GC Repo mid-rates directly from the Japanese National Bank, the results in terms of sign and magnitude of the repo-basis are very similar.

For the euro-basis the standard deviation of the basis is a lot smaller compared to its mean, additionally the quarter-end effects are not as visually recognizable as in the case of the yen. Differently to Du et al. (2018), the basis is positive for 86.49% of observed one-week trades. The deviations from the reported results in Du et al. (2018) are quite significant since they report a mostly negative basis for the euro. This difference in reported results, is most likely caused by a difference in raw data. Du et al. (2018) obtain their U.S. GC Repo rates from the Thomson Reuters Tick History database. Ad-

[13]This table was created using the R package “stargazer” (Hlavac, 2018).

ditionally, they mention that bid-ask spreads were not available for the euro which is not the case when downloading the corresponding time-series from Bloomberg. This might elude to the fact that Du et al. (2018) had access to a completely different time-series of Repo rates that may have offered better data availability[14] but only for mid-rates.

The repo-basis for the GBP, interestingly offers the most consistently negative basis with the smallest variance compared to the absolute of the mean. Unfortunately, the time-series for the required time-span misses more than half of the potentially observable CIP trades. This will be further discussed in subsection 4.4 on the next page, but one may imagine that this will render most statistical analysis meaningless. Last, when observing the three different basis there is one remaining interesting observation to be made, when looking at the GC Repo mid-rates.

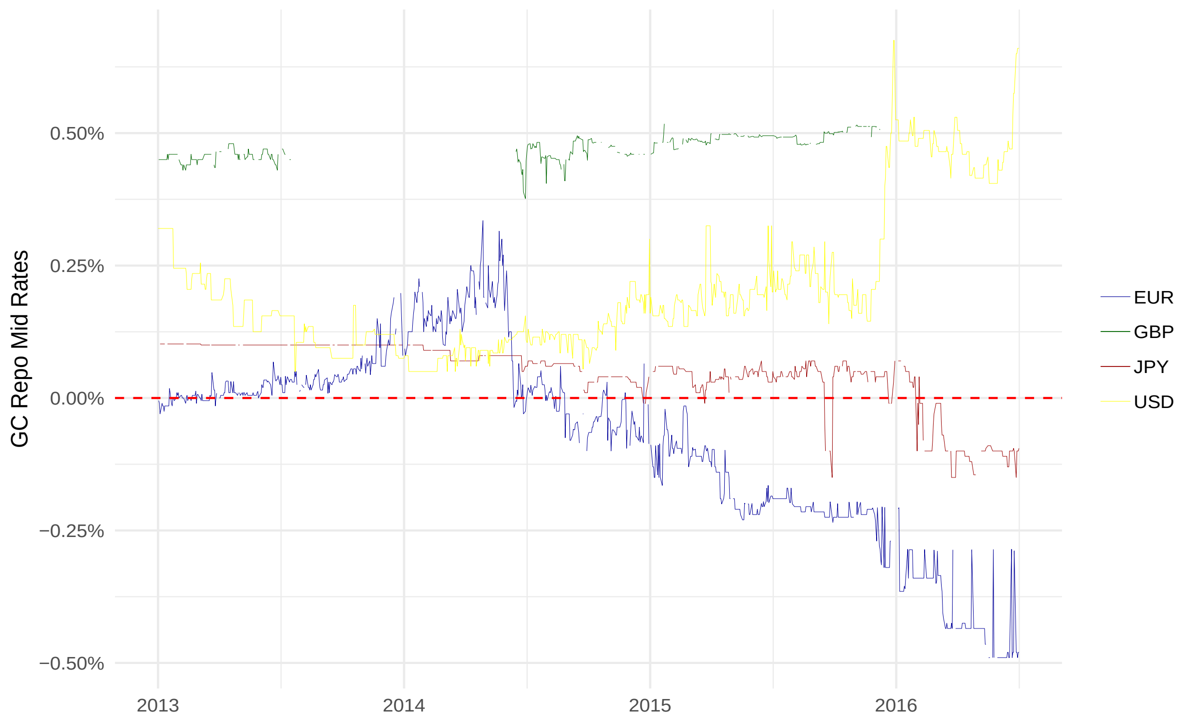

Figure 2: GC Repo Mid Rates

[14]Fewer missing values.

For the pound sterling and the euro, the basis is positive for time-spans in which the GC Repo rate is higher in the two foreign currencies rate when compared to the U.S. dollar. Meaning that when recalling the definition of the basis for mid-rates (4.3), an investor would borrow in the lower interest rate currency and lend in the higher interest rate currency, which intuitively makes sense. However, in the case of the Japanese yen, one can observe that the yen repo rate is lower than the U.S. repo-rate almost for the entire time-series. At the same time, the basis is negative, implying that an investor may borrow U.S. dollars and lend in yen. It follows that unintuitively, an investor may borrow in the higher interest country and lend in the lower interest rate country, while hedging currency risk (Du et al., 2018).

4.4 Methods, Model and Robustness

4.4.1 Conceptual Assumptions

As stated in the hypothesis 1 on page 13 the main purpose of this work is to test whether one-week CIP arbitrage trades which cross quarter end reporting dates after 2015 exhibit larger CIP deviations than weekly trades that do not intersect with quarter end reporting dates.

This difference between the explained CIP trades can be organized into groups, in order to then apply the DD (difference-in-difference) estimator. Normally the mentioned estimator is based on a quasi-experimental design and is used to test the effects of an intervention or treatment, by comparing two groups over a period of time. An excellent example of a standard approach of the DD estimation is Card and Krueger (1993). The authors examine the effects of the introduction of a minimum wage law on employment. In their case, the estimator requires a panel, since they require two different time series. One state that introduces the minimum wage at a known point in time and one that does not. Additionally, one also needs to assume that, had the introduction of the minimum wage never happened, the two states' employment characteristics would have developed in a similar fashion. Accordingly, now that one state did in fact pass a minimum wage law, the differences in employment characteristics can be attributed to the minimum wage in one of the two states. This assumption is widely considered to be the conceptually most important one and is also often referred to as the "parallel paths" assumption (Ryan, Burgess Jr., & Dimick, 2015). Applying the previously explained concept to time-series based DD estimation used in this thesis, it quickly becomes apparent that this assumption is a lot more likely to be fulfilled. Instead of assuming parallel development of two completely separate entities, one only needs to assume that had the "European Leverage Ratio Delegation Act" not been passed, then quarter-end crossing CIP trades would have exhibited no differences in mean, when compared to non-quarter-end crossing CIP trades after 2015.

Besides the most prominent assumption of "parallel paths", there is one additional assumption that is often neglected. It is usually referred to as "exchangeability". In the case of the DD estimation in this paper it can be envisaged as, had the treatment been on any other date besides quarter-ends, would the effect have been the same. When observing figure 1 on page 18 one may conclude that quarter-ends exhibit no isolated characteristics different to the remaining dates previous to 2015. However, with one exception in the case of the Japanese yen for which the quarter-end anomalies seem to start two quarter-ends prior to the introduction of the new reporting standard. This may have been due to banks internally preparing for the incoming change in regulation. As this is not consistent for the time period prior to 2015 the assumption is not violated, in fact the absolute increase of deviations on quarter ends will bias the estimates post 2015 to appear smaller than they would have been, in comparison to pre 2015, had those two isolated quarter effects not existed.

4.4.2 Model

The DD model for the three individual time-series has five components. The variables $Post15$ and $QendW_t$ are equal to one for the basis after 2015 and for quarter-ends respectively and zero otherwise. It follows, that the different estimates represent the means for different groups of ccy-basis pre and post 15. The intercept α_0 represents the mean of the ccy-basis for observations previously to 2015 and for trades that do not cross quarter ends. A similar interpretation but for different groups offer β_1 and β_2, where the former represents the change in mean for observations not at quarter ends but after 2015 and the latter displays the difference in mean between trades that cross quarter ends and those that do not, prior to 2015. The arguably most important estimate of the DD estimation is the interaction term γ_1 which is a direct measure of the difference-in-difference of the trades. For additional intuition (4.5) displays a rewritten form of the estimate obtained from the regression. The estimate can be rewritten as the difference between the differences that are obtained over time and over groups (Wooldridge, 2012).

$$x_{1w,t} = \alpha_0 + \beta_1 Post15_t + \beta_2 QendW_t + \gamma_1 QendW_t \times Post15_t + \epsilon_t \tag{4.4}$$

$$\hat{\gamma}_1 = (\bar{x}_{Post15,Qend} - \bar{x}_{Post15,NotQend}) - (\bar{x}_{Pre15,Qend} - \bar{x}_{Pre15,NotQend}) \tag{4.5}$$

4.5 Results

Table 2: Regression Output

	Dependent variable:					
	JPY	JPY	EUR	EUR	FWD JPY	FWD JPY
	OLS	*Newey West*	*OLS*	*Newey West*	*OLS*	*Newey West*
	(1)	(2)	(3)	(4)	(5)	(6)
$QendW_t$	-11.840^{**}	-11.840^{**}	-8.090	-8.090	0.00450^{**}	0.00450
	(4.665)	(5.883)	(8.706)	(13.438)	(0.0014)	(0.0031)
$Post15_t$	-7.531^{***}	-7.531^{**}	102.796^{***}	102.796^{***}	0.000871	0.000871
	(2.092)	(3.132)	(3.577)	(22.035)	(0.00063)	(0.00066)
$QendW_t \times Post15_t$	-79.983^{***}	-79.983^{***}	66.066^{***}	66.066	0.0058^{**}	0.0058
	(6.989)	(25.581)	(12.835)	(56.454)	(0.0021)	(0.0050)
Constant	-15.011^{***}	-15.011^{***}	29.125^{***}	29.125^{***}	0.014^{***}	0.014^{***}
	(1.367)	(1.188)	(2.346)	(11.154)	(0.00041)	(0.00045)
Observations	856	856	874	874	856	856
R^2	0.305		0.542		0.113	
Adjusted R^2	0.303		0.540		0.107	
Note:						*p<0.1; **p<0.05; ***p<0.01

Table 2[15] offers the regression results obtained from the model displayed in the previous subsection, for the sample period between 01/01/2013 and 07/01/2016. The DD estimate is fit twice for each currency with the standard OLS variance covariance matrix and also with a heteroskedasticity and serial correlation consistent variance covariance matrix, provided by Newey and West (1987). Unsurprisingly, the OLS standard errors do not account for the serial correlation in errors, that is usually associated with time series error terms. To leave no doubts, a Breusch-Pagan test for heteroskedasticity as well as a Breusch-Godfrey test for serial correlation are performed. For both tests the

[15]This table was created using the R package "stargazer" (Hlavac, 2018).

null-hypothesis for homoskedasticity and no serial correlation is rejected at any reasonable significance level for every currencies time-series.

For the case of the Japanese yen the DD estimate $\hat{\gamma}_1$ is negative and significant at the 1% level, indicating that the quarter-end crossing CIP trades in the post 2015 sample exhibit a 79.98 basis points higher[16] deviation from CIP on average, when compared to the one-week deviations that cross quarter-ends previous to 2015. Besides that, in the case of the JPY time-series the basis already showed quarter-end anomalies visible in $\hat{\beta}_2$ prior to the introduction of the "Leverage Ratio Delegation Act". However, when closely observing figure 1 on page 18 one can tell that the significance of this estimate could be due to the last two quarter ends in 2014. A potential explanation could be that banks which were aware of the incoming introduction of the new regulation were internally preparing and testing balance sheet management operations. Additionally, as mentioned in subsection 4.3.1 on page 16, model (6) offers a similar DD approach to test for quarter end differences in forward rate transaction costs that could potentially be mistaken for increased deviations from CIP, in the case of the Japanese yen time-series. The estimates of the regression allow the conclusion that the forward rates are not subject to similar quarter-end anomalies, like the ccy-basis. Therefore one cannot only conclude that the quarter-end ccy-basis anomalies are not driven by forward rate transaction costs but also that economic agents that act as counter-parties for forward contracts, which introduces on balance sheet market risk, are most likely not subject to quarter-end reports that introduce the examined balance sheet costs, in the case of the Japanese yen.

Interestingly, in the case of the euro, $\hat{\gamma}_1$ does not imply a statistically significant difference in means. The only estimate that is significant when applying Newey West standard errors is β_1, implying that the average deviations from CIP are higher after 2015 on average when compared to deviations previous to 2015. Whether or not Du et al. (2018)

[16]Even though the estimate is negative, the deviations are always measured in absolute terms and therefore a negative estimate with an overall negative ccy-basis displays higher deviations from the parity condition

measured significant quarter end effects for the euro is difficult to tell because only panel estimates are reported in their work. It is mentioned, however, that the Japanese yen exhibits the highest quarter-ends effects post 2015. Regarding this fact, they theorize that this difference in magnitude among currencies could suggest that European banks are of particular importance in intermediating dollars to Japan.
For the British pound there is unfortunately no reasonable argument to be made that the state of the time-series would allow to draw any conclusions. The fact that there is a severe lack of data renders any possible analysis impossible since the mean of the quarter-end group post 2015 cannot be compared to adequate data points previous to the passing of the policy.

5 Conclusion

This paper offers a concise summary of the theory behind Covered Interest Parity, the cross-currency basis and an in part replication and extension of the work by Du et al. (2018). In contrast to the authors above, the individual currencies ccy-basis is more closely examined on an individual time-series level. The resulting findings are that the Japanese yen exhibits the strongest quarter-ends anomalies linked to increasing balance sheet costs. As Du et al. (2018) theorize, this greater difference in ccy-basis among quarter-end crossing CIP trades could be caused by European banks playing an important role in intermediating U.S. dollars to Japan. Additionally, in contrast to Du et al. (2018), this paper quantifies the difference in quarter-end effects between the Japanese yen and the euro. Upon application of heteroskedasticity and serial correlation consistent standard errors the euro time-series does not exhibit statistically significant quarter-end effects. However, a shift in levels is associated with the introduction of the “European Leverage Ratio Delegation Act” in 2015.

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