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Covered Interest Parity: violations and arbitrage opportunities

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INTRODUCTION

The 2007 great financial crisis has been the worst economic disaster since the great depression in 1930. It started in 2007 after a subprime mortgage bubble in the U.S., and then it developed into a massive international banking crisis after the collapse of Lehman Brothers, one of the biggest investment banks in the world. The following period was characterized by a global economic downturn and massive financial distresses, which led to liquidity shortages. One of the many and most considerable consequences that the crisis left behind is the main object of this paper, which tries to analyse the main causes and the consequences of the recent manifestation of deviations from the covered interest parity condition. The CIP (covered interest parity) is the closest thing to a physical law in international finance (e.g. Obstfeld and Rogoff 1996, Krugman etal. 2015) and it relies on a simple no-arbitrage condition. More precisely it states that the interest rate differential between two currencies in the money markets should be equal to the differential between the forward and spot exchange rates. If this fundamental condition does not hold then arbitrageurs could potentially make a risk-less profit. As we will observe in this paper since the start of the Global Financial Crisis (GFC), CIP has failed to hold and it is systematically and persistently violated among G10 currencies, leading to significant arbitrage opportunities in currency and fixed income markets. Another aim of this paper is to explain the persistence of these violations even in tranquil markets.

In the first chapter we will briefly examine the main theoretical concepts which are involved in the analysis of CIP deviations, starting from the CIP condition itself, then focusing on the cross-currency basis which is the difference between the direct dollar interest rate from the cash market and the synthetic dollar interest rate from the swap market obtained by swapping the foreign currency into U.S. dollars, analysing also the differences between short-term and long-term basis, and then finally we will define the concept of FX swap contracts, which is crucial for our analysis as interest rate differentials between currencies should be perfectly reflected in the FX forward discount rates because, otherwise, an arbitrageur could transact in interest and FX markets to make a risk-free profit. This means that uncertainty and turmoil in the FX market can bring to deviations from CIP.

In the second chapter we will observe the results that Q. Farooq Akram, Dagfinn Rime and Lucio Sarno had in their study on CIP deviations in order to better understand when and for how long the deviations arise and check if it is possible to implement an arbitrage strategy and exploit these opportunities.

In the third chapter we will analyse the possible causes of these CIP deviations, focusing on two main arguments; first costly financial intermediation and then international imbalances in the interest rates which could explain the presence of deviations even in tranquil markets. Then we are going to see some characteristics of the basis and consequently the basis of KfW bonds that are issued from an AAA-rated German government-owned development bank, with all its liabilities fully backed by the German government. Finally, we are going to conclude the analysis with some general considerations on the CIP condition and on the results we obtained.

Chapter 1
The covered interest parity concept

1.1 The CIP condition

The CIP (covered interest parity) is the closest thing to a physical law in international finance (e.g. Obstfeld and Rogoff 1996, Krugman etal. 2015) and it relies on a simple no-arbitrage condition. More precisely it states that the interest rate differential between two currencies in the money markets should be equal to the differential between the forward and spot exchange rates. If this fundamental condition does not hold then arbitrageurs could potentially make a risk-less profit. For example, an investor able to borrow dollars cheaply in the money market could make a profit by entering in a FX swap, selling dollars for yen at the spot rate today and repurchasing them cheaply at the forward rate at a future date. Let $y^{\$}_{t,t+n}$ denote the n-year risk-free interest rates in U.S. dollars and $y_{t,t+n}$ the foreign currency one. The spot exchange S_t rate is expressed in units of foreign currency per U.S. dollar: an increase in S_t thus denotes a depreciation of the foreign currency and an appreciation of the U.S. dollar. Likewise, $F_{t,t+n}$ denotes the n-year outright forward exchange rate in foreign currency per U.S. dollar at time t. The CIP condition states that the forward rate should satisfy:

$$(1 + y^{\$}_{t,t+n})^n = (1 + y_{t,t+n})^n \frac{S_t}{F_{t,t+n}}$$

It implies that, the forward premium, $\rho_{t,t+n}$, is equal to the interest rate difference between interest rates in the two currencies:

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

To prove this no-arbitrage condition consider that an investor with one U.S. dollar in hand today would own $(1 + y^{\$}_{t,t+n})^n$ U.S. dollars n years from now by investing in U.S. dollars. But the investor may also exchange her U.S. dollar for St units of foreign currency and invest in foreign currency to receive $(1 + y_{t,t+n})^n S_t$ units of foreign currency n years from now. A currency forward contract signed today would convert the foreign currency earned into $(1 + y_{t,t+n})^n S_t / F_{t,t+n}$ U.S. dollars. If both domestic and foreign notes are risk-free aside from the currency risk and the forward contract has no counterparty risk, the two investment strategies are equivalent and should thus deliver the same payoffs. The CIP condition is thus a simple no-arbitrage condition.

1.2 Cross-Currency Basis

Denoting $x_{t,t+n}$, as the deviation from the CIP condition, the basis is defined as:

$$(1+y^{\$}_{t,t+n})^n = (1+y_{t,t+n})^n \frac{S_t}{F_{t,t+n}}$$

Equivalently, it implies that, the currency basis is equal to:

$$x_{t,t+n} = y^{\$}_{t,t+n} - (y_{t,t+n} - \rho_{t,t+n})$$

The cross-currency basis is the deviation from the CIP condition or more precisely is the difference between the direct dollar interest rate from the cash market and the synthetic dollar interest rate from the swap market obtained by swapping the foreign currency into U.S. dollars. With cash market we intend the marketplace for the immediate settlement of transactions involving commodities and securities. This type of market is more precisely a spot market as the exchange of goods and money between the seller and the buyer takes place in the present. While when we talk about swap market we refer to an over-the-counter market where all kind of swaps are traded to either edge some kind of exposure or for speculation purposes.

If the no-arbitrage condition holds the basis should be zero. A positive (negative) currency basis means that the direct dollar interest rate is higher (lower) than the synthetic dollar interest rate.

As stated before, if the CIP holds there are no arbitrage opportunities. In the case of the basis not being zero, arbitrage opportunities theoretically appear. For example, when the basis is negative, $x < 0$, the dollar arbitrageur can earn risk-free profits equal to an annualized [x] of the trade notional by borrowing at the direct dollar risk-free rate $y^{\$}_{t,t+n}$, investing at the foreign currency risk-free rate $y_{t,t+n}$ and signing a forward contract to convert back the foreign currency into U.S dollars. Otherwise if the basis is positive, the opposite arbitrage strategy of funding in the synthetic dollar risk-free rate and investing in the direct dollar risk-free rate would also yield an annualized risk-free profit equal to [x] of the trade notional. In the presence of transaction costs, the absence of arbitrage is characterized by two inequalities: arbitrage must be impossible either by borrowing the domestic currency and lending the foreign currency, or doing the opposite, hedging the currency risk with the forward contract in both cases (see Bekaert and Hodrick, 2012, for a textbook exposition).

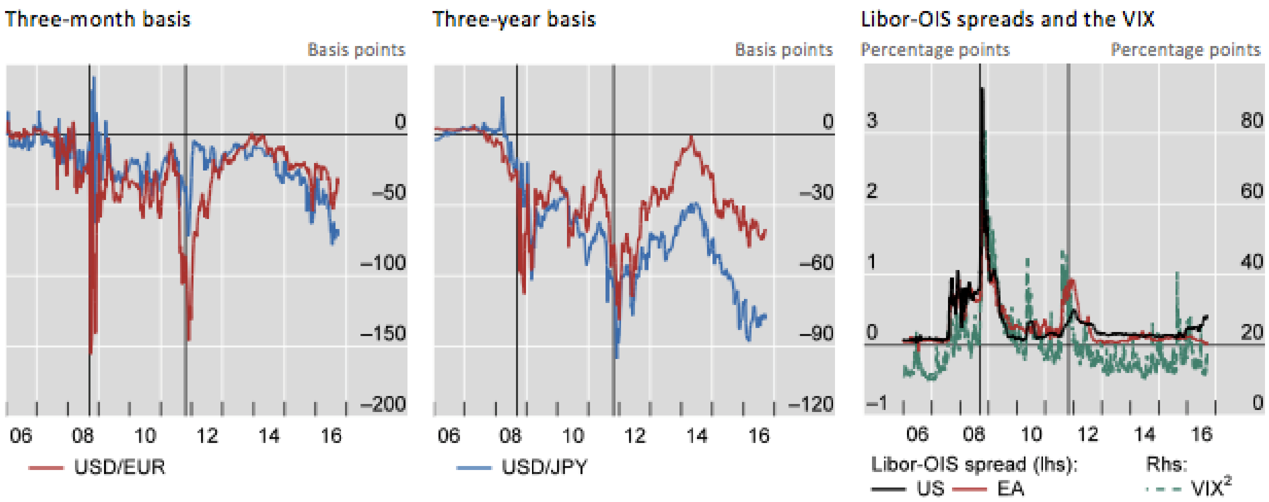
As a result, the bid and ask forward rates satisfy:

$$\frac{F_{t,t+n}^{ask}}{S_t^{bid}} \geq \frac{(1+y_{t,t+n}^{bid})^n}{(1+y_{t,t+n}^{\$,ask})^n} \quad \text{and} \quad \frac{F_{t,t+n}^{bid}}{S_t^{ask}} \leq \frac{(1+y_{t,t+n}^{ask})^n}{(1+y_{t,t+n}^{\$,bid})^n}$$

where $F_{t,t+n}^{ask}$ denotes the n-year outright forward exchange ask rate in foreign currency per U.S. dollar at time t, the variable S_t^{bid} is the spot exchange bid rate expressed in units of foreign currency per U.S. dollar, the $y_{t,t+n}^{\$,ask}$ refers to n-year risk-free interest ask rates in US dollars and the $y_{t,t+n}^{bid}$ stands for n-year risk-free interest bid rates in the foreign currency. The variables in the second equation instead are the opposite ask-bid rates.

Cross-currency basis against the US dollar, interbank credit risk and market risk

(Table 1)



The vertical lines indicate 15 September 2008 (Lehman Brothers file for Chapter 11 bankruptcy protection) and 26 October 2011 (euro area authorities agree on debt relief for Greece, leveraging of the European Financial Stability Facility and the recapitalisation of banks). 2 Chicago Board Options Exchange S&P 500 implied volatility index; standard deviation, in percentage points per annum.

Sources: Bloomberg; authors' calculations.

Table 1 presents the persistence of a cross-currency basis since 2007 (the start of the Global Financial Crisis), which has been positive for some currencies against the US dollar. In the third graph we can also see the Libor-OIS spread which is a measure of the credit risk in the banking sector. Before the 2007 Crisis this spread (difference between the London Interbank Offered Rates and the Overnight Indexed Swap) was so small (0.01 percentage points) that it was not even taken into consideration by traders. At the height of the crisis the spread reached 3.65% and still today it is a key indicator in the financial sector.

1.2.1 Short-Term Libor Cross-Currency Basis

Textbook tests definition of the CIP condition usually relies on Libor rates. At the longer maturities (typically one year or greater), CIP violations based on Libor are directly defined as spreads on Libor cross-currency basis swaps.

We define the Libor basis as equal to:

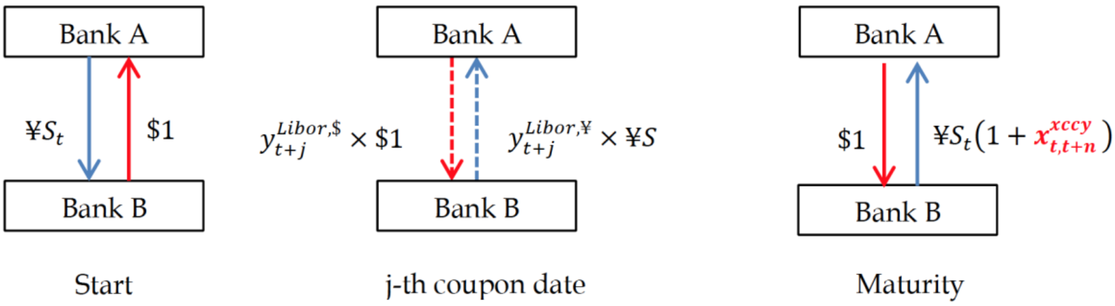
$$x_{t,t+n}^{Libor} \equiv y_{t,t+n}^{\$,Libor} - (y_{t,t+n}^{Libor} - \rho_{t,t+n})$$

where the generic dollar and foreign currency interest rates of the CIP Equation are replaced with Libor rates.

1.2.2 Long-Term Libor Cross-Currency Basis

At long maturities, the long-term CIP deviation based on Libor is given by the spread on the cross-currency basis swap. A cross-currency basis swap involves an exchange of cash flows linked to floating interest rates referenced to interbank rates in two different currencies, moreover there is an exchange of principal in two different currencies at the inception and the maturity of the swap. For example, if we have a yen/U.S. dollar cross-currency swap on \$1 notional between Bank A and Bank B. At the inception of the swap, Bank A receives \$1 from Bank B in exchange of ¥S_t. At the j-th coupon date, Bank A pays a dollar floating cash flow equal to $y_{t+j}^{Libor,\$}$ percent on the \$1 notional to Bank B, where $y_{t+j}^{Libor,\$}$ is the three-month U.S. dollar Libor at time t + j. In return, Bank A receives from Bank B a floating yen cash flow equal to $(y_{t+j}^{Libor,¥} + x_{t,t+n}^{xccy})$ on the ¥S_t notional, where $y_{t+j}^{Libor,¥}$ is the three-month yen Libor at time $t + j$, and $x_{t,t+n}^{xccy}$ is the cross-currency basis swap spread, which is pre-determined at date t at the inception of the swap transaction. When the swap contract matures, Bank B receives \$1 from Bank A in exchange of ¥S_t, undoing the initial transaction. The spread on the cross-currency basis swap, $x_{t,t+n}^{xccy}$, is the price at which swap counterparties are willing to exchange foreign currency floating cash flows against U.S. cash flows. In the case of the yen/U. S dollar cross-currency swap over the recent period, $x_{t,t+n}^{xccy}$ is often negative. For example, assume that Bank B can lend at risk-free rate in yen at the 3-month yen Libor rate, $y_{t+j}^{Libor,¥}$. Next, according to the cross-currency basis swap contract, Bank B has to pay to Bank

A the yen cash flows ($y_{t+j}^{Libor,¥} + x_{t,t+n}^{xccy}$), which are consequently smaller than the yen Libor rate $y_{t+j}^{Libor,¥}$ that Bank B would collect by investing the yen originally received from Bank A. In this example, Bank B gets a sure profit by lending U.S. dollars to Bank A. In other words, if both banks can borrow and lend risk-free at Libor rates, then the cross-currency basis should be zero. As soon as the cross-currency basis swap is not zero, one counterparty seems to benefit from the swap, meaning that there could be potential deviations from the CIP condition at the long end of the yield curve.



1.3 FX Swap Contracts

Now we will introduce the concept of FX swap contracts which are crucial in the robustness of CIP condition as the latter states that interest rate differentials between currencies should be perfectly reflected in the FX forward discount rates because, otherwise, an arbitrageur could transact in interest and FX markets to make a risk-free profit. This means that uncertainty and turmoil in the FX market can bring to deviations from CIP.

A foreign currency swap is defined as an agreement between two foreign parties to execute a currency exchange. In particular, the agreement consists of swapping principal and interest payments on a loan made in one currency for principal and interest payments of a loan of equal value in another currency. Although FX swaps can be considered as efficiently collateralised transactions, the collateral does not cover the entire counterparty risk. For example, if one party of the swap defaults during the contract period, the counterparty needs to reconstruct the position at the current market price, which involves replacement cost. Further, Duffie and Huang (1996) show that FX swaps are subject to greater counterparty risk than interest rate swaps because, unlike interest rate swaps, FX swaps involve the exchange of notional amounts at the start of the contract. In addition, the volatility of FX rates tends to be greater than that of interest rates, another factor likely to elevate counterparty risk in

FX swaps above that of interest rate swaps. A financial institution or other entity needing foreign currency funding can either borrow directly in that currency's uncollateralised cash market or borrow in another (typically the domestic) currency's uncollateralised cash market and convert the proceeds into an obligation in the desired currency through an FX swap.

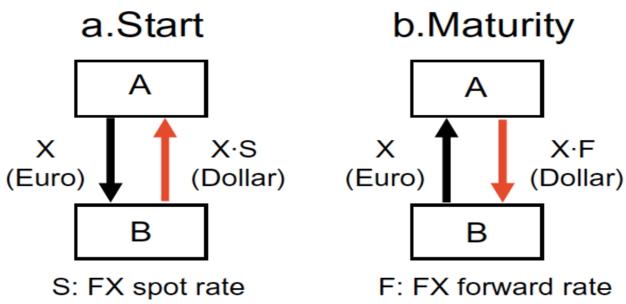


Fig. 2. Flow of funds in FX swap.

The latter leads to a funding rate often referred to as the "swap-implied rate" for the foreign currency. The swap-implied rate is akin to the synthetic interest rate discussed above since the FX swap combines spot and forward rates.

For example, when a financial institution raises dollars via the euro interbank market, it sells euros for dollars at the EURUSD spot rate while contracting to exchange in the reverse direction at the maturity date of the contract. Under CIP, the cost of funding using either method should be equal.

The FX swap is a liquidity-management tool, used to manage exchange rate mismatches. Global banks use FX swaps to fund their foreign currency assets, while multinational corporations use them to manage their cash flows in different currencies. The market is predominantly short term, with most of the activity occurring between 3 months to 1 year.

Chapter 2
Violations and arbitrage opportunities

2.1 Frequency and durations of the deviations

2.1.1 Literature review

In the literature the first one testing the no-arbitrage conditions in the FX market is Taylor (1987), which questioned the published evidence of deviations from CIP as it was not based on contemporaneously sampled real-time quotes of comparable domestic and foreign interest rates and spot and forward exchange rates. According to Taylor's research, it was not possible to prove if an apparent deviation from CIP condition actually denoted a profitable deviation that market agents could exploit. In his research, Taylor (1987) used interest rate and exchange rate data points recorded within more or less 1 min of each other, by contacting telephonically different London brokers at ten-minute frequency between 9.00 and 16.30 o'clock, which were the most active hours of the market, over three days in 1985. The study provided strong evidences of CIP condition relatability, as no profitable CIP arbitrage opportunity were observed. Taylor's (1987) analysis was not conclusive mainly because of several aspects. First of all, the data covered a period of time that may be too short for extrapolating general conclusions. Second, the used quotes were not strictly contemporaneous since quotes could change during a minute. Finally, the ten-minute frequency at which the observations were documented seemed to be relatively too low not enabling to distinguish dynamics of possible deviations from CIP arbitrage. The ten-minute interval frequency employed by Taylor (1987) could, however, have been sufficiently high to provide accurate results using data from the mid-1980s, especially considering the fact that there was no centralized (electronic) market at that time. Since Taylor's research the literature on testing no-arbitrage conditions in currency markets has been scant in the last twenty years, mainly due to the presence of non-electronic, highly decentralized markets until the early 1990s, making extremely difficult to improve the quality of the data beyond Taylor's (1987,1989) papers. All the following studies generally supported the absence of arbitrage opportunities including Rhee and Chang (1992), Fletcher and Taylor (1996), Aliber et al. (2003) and Juhl et al. (2006).

2.1.2 Data Collection

The most recent research on arbitrage opportunities in the foreign exchange market was conducted in 2004 by Q. Farooq Akram, Dagfinn Rime and Lucio Sarno which employed new trading systems to collect a huge amount of data on three major capital and foreign exchange markets. More specifically data were obtained from the Reuters trading system, which embeds general market quoting and maturity conventions. Eventually these data were elaborated with a formula for calculating deviations from the no-arbitrage conditions in light of these conventions as well as transaction costs that a trader would typically face when dealing through this system.

In the interbank market, dealers generally trade swaps rather than (outright) forwards. Swaps are denominated in so-called swap points, which express a multiple of the difference between forward and spot exchange rates. By the convention of that time, all of the spot exchange rates were quoted with four decimals, except for the Japanese yen, where two decimals were used. The above decimals define the smallest measure of movement for an exchange rate, which is called a "pip". Swap points, which are expressed in pips, are therefore obtained by multiplying the difference between forward and spot exchange rates by 10^4 in general, and by 10^2 in the case of the Japanese yen. If we consider the quoting currency as the domestic currency (d) and the base currency as the foreign currency (f), for convenience, since we overlook cases where both the quoting as well as the base currencies are actually foreign currencies for a dealer. Investigating potential returns from arbitrage by comparing the swap points quoted through Reuters with corresponding derived (or theoretical) swap points we can see that the deviations from CIP on the bid side and the ask side, respectively, can be expressed as

$$Dev_{CIP}^{b} = (F^{b} - S^{a}) \times 10^{4} - \frac{S^{a}(i_{d}^{a} \times \frac{D}{360} - i_{f}^{b} \times \frac{D}{360})}{(100 + i_{f}^{b} \times \frac{D}{360})} \times 10^{4}$$

$$Dev_{CIP}^{a} = -(F^{a} - S^{b}) \times 10^{4} - \frac{S^{b}(i_{d}^{b} \times \frac{D}{360} - i_{f}^{a} \times \frac{D}{360})}{(100 + i_{f}^{a} \times \frac{D}{360})} \times 10^{4}$$

where the first term on the right-hand side of each equation represents market swap points for a given maturity obtained from Reuters, while the second term represents the corresponding derived swap points. In order to calculate derived swap points that are directly comparable to the market swap points quoted on Reuters, we adjust the interest rates i, which are quoted in percent per annum, to obtain interest rates for maturities less than a year. Specifically, D denotes the number of days to maturity of swap and deposit contracts. It is calculated as the actual number of business days between the (spot) value date and the maturity date of a contract while taking into account bank holidays in the home countries of currencies and securities, and other conventions. Thereafter, the resulting term is multiplied by 10^4 (or 10^2 in the case of the Japanese yen) to obtain the derived swap points. The deviations from the no-arbitrage conditions stated in the two previous equations are expressed in pips since they are defined as the difference between quoted and derived swap points. CIP deviations are profitable if they are positive net of other transactions costs. That is, when defining a profitable arbitrage deviation, the expressions for returns presented in the previous equations must be greater than 1/10 of a pip in order to cover brokerage and settlement costs.

Data were collected via a continuous feed from Reuters over the period from February 13 to September 30 2004 enabling them to investigate CIP arbitrage for three major exchange rates at four different maturities: 1, 3, 6 and 12 months. It includes all best ask and bid spot exchange rates for three major exchange rates: USD/EUR, USD/GBP and JPY/USD—hereafter EUR, GBP and JPY. It also includes ask and bid quotes for the exchange rate swaps for the four maturities as well as for euro-currency deposits for the currencies involved. An advantage of using deposit rates for interest rates is that an arbitrageur would know when and how much she will pay or receive. The use of deposits implies, however, that we limit the pool of potential arbitrageurs to those that have credit agreements, since deposits are on-balance sheet instruments.

For the spot exchange rate firm quotes from Reuters electronic brokerage system were used(D3000-2); these quotes are tradable spot transactions which can be carried out with a market order in the Reuters system. For swaps and euro-currency deposits only indicative ask and bid quotes were available through Reuters Monitor (i.e. Reuters 3000 Xtra). This is mainly because both swaps and deposits are primarily traded bilaterally between interbank dealers, typically over telephone or Reuters D2000-1. Data from these sources is virtually impossible to obtain.

2.1.3 Results

This table from the Q. Farooq Akram, Dagfinn Rime and Lucio Sarno paper, previous mentioned, shows the results:

(Table 2)

Descriptive statistics of CIP deviations

Exchange rate			a) All deviations						b) Profitable deviations					
			All dev.	Mean	t-value	Median	Ann. mean	Inter-quote time (s)	Pa dev.	Share (%)	Mean	Median	Ann. mean	Inter-quote time (s)
EUR	1M	Ask	2,037,923	-0.90	-4.2	-0.9	-11	2.9	1975	0.10	0.26	0.24	3	2.7
		Bid	2,037,923	-1.00	-4.6	-1.0	-12	2.9	73	0.00	0.18	0.13	2	25.0
	3M	Ask	2,068,143	-2.67	-3.3	-2.7	-11	2.9	30,116	1.46	0.85	0.39	3	2.8
		Bid	2,068,143	-2.77	-3.7	-2.7	-11	2.9	3500	0.17	0.88	0.66	4	2.2
	6M	Ask	2,309,197	-5.78	-3.1	-5.7	-12	2.6	12,844	0.56	1.44	1.30	3	1.9
		Bid	2,309,197	-5.31	-3.2	-5.3	-11	2.6	8559	0.37	2.58	2.42	5	2.1
	1Y	Ask	2,560,419	-12.43	-2.9	-12.4	-12	2.3	21,495	0.84	5.33	4.69	5	2.0
		Bid	2,560,419	-10.64	-2.9	-10.6	-11	2.3	8966	0.35	3.29	2.14	3	2.2
GBP	1M	Ask	2,445,312	-1.36	-2.5	-1.4	-16	2.4	35,110	1.44	0.35	0.26	4	2.4
		Bid	2,445,312	-1.72	-3.4	-1.7	-21	2.4	16,835	0.69	0.69	0.68	8	2.8
	3M	Ask	2,450,660	-4.06	-1.9	-4.1	-16	2.4	57,523	2.35	2.13	1.40	9	2.5
		Bid	2,450,660	-4.25	-2.0	-4.1	-17	2.4	24,124	0.98	2.90	3.09	12	1.9
	6M	Ask	2,594,610	-7.91	-2.3	-7.9	-16	2.3	37,820	1.46	4.91	3.27	10	2.0
		Bid	2,594,610	-9.43	-2.8	-9.3	-19	2.3	5950	0.23	1.70	1.38	3	2.4
	1Y	Ask	2,746,288	-16.01	-2.6	-16.2	-16	2.2	37,987	1.38	9.09	7.38	9	2.0
		Bid	2,746,288	-17.85	-2.8	-17.4	-18	2.2	4593	0.17	4.52	2.35	5	2.5
JPY	1M	Ask	804,885	-1.04	-3.4	-1.0	-12	7.3	1545	0.19	0.37	0.15	4	13.8
		Bid	804,885	-1.02	-3.5	-1.0	-12	7.3	2068	0.26	0.23	0.18	3	6.2
	3M	Ask	818,537	-2.66	-3.4	-2.6	-11	7.2	491	0.06	3.86	3.00	15	10.5
		Bid	818,537	-2.85	-3.3	-2.9	-11	7.2	2891	0.35	1.83	1.72	7	15.6
	6M	Ask	838,047	-4.61	-2.9	-4.6	-9	7.0	718	0.09	4.71	0.90	9	15.0
		Bid	838,047	-5.69	-3.5	-5.6	-11	7.0	4140	0.49	1.45	1.25	3	2.8
	1Y	Ask	892,242	-8.37	-2.3	-8.3	-8	6.6	3403	0.38	6.21	2.00	6	10.9
		Bid	892,242	-13.42	-3.4	-13.6	-13	6.6	4358	0.49	3.50	3.26	4	4.6

The column headed by “All dev.” presents the number of all profitable and non-profitable deviations, while the one headed by “Pa dev.” records the number of the profitable deviations, i.e. deviations that are larger than 1/10 of a pip. Entries in the “Share” column are profitable deviations as a percentage of all of the deviations in column “All dev.”. The “Mean” and “Median” columns present the average sizes and median values of the deviations, both measured in pips. The “Ann. mean” columns show annualized mean values of the period returns (deviations), reported in the “Mean” columns. Annualized values for the 1-month, 3-month and the 6-monthmaturities are obtained by multiplying the (period) mean value by 12, 4 and 2, respectively. The “t-value” is simply the (period)mean value divided by the respective sample standard deviation. The “Inter-quote time (s)” columns present the average time in seconds from the previous deviation. In Panel b) the “Interquote time” is conditioned on the current deviation being profitable.

In all the cases examined, the average return from CIP arbitrage is negative meaning that on average, CIP arbitrage is loss-making. Furthermore, the associated t-values suggest that the losses are statistically significant at conventional levels of significance. One would expect that arbitrage would eliminate any systematic negative or positive deviations from CIP and make CIP hold on average. One possible explanation for the negative mean of CIP deviations could be that market makers (quote providers) in the currency and deposit markets do not knowingly offer counterparts risk-free arbitrage opportunities and thus contribute to shift the returns towards negative values through their price offers. This would especially be the case if dealers, when pricing, say, the swap, worry about the fact that prices of other instruments, say deposits, may move in the next few seconds in a way to generate arbitrage. Accordingly, they may price more conservatively than CIP conditions imply in order to avoid arbitrage and be on the safe side. If prices are set in the deposit market in the same way, then equilibrium (average) prices will be consistent with a negative deviation from CIP rather than zero. Nevertheless, the negative average return from CIP arbitrage is not sufficient to prevent arbitrage in continuous time completely since the maximum point of the distribution of returns is not zero, which is the sufficient condition that is needed to prevent any arbitrage opportunity. Focusing on only profitable CIP deviations instead, we can see from the column headed "Pa dev" which reports the number of profitable arbitrage opportunities out of the total number of data points available ("All dev."), calculated for each of the exchange rates and maturities considered. Profitable deviations from CIP arbitrage are defined as the subset of CIP deviations with values in excess of 0.1 pip. The results suggest thousands of profitable arbitrage opportunities for all exchange rates, at most of the maturities. As shares of the total number of data points considered, however, the profitable arbitrage opportunities are minuscule. The shares range from zero to 1.5% in the case of EUR, from 0.2% to 2.4% for GBP, and from 0.1% to 0.5% for JPY.

When examining the annualized mean return from profitable arbitrage deviations, we find that these returns range from a minimum of 2 pips in the case of EUR at the one-month bid side to a maximum of 15 pips for the JPY at the three-month ask. The returns show no systematic pattern with maturity of the instruments involved in arbitrage. Also, the average inter-quote time for profitable deviations ranges from less than 2 seconds to 15.6 seconds, except for one extreme case of 25 seconds for EUR at the one-month bid. However, in the latter case, the average inter-quote time is calculated only across 73 data points, which is the smallest number of arbitrage opportunities observed. These results show also that there are fewer profitable arbitrage opportunities with lending dollar funds than when lending funds in euro, sterling and yen. This tendency is implied by the relatively higher share of profitable arbitrage opportunities on the ask sides relative to the bid sides in the case of EUR and

GBP and on the bid side relative to the ask side in the case of JPY, as in the EUR/USD and GBP/USD exchange rates the base currencies are respectively the EUR and GBP while in the USD/JPY rate the base currency is the USD.

The research previous mentioned (Q. Farooq Akram, Dagfinn Rime and Lucio Sarno paper) reports also the duration of sequences of profitable deviations from the CIP condition. More specifically shows the number of sequences across exchange rates and maturities, ranges from a minimum of 8 to a maximum of 923. Notably, most sequences of profitable CIP deviations do not seem to last beyond a few minutes and in most of the cases average duration falls in the range from 30 s to less than 4 min. Median values of durations are even lower than the corresponding average durations: they are generally less than 1 min in the case of EUR; at most 1:43 min in the case of GBP; and at most 4:34 min in the case of JPY. It is worth noting that durations of sequences tend to decline with the maturity of contracts. This seems to be consistent with the relatively high market pace (low inter-quote time) at higher maturities.

Sample standard deviations of the durations reveal large variations in the duration of profitable CIP deviations but the standard deviations are quite different across the cases examined: they are mostly lower than a few minutes, but exceptionally they can be higher than 10 min. Often the relatively large standard deviations occur when there are relatively few observations, meaning small number of sequences. The first and third quantiles in the last two columns of the following table indicate that duration is not particularly high even at these quantiles of the distribution of durations, suggesting that the high standard deviations reported are potentially driven by relatively few outliers. They also explain the particularly long average duration of a few clusters of profitable CIP deviations. In conclusion we can state that the duration of profitable CIP deviations is relatively low but sufficiently high on average for a trader to exploit the arbitrage opportunities. Even if these opportunities amount to small numbers when one compares them to the total number of observations examined we can assume that the size of profitable CIP deviations is, however, economically appealing, with period returns up to 15 pips. These are relatively large returns when compared with the typical size of spreads in the major dealer markets, usually around 2 pips. The size of the returns may seem small relative to the returns targeted by major players in the FX market, such as hedge funds, but it is not small if we bear in mind that they are riskless and as the authors of the paper (Q. Farooq Akram, Dagfinn Rime and Lucio Sarno) mentioned, taking such arbitrage positions does not require own capital.

(Table 3)

Durations of sequences of CIP arbitrage opportunities (in minutes)

Exchange rate			# Clusters	Mean	Stdev	Median	Q1	Q3
EUR	1M	Ask	55	1:35	1:56	0:49	0:18	2:05
		Bid	8	4:03	9:33	0:39	0:09	1:35
	3M	Ask	293	4:44	12:11	1:04	0:21	3:34
		Bid	81	1:36	2:01	0:57	0:26	2:14
	6M	Ask	419	0:57	1:29	0:26	0:12	1:01
		Bid	416	0:44	2:01	0:18	0:08	0:30
	1Y	Ask	660	1:06	2:33	0:23	0:11	1:07
		Bid	518	0:36	1:01	0:14	0:06	0:36
GBP	1M	Ask	339	4:11	10:46	1:30	0:25	4:00
		Bid	70	11:02	55:16	0:39	0:14	1:23
	3M	Ask	404	5:54	13:59	1:43	0:26	5:05
		Bid	86	8:47	4:23	0:37	0:11	1:59
	6M	Ask	554	2:18	8:34	0:25	0:10	1:09
		Bid	207	1:10	2:05	0:27	0:11	1:33
	1Y	Ask	923	1:20	4:17	0:19	0:09	0:55
		Bid	232	0:48	1:46	0:18	0:08	0:46
JPY	1M	Ask	38	10:14	13:36	4:34	2:52	10:45
		Bid	60	3:28	8:07	1:36	0:54	2:53
	3M	Ask	17	5:22	13:46	0:16	0:06	1:36
		Bid	103	7:32	15:51	3:01	2:05	9:12
	6M	Ask	52	3:15	8:45	0:27	0:10	2:07
		Bid	133	1:20	3:05	0:23	0:10	1:01
	1Y	Ask	415	1:20	4:36	0:29	0:13	1:04
		Bid	183	1:47	3:26	0:41	0:16	1:51

A cluster(sequence) consists of at least two profitable CIP deviations in a row. The entries in the "Mean" column denote the average duration (min: s) of the clusters (based on the corresponding entries in the column "# Clusters"), while those in the "Median" column refers to the median duration of the clusters. The "Q1" and "Q3" columns present the first and the third quantiles of the duration of clusters, respectively. The "Stdev" column includes sample standard deviations of the duration of the clusters.

In order to exploit an arbitrage opportunity, however, a trader needs to undertake three deals virtually simultaneously or as fast as possible. Otherwise, there is a risk that prices of one or more instruments move such that an apparent arbitrage opportunity disappears before the trader has been able to conclude all the three deals. Reuters electronic trading system, which provides easy access to money and currency markets from one platform, allows a trader to undertake almost simultaneously several deals with counterparts. Alternatively, virtually simultaneous trading in the money markets and the swap markets can be accomplished through tight cooperation between money market dealers and swap market dealers which seems to exist in a typical dealing room.

The results obtained so far in the research do not imply that the profits are economically significant as these deviations are costly to investigate and may not be worth the inquest. This requires information about currency volumes available for trading at quotes suggesting profitable arbitrage opportunities. Information about exact volumes available for trading were not available to the scholars conducting the research (Q. Farooq Akram, Dagfinn Rime and Lucio Sarno) and furthermore, for the swap and the deposit markets, where there are only indicative quotes and no information on trades, alternative measures of volume available for trading are likely to be very imprecise. For the spot market, instead, firm quotes and information on the number of trades were available, making possible the estimation of orders available for trade, so-called limit orders, at ranges of spot exchange rate quotes. These limit orders indicate the liquidity in the spot currency market since–for a given order size–the higher the number of limit orders the more volume is available for trading. The liquidity of the spot market may give an indication about how liquidity providers in these markets behave in situations of profitable arbitrage. Since the spot exchange market is deeper than the markets for the currency deposits and exchange rate swaps, the estimated orders available for trading in the spot market can be considered as the upper bound on orders available for trading at CIP deviations.

To calculate the limit orders available, we need to know how much the spot exchange rate can deviate from the current level before an arbitrage opportunity will be lost. So the expression for CIP deviations was reformulated on the bid side and ask sides, while assuming that the interest rate and forward quotes remain unaltered:

$$(F^b - \frac{\delta}{10^4}) \times \frac{100 + i_f^b \times \frac{D}{360}}{100 + i_d^a \times \frac{D}{360}} - S^a = \frac{Dev_{CIP}^b - \delta}{10^4} \times \frac{100 + i_f^b \times \frac{D}{360}}{100 + i_d^a \times \frac{D}{360}}$$

$$S^b - (F^a - \frac{\delta}{10^4}) \times \frac{100 + i_f^b \times \frac{D}{360}}{100 + i_d^b \times \frac{D}{360}} = \frac{Dev_{CIP}^a - \delta}{10^4} \times \frac{100 + i_f^a \times \frac{D}{360}}{100 + i_d^b \times \frac{D}{360}}$$

where δ=1/10 of a pip, and Fb is the forward rate (i.e. the spot ask quote plus the swap bid quote). If we define the first term in the first expression as S_{exp}^a and the second term in the second expression as S^{b}_{exp}, we can say that these two parts express the spot quote at which the profit from CIP arbitrage will be zero; while S^{a} and S^{b} are the best ask and bid spot quotes observed. Profitable arbitrage at the CIP bid side requires the ask spot quote S^{a} to be lower than the critical value defined by the first expression, S^{a}_{exp}; while profitable arbitrage at the CIP ask side requires that the spot quote S^{b} is higher than the critical value defined by the second expression, S^{b}_{exp}. The critical values S^{a}_{exp} and S^{b}_{exp} essentially define a band of ask and bid spot quotes, respectively, at which trading on the CIP deviation will be profitable, at given interest rates and forward rates. After having defined the ranges of bid and ask prices for which profit opportunities exist we can then identify the corresponding outstanding limit orders.

The following table presents the average and median numbers of limit orders at best spot prices when there are profitable arbitrage opportunities.

Spot market characteristics when CIP deviations are profitable. Limit order depth (in number of orders) and deviations from arbitrage-free prices (in pips)

Exchange rate			a) Spot market limit order depth					b) Spot price deviations		
			Pa dev.	(i) Best depth		(ii) Total depth		Pa dev.	Mean	Median
				Mean	Median	Mean	Median			
EUR	1M	Ask	52	4.14	2	4.14	2	73	0.08	0.03
		Bid	1685	4.92	3	4.92	3	1975	0.16	0.14
	3M	Ask	3215	6.06	4	6.63	5	3500	0.78	0.56
		Bid	26,254	7.65	5	9.47	6	30,116	0.75	0.29
	6M	Ask	6789	6.78	4	10.30	8	8559	2.48	2.33
		Bid	10,529	5.62	3	7.64	5	12,844	1.34	1.20
	1Y	Ask	6969	6.36	4	9.72	8	8966	3.20	2.04
		Bid	17,519	7.34	4	13.36	11	21,495	5.23	4.59
GBP	1M	Ask	16,333	3.90	3	4.11	3	16,835	0.59	0.59
		Bid	34,257	4.17	3	4.22	3	35,110	0.25	0.16
	3M	Ask	23,437	5.73	4	10.95	9	24,124	2.82	3.01
		Bid	54,251	4.16	3	5.45	4	57,523	2.04	1.31
	6M	Ask	5426	3.94	3	5.28	4	5950	1.63	1.30
		Bid	34,442	4.11	3	8.11	6	37,820	4.87	3.21
	1Y	Ask	3967	4.47	3	7.62	6	4593	4.54	2.32
		Bid	32,940	4.25	3	8.26	6	37,987	9.24	7.50
JPY	1M	Ask	1885	3.65	2	3.67	2	2068	0.13	0.08
		Bid	1353	2.23	1	2.24	1	1545	0.27	0.05
	3M	Ask	2085	2.39	1	3.87	3	2891	1.74	1.63
		Bid	420	3.19	2	4.29	4	491	3.78	2.91
	6M	Ask	3838	5.58	4	8.34	7	4140	1.36	1.16
		Bid	525	2.78	2	3.98	2	718	4.66	0.80
	1Y	Ask	3602	3.32	2	5.97	5	4358	3.48	3.24
		Bid	2176	3.05	2	5.34	4	3403	6.25	1.94

Panel a) shows the average and median depth (measured in number of orders) at (i) the best prices (i.e. lowest ask and highest bid), and (ii) the total depth between the current best price and the critical value (no arbitrage) of the spot price. Panel b) shows the average sizes and median values of the difference between the current spot rate and the spot rate implied by no arbitrage, both measured in pips. The columns headed by "Pa dev." present the number of profitable deviations, i.e. CIP deviations that are larger than 1/10 of a pip. In Panel a) we only use the profitable deviations where we also have observations on depth. The rows "Ask" and "Bid" refer to the spot prices, and that the spot ask (bid) price enters in the bid (ask) CIP calculation.

The results show that the average number of the limit orders varies from about 3 to 7, while the median numbers are in the somewhat lower range of 1 to 5. This suggests that occasionally there can be a relatively large number of limit orders at the best quotes. Moreover, since the size of profitable deviations may amount to several pips in some cases, the spot quotes can deviate from the best quotes without necessarily eliminating the arbitrage opportunities. The availability of several limit orders when there are profitable arbitrage opportunities suggests that profits from exploiting arbitrage opportunities can be economically significant.

Considering the high frequency of the data examined in this study, it is difficult to undertake an exhaustive empirical analysis of the economic conditions under which arbitrage arises as most economic and financial variables are not available at this frequency.

However, it is possible to investigate whether frequency, size and duration of profitable arbitrage opportunities are influenced by the pace of the market and with market volatility. For this purpose, the researchers estimated a simple linear cross-sectional regression models with measures of frequency (share), size and duration of profitable CIP violations as dependent variables,

regressed on an intercept, inter-quote time and a proxy for market volatility as the explanatory variables. That’s to say:

$$y_j = \alpha_y + \beta_y IQ_{y,j} + \gamma_y DIVol_{y,j} + \varepsilon_{y,j}$$

where y stands for Share, Size, or Duration of deviations from no-arbitrage conditions; $IQ_{y,j}$ denotes inter-quote time, which is a measure of market pace; $DIVol_{y,j}$ is the difference between maximum and minimum implied volatility and is a measure of the degree of uncertainty (variability) in volatility; and $\varepsilon_{y,j}$ is an error term. Subscript j indicates an observation number; j=1,2, 3, …. Ny. The Greek letters represent time-invariant parameters. The models are estimated by ordinary least squares (OLS) for each of the currency pairs examined. Accordingly, values for y, $IQ_{y,j}$ and $DIVol_{y,j}$ as well as the total numbers of observations (Ny) depend on the currency pair analysed. The results from estimating regression for frequency, size and duration, for all three currency pairs and no-arbitrage conditions, are given in the table shown in the next page. The information obtained suggest that these characteristics of CIP arbitrage violations are highly influenced by the pace of the market, as suggested by the inter-quote time, and by the variability of volatility. More specifically, frequency, size and duration are positively correlated both to IQ and to variability of volatility, while they are negatively correlated to the market pace and to $DIVol_{y,j}$. This proves that when markets are particularly active, as suggested by a high number of new quotes per unit of time, and when the degree of uncertainty is relatively more stable, the amount of observed arbitrage opportunities is lower, consequently arbitrage profits are smaller while the duration of arbitrage opportunities decreases. This suggests that high market pace and stable volatility are closely correlated to arbitrage opportunities, that are more short-lived.

Estimated relationships between the characteristics of CIP arbitrage opportunities and market pace and volatility

		IQ-time	DIVol	Obs
a) Share	EUR	0.0064	1.7973	514
		(5.77)	(2.17)	
	GBP	0.0085	2.2536	696
		(4.26)	(5.66)	
	JPY	0.0028	1.5365	184
		(9.54)	(4.64)	
b) Size	EUR	0.0219	-0.0482	2448
		(1.03)	(−0.00)	
	GBP	0.1348	4.4103	2812
		(3.51)	(0.48)	
	JPY	0.0628	89.1078	1000
		(4.77)	(5.47)	
c) Duration	EUR	21.23	3,087.5	2448
		(25.09)	(5.65)	
	GBP	7.19	13,333.3	2812
		(2.02)	(15.73)	
	JPY	7.46	3,755.0	1000
		(20.38)	(8.29)	

Panel a) reports estimation results for the relationship between frequency ("Share"), inter-quote time ("IQ time") and the difference between maximum implied volatility and minimum implied volatility ("DIVol"). The dependent variable "Share" is defined as the share of profitable deviations out of the total number of deviations in a business hour (containing profitable deviations) over the sample period, while "IQ time", measured in seconds, is the average time between all of the (profitable and non-profitable) deviations used when calculating the corresponding observation for the frequency. Panels b) and c) report estimation results for the relationships between the average size of profitable deviations (in pips) from clusters of profitable deviations and IQ-time and DIVol, and duration of clusters of profitable deviations and IQ-time and DIVol. A profitable deviation is a deviation that is larger than 1/10 of a pip. A cluster consists of at least two profitable deviations in a row. The inter-quote time in the regressions for size and durations is the average time between the rows of profitable deviations constituting a profitable cluster. OLS estimates of the intercept terms (positive, and statistically significant at the 5% level in all cases) have not been reported for the sake of brevity. Associated t-values are reported in parenthesis below the coefficient estimates. The column "Obs" presents the numbers of observations used in estimation.

Moreover, the experimenters proved that the arbitrage opportunities investigated were not due to stale quotes as the core analysis was restricted to the most active periods of market activity. This was achieved by excluding weekends and days with unusually low or no trading activity (either due to a holiday or failure of the feed), and by including only quotes during the highest activity part of the trading day, namely 07:00–18:00 GMT. Most of the deviations seems not to have a relation with some specific days of the week and even more specifically not with parts of the trading day as the outcomes of the analysis underline in the following tables:

CIP arbitrage opportunities by day of week

Exchange rate			Monday		Tuesday		Wednesday		Thursday		Friday		All
			Pa dev.	Share (%)	Pa dev.	Share (%)	Pa dev.	Share (%)	Pa dev.	Share (%)	Pa dev.	Share (%)	
EUR	1M	Ask	96	5	662	34	369	19	294	15	554	28	1975
		Bid	5	7	25	34	1	1	5	7	37	51	73
	3M	Ask	4506	15	882	3	18,546	62	817	3	5365	18	30,116
		Bid	202	6	1360	39	132	4	1607	46	199	6	3500
	6M	Ask	1941	15	1609	13	3106	24	2530	20	3658	28	12,844
		Bid	1156	14	956	11	692	8	3421	40	2334	27	8559
	1Y	Ask	3576	17	9062	42	2621	12	3115	14	3121	15	21,495
		Bid	2057	23	935	10	877	10	1468	16	3629	40	8966
GBP	1M	Ask	8982	26	951	3	11,188	32	12,977	37	1012	3	35,110
		Bid	29	0	923	5	782	5	1149	7	13,952	83	16,835
	3M	Ask	12,867	22	4101	7	18,265	32	8156	14	14,134	25	57,523
		Bid	405	2	90	0	21,312	88	869	4	1448	6	24,124
	6M	Ask	12,276	32	2878	8	6202	16	10,100	27	6364	17	37,820
		Bid	181	3	4485	75	358	6	78	1	848	14	5950
	1Y	Ask	7499	20	9387	25	7719	20	6794	18	6588	17	37,987
		Bid	265	6	340	7	397	9	118	3	3473	76	4593
JPY	1M	Ask	1	0	161	10	1358	88	25	2	0	-	1545
		Bid	61	3	5	0	20	1	0	-	1982	96	2068
	3M	Ask	2	0	259	53	0	-	22	4	208	42	491
		Bid	2240	77	176	6	119	4	19	1	337	12	2891
	6M	Ask	112	16	43	6	53	7	162	23	348	48	718
		Bid	1052	25	134	3	563	14	439	11	1952	47	4140
	1Y	Ask	381	11	610	18	886	26	390	11	1136	33	3403
		Bid	1261	29	1926	44	55	1	327	8	789	18	4358

The columns headed by "Pa dev." record the number of the profitable deviations, i.e. deviations that are larger than 1/10 of a pip. Entries in the "Share" columns are profitable deviations in percent of all of the profitable deviations (reported in column "All"). Sample: Based on Reuters tick quotes. February 13–September 30, 2004, weekdays, between GMT 07:00 and 18:00. The following dates have been removed: April 2, 5–9, 12, May 3 and 31, June 17 and 18, August 10, 13, 24, and September 15.

Upon examining the share of profitable CIP opportunities across days, we find that arbitrage violations occur throughout the week (Monday to Friday), suggesting the absence of a systematic pattern of CIP violations during the week days. Specifically, it is never the case that CIP arbitrage is more frequent across maturities or exchange rates in any given day relative to another. In conclusion there is no significant correlation between the day of the week and the presence of profitable deviations.

Shares of CIP arbitrage opportunities by hour of day

Exchange rate			[07–08) (%)	[08–09) (%)	[09–10) (%)	[10–11) (%)	[11–12) (%)	[12–13) (%)	[13–14) (%)	[14–15) (%)	[15–16) (%)	[16–17) (%)	[17–18) (%)	All
EUR	1M	Ask	40.2	15.6	5.5	2.5	10.3	11.1	14.8	0.1	-	-	-	1975
		Bid	-	54.8	12.3	-	-	-	6.8	-	-	8.2	17.8	73
	3M	Ask	4.8	6.4	8.8	6.6	8.2	15.6	12.2	14.0	12.7	6.7	4.0	30,116
		Bid	78.5	11.2	1.8	1.6	2.2	1.4	-	1.9	0.8	0.2	0.2	3500
	6M	Ask	20.6	3.8	2.6	1.0	4.3	22.6	19.8	18.7	6.4	0.1	0.0	12,844
		Bid	48.9	4.1	4.6	2.8	4.2	12.3	9.5	8.0	2.9	1.8	1.0	8559
	1Y	Ask	21.8	3.7	3.4	0.9	3.1	19.0	15.2	19.0	10.6	1.5	1.9	21,495
		Bid	20.8	8.9	7.7	3.3	2.7	10.0	6.6	18.4	16.5	3.8	1.4	8966
GBP	1M	Ask	3.3	8.4	2.6	5.0	7.0	18.4	17.5	16.6	9.9	8.3	3.0	35,110
		Bid	5.6	5.2	9.2	5.4	6.5	20.9	15.8	11.8	10.3	5.4	3.9	16,835
	3M	Ask	7.0	6.0	7.8	1.5	7.4	15.4	17.5	14.3	11.5	7.7	3.9	57,523
		Bid	12.0	11.5	8.6	10.6	9.5	9.9	9.1	10.9	9.4	4.5	4.1	24,124
	6M	Ask	14.1	12.9	2.6	1.7	9.0	24.5	17.7	13.0	4.4	0.0	-	37,820
		Bid	12.7	10.8	28.2	14.9	14.9	6.6	1.7	2.0	3.3	2.2	2.8	5950
	1Y	Ask	17.9	6.9	4.0	3.4	6.5	23.0	12.4	14.6	6.6	2.3	2.4	37,987
		Bid	9.5	2.2	11.9	0.2	0.5	16.4	2.5	15.2	18.2	17.2	6.1	4593
JPY	1M	Ask	3.8	9.8	4.1	9.7	3.0	17.2	27.7	19.2	2.6	2.1	0.7	1545
		Bid	11.5	7.8	23.2	13.7	4.8	27.6	3.7	5.6	2.2	-	0.0	2068
	3M	Ask	1.4	40.5	-	-	-	35.8	11.8	4.7	-	3.1	2.6	491
		Bid	29.1	14.5	11.3	12.5	2.4	9.2	5.6	4.8	7.0	2.4	1.2	2891
	6M	Ask	6.7	44.8	-	-	-	14.2	4.6	13.2	10.6	2.6	3.2	718
		Bid	61.1	0.2	0.1	0.8	1.9	11.9	9.2	13.2	1.1	0.1	0.2	4140
	1Y	Ask	6.6	7.0	3.3	4.6	3.3	16.7	13.8	22.5	11.8	7.3	3.1	3403
		Bid	36.1	0.9	0.6	1.0	1.2	10.5	15.6	18.2	13.7	0.9	1.2	4358

Similarly, the results in this table, reporting the share of profitable CIP opportunities during a trading day from 07:00 to 18:00 GMT, do not indicate obvious accumulation of deviations at a particular time of the day. However, in general, CIP opportunities appear to be somewhat more frequent early in a trading day and around the middle of the day, mainly due to the fact that market pace is lower and quotes are updated less frequently at those periods of the day. To conclude, we can fairly assume that arbitrage opportunities may occur at any time and cannot be easily predicted.

In conclusion, even if finance theory states that in well-functioning markets there are no-arbitrage conditions which hold continuously, the research analysed in this chapter shows that short-lived arbitrage opportunities arise in the major FX and capital markets, challenging the theory of the CIP condition. The size of CIP arbitrage opportunities can be economically significant for the three exchange rates observed and for different maturities of the instruments involved in arbitrage. Moreover, the duration of arbitrage opportunities is usually high enough to make it possible for agents to exploit deviations from the CIP condition. At the same time, duration is low enough to suggest that before the GFC (Great Financial Crisis), in the markets arbitrage opportunities dissipate rapidly. These results entail that a researcher in international macro-finance can safely assume that prices in the FX market are arbitrage-free as using daily or lower frequency data. Contrary to previous researches which used low frequency data, the high speed of arbitrage documented in this chapter can explain why such opportunities have gone undetected until now. As a matter of fact, only if we use a data set at tick frequency for quotes of comparable domestic and foreign interest rates and spot and forward exchange rates, it is possible to identify the existence and measure the duration of a number of short-lived arbitrage opportunities.

2.2 Arbitrageurs' strategy

After having analysed the size, duration and frequency of the profitable deviations we can focus on the way agents in the market can exploit these arbitrage opportunities. We can define CIP arbitrage strategy as a self-financing strategy which fully hedges exchange rate risk. In this situation, demand shocks have no impact on prices because demand shocks are offset by arbitrage, with the strategy being profitable until CIP is re-established. Contrary to what we stated before about the profitability of these deviations it is clear that even small counterparty and market risks of FX swaps can lead to balance sheet costs that make CIP deviation unprofitable to arbitrage unless these are large enough. The no-arbitrage restrictions increase proportionally with the size of the balance sheet exposed to the exchange, bringing the balance sheet exposure of CIP arbitrageurs equal to net FX hedging demand. Balance sheet exposure is not the only trouble an agent could face when trying to exploit CIP deviations. For example, a potential arbitrageur which notices a negative Libor CIP basis on the yen/dollar market, could borrow in U.S. dollars at the dollar Libor rate, invest in yen at the yen Libor rate and at the same time enter a forward contract to convert back yen into U.S dollars at the end of her investment period. This investment strategy could hide several loss-making situations. First of all, it is not sure that the arbitrageur can really borrow and lend at the Libor rates. That's because Libor rates are only indicative quotes and do not correspond to actual transactions. The actual borrowing rate in U.S. dollars of the arbitrageur may thus be higher than the indicative Libor rate, even in the absence of any deviation. More generally, transaction costs exist for both spot and derivative contracts and may lower or even eliminate the actual returns. Moreover, when undertaking this strategy, the arbitrageur is taking on credit risk when lending at the yen Libor rate. Libor rates are unsecured: if the arbitrageur faces a risk of default on his loan, he should be compensated by a default risk premium, which may then compensate the return from the CIP deviations.

Finally, the fact that the arbitrageur is taking on counterparty risk when entering an exchange rate forward contract. This situation, however, can be ignored because the impact of counterparty risk on the pricing of forwards and swaps is mainly irrelevant due to the high degree of collateralization. So in case of a counterparty default, the collateral is confiscated by the other counterparty to cover the default cost.

The uncertain value of Libor rates and the potential default risk attached to them are instead effective distresses. In fact, cross-country differences in credit worthiness of several Libor panel banks may explain the default risk of CIP deviations. For example, assuming that the mean credit spread for the yen Libor panel is given by sp^{JPYt} and at the same time the mean credit spread for the U.S. dollar Libor panel is given by sp^{USDt}. Let y_t^{*JPY} and y_t^{*USD} be the true risk-free rates in yen and U.S. dollars and assume that CIP holds for risk-free rates, while $\rho_t^{JPY/USD}$ is the forward discount rate. If we replace each interest by the sum of the risk-free rate, then the credit spread equals to:

$$x_t^{JPY/USD,Libor} = (y_t^{*USD} + sp_t^{USD}) - (y_t^{*JPY} + sp_t^{JPY} - \rho_t^{JPY/USD}) =$$
$$= [y_t^{*USD} - (y_t^{*JPY} - \rho_t^{JPY/USD})] + (sp_t^{USD} - sp_t^{JPY})$$

The term inside the brackets is zero when there are no CIP deviations for risk-free rates. In this case, the Libor-based currency basis of the yen/dollar is given by the difference between credit risk in dollar and yen Libor panels:

$$x_t^{JPY/USD,Libor} = sp_t^{USD} - sp_t^{JPY}$$

Therefore, the yen basis can be negative if the yen Libor panel is riskier than the U.S. Libor panel. We test this hypothesis by regressing changes in the Libor basis $\Delta x_t^{i,Libor}$ for currency i on changes in the mean credit default swap spreads (CDS) between banks on the interbank panel of currency i and the dollar panel:

$$\Delta x_t^{i,Libor} = \alpha^i + \beta\Delta\left(cds_t^i - cds_t^{USD}\right) + \epsilon_t^i$$

Chapter 3

Possible causes of CIP deviations

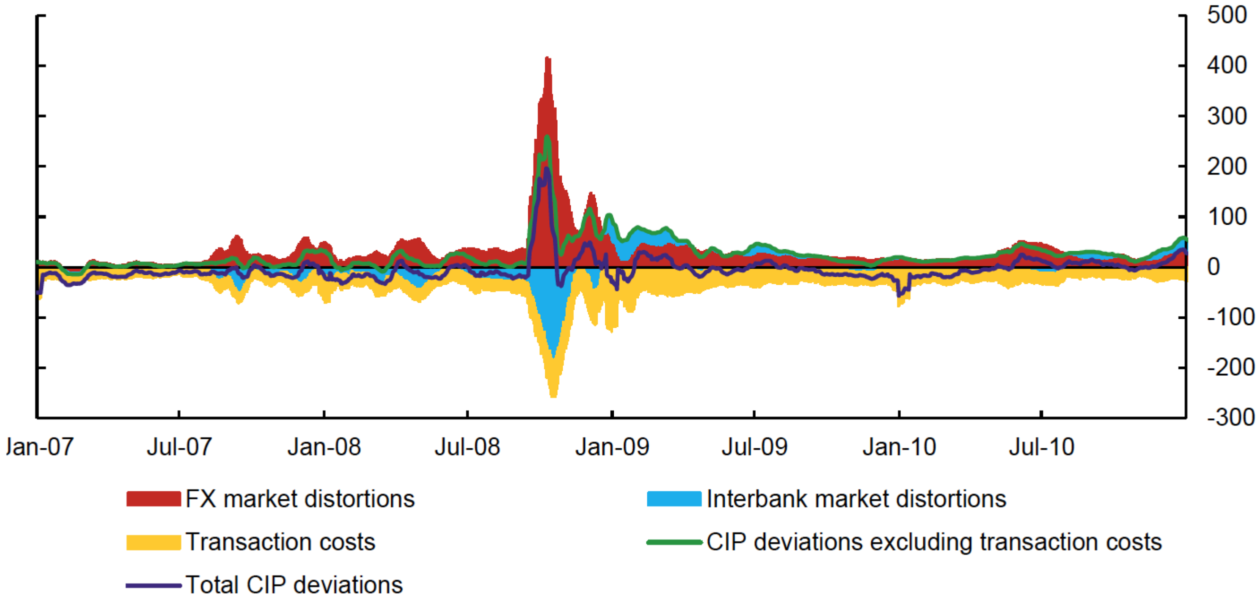
3.1 2007 Great Financial Crisis

In this chapter we are going to analyse the possible causes of CIP deviations and consequent arbitrage opportunities. In the past, and more specifically before the 2007 crisis, CIP deviations were arbitraged almost immediately and the CIP was enforced, with the exceptions of short-lived periods when arbitrage was constrained by bank counterparty risks, for example, during the Japan banking crisis and by wholesale US dollar funding strains, particularly during the Crisis and during the Eurozone sovereign debt crisis. That's because during that period it became more expensive to borrow dollars against most currencies, especially the yen and the euro, through FX swaps rather than in the money market. Originally, the common thought suggested that during times of stress, counterparty risk inhibited arbitrage. But, after an initial narrowing of the basis, it still increased around 2014, despite tranquil market and funding conditions. Moreover, the basis has been so wide that borrowing dollars in the cash market, swapping them for yen or euros and investing the returns at negative rates could still give a profit. That's because the balance sheet obligation to take the other side of net FX hedging imbalances in order to trade against CIP violations is costly. While balance sheet capacity has several number of dimensions, the important part for this analysis is a specific structure that emphasizes the costs coming from risks that arise when taking exposures to FX derivatives. This is justified from the fact that, regardless of the several ways in which CIP arbitrage can be funded, or foreign currency invested for the duration of the trade, all arbitrageurs would have to take positions in FX swaps or similar instruments. Balance sheet costs have become a mandatory constraint after the 2007 crisis. Prior to the crisis, in fact, the standard practice in the industry was to mark derivatives portfolios to market without taking the counterparty's credit quality into account, giving rise to bank trading models, because of the fact that balance sheets could be expanded essentially unconstrained in response to new movements hitting the swap trading desks.

After the crisis period of 2008-2011, the flow model has been replaced by a safer and more cost sensitive approach of balance sheet management. In FX derivatives, this means that market risk and counterparty risk are being priced-in at all times, even when measured risks are low. This brought to a consistent decline in the trading in interbank currency forwards in favour of currency futures, due to the fact that futures are traded on an exchange and counterparties post margins, they involve significantly lower counterparty risks than forward contracts, which are over-the-counter.

The balance sheet costs of CIP arbitrage arise endogenously because of a combination of counterparty and market risk. Meaning that if the counterparty defaults on the forward leg an FX swap, then a CIP arbitrageur will face market risk from exposure to foreign currency collateral. As long as markets clear, the aggregate CIP arbitrageurs' balance sheet exposure to FX swaps will exactly offset the net demand for FX swaps by those seeking to hedge currency risk. As a result, the currency basis responds to demand shocks to hedge currency risk forward and CIP can fail even in calm markets.

(Chart 1) Spread between EURUSD swap-implied dollar rate and USD Libor rates between 2007 and 2010



Sources: Bloomberg and Bank of Canada calculations

In this chart we can see how the spread opened up during the financial crisis. As shown by the blue line, the spread between USD LIBOR and OIS reached unprecedented levels, reflecting severe dollar funding shortages. However, the extent of funding market alterations was much bigger than that implied by the USD LIBOR-OIS spread, which applies only to LIBOR panel banks. Many banks were completely excluded of wholesale dollar funding markets and resorted to using FX swap markets to borrow dollars. Chart 1 captures this effect in the foreign exchange market distortions component, as shown by the red line. The net effect of these two opposite forces was a positive USD basis (considering transaction costs), which implied arbitrage opportunities to be exploited by borrowing USD and lending EUR.

3.2 Possible causes of CIP deviations

Deviations from CIP are at odds with a frictionless financial market. The main hypothesis is that the persistent and systematic CIP deviations can be explained by a combination of two factors: costly financial intermediation, which affects the supply of exchange rate forwards and swaps, and international imbalances in investment demand and funding supply across currencies, which affect the demand for exchange rate forwards and swaps. The cross-currency basis measures the cost of currency hedging subject to supply and demand side shocks.

3.2.1 Costly Financial Intermediation

Before the great financial crisis, global banks used to actively arbitrage funding costs in the interbank markets across currencies and doing so, enforcing the CIP condition. Since the crisis, a broad range of regulatory reforms has considerably increased the banks' balance sheet costs associated with arbitrage and market making activities. Bank regulations expectedly affected other non-regulated institutions, such as hedge funds, increasing the cost of leverage for the overall financial market. The main focus here is on how the recent banking regulations affected the CIP arbitrages: non-risk weighted capital requirements, or the leverage ratio, risk weighted capital requirements, and other banking regulations, such as the restrictions on proprietary trading and Liquidity Coverage Ratio. At the end, we will also focus our attention on the limits to arbitrage that other players, such as hedge funds, money market funds, FX reserve managers and corporate issuers are facing.

First of all, non-risk-weighted capital requirements are predominantly relevant for short-term CIP arbitrage. The leverage ratio requires banks to hold a minimum amount of capital against all on-balance-sheet assets and off balance- sheet exposure, without taking into consideration the degree of risk. Although short-term CIP trades have very little market risk, they still expand bank balance sheets and consequently decreases the leverage ratio. Before the crisis, the leverage ratio was not required for foreign banks; after Basel III, the leverage ratio is equal to 3%. For U.S. banks, even though the leverage ratio existed before the crisis, the required ratio became stricter after the crisis with the introduction of the supplementary leverage ratio, which equals 6% for systematically important financial institutions. The leverage ratio requirement is likely to be representing an important constraint on the bank balance sheet. If the binding leverage ratio is equal to 3% and if we assume that banks need to hold 3% of their capital against the CIP arbitrage trades and that their overall objective in terms of rates of return on capital is around 10%, then banks need at least a 3% × 10% = 30 basis point cross-currency basis to engage in the trade.

This means that many of the arbitrage opportunities that were shown previously may not be attractive enough for banks: to sum things up, CIP arbitrage has become balance sheet-intensive post crisis. This would bring banks to be reluctant to perform this activity. Moving to the Risk-weighted Capital Requirements, we observe that global banks face considerably higher capital requirements since the global financial crisis. Making an example, for the eight U.S. globally systematically important banks, under Basel III, the Tier 1 capital ratio increased from 4% pre-crisis to the 9.5%–13% range and the total capital ratio increased from 8% to the 11.5%–15% range. Moreover, together with higher capital ratios against the risk-weighted assets (RWA), the estimation of the RWA itself also increased significantly due to more severe capital rules and the higher volatility of the cross-currency basis.
The main component of the RWA calculation for a CIP trade is the 99% Value-at-Risk (VaR), which is a measure based on the 10-business-day holding period returns, normally calculated over a sample period that corresponds to the past calendar year. Since one-week arbitrage opportunities presents zero VaR, constraints about RWA only matter for long-term CIP arbitrages. For this reason, Basel II.5, which is effective from January 2013 in the United States, introduced an additional "stress-VaR" (SVaR) adjusted for the stress period. The cross-currency basis became significantly more volatile after the crisis, consequently increasing the VaR on the CIP trade, as we can see in the following chart.

(Chart 2) Long-Term Libor-Based Deviations from Covered Interest Rate Parity

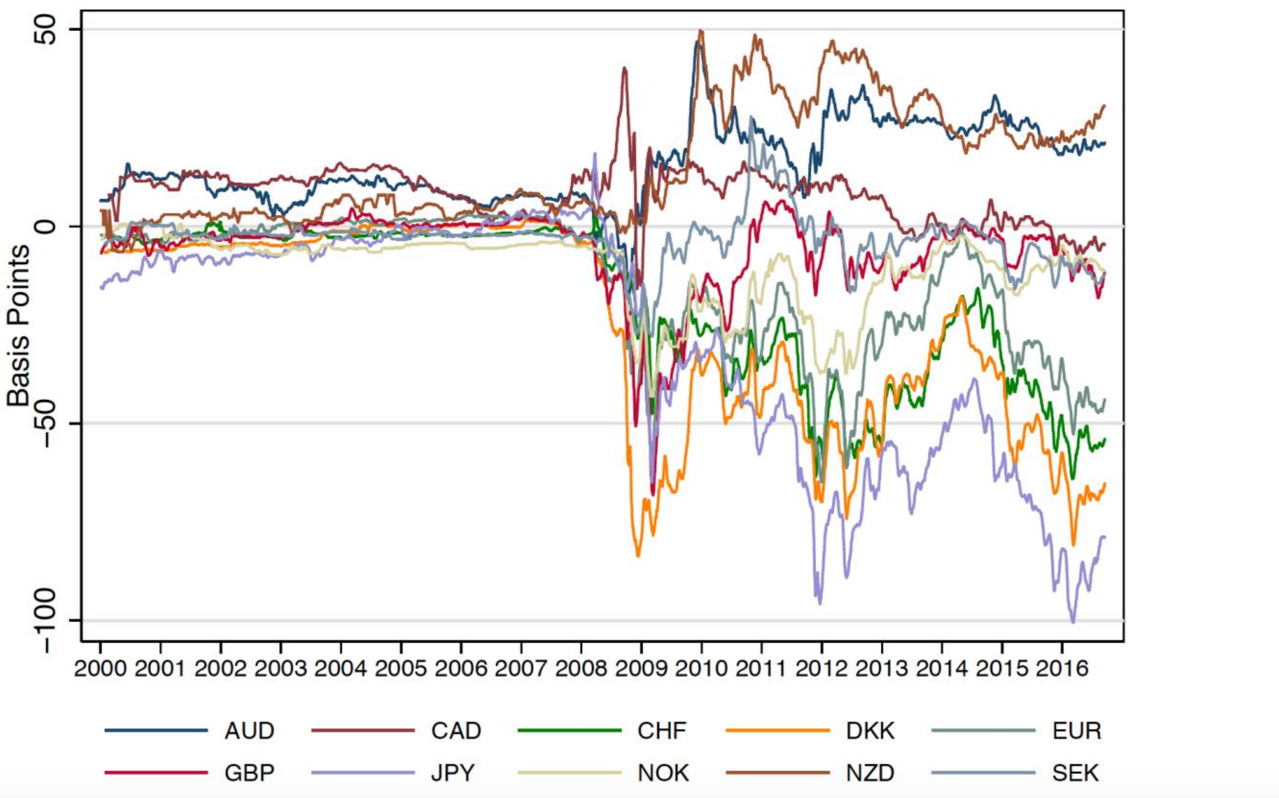


Chart 2 plots the 10-day moving averages of the five-year Libor cross-currency basis, measured in basis points, for G10 currencies. As we said, the covered interest rate parity implies that the basis should be zero.

(Table 1) U.S. Banks Capital Charges Against a Five-year Libor CIP Trade

Year	VaR	SVaR	Capital Ratio	Capital Charge (% of notional)
2000	4.87%		8%	0.56%
2001	3.34%		8%	0.39%
2002	3.65%		8%	0.42%
2003	3.64%		8%	0.42%
2004	3.12%		8%	0.36%
2005	2.07%		8%	0.24%
2006	1.92%		8%	0.22%
2007	3.26%		8%	0.38%
2008	19.21%		8%	2.22%
2009	20.28%		8%	2.34%
2010	12.03%		8%	1.39%
2011	12.78%		8%	1.47%
2012	14.39%		8%	1.66%
2013	8.94%	20.28%	8%	3.37%
2014	6.43%	20.28%	11.50%	4.44%
2015	9.20%	20.28%	11.50%	4.88%

From Table 1 instead, we can see the increase in capital charges against a five-year Libor CIP trade in recent years. The first column reports the 99% VaR measure for the trade based on the 10-business-day holding period; the VaR is annualized (multiplied by 26). The VaR measure was below 5% before the crisis, but increased to 20% during the peak of the crisis and remained elevated after the crisis. The second column reports the SVaR, implemented in January 2013 in the United States under Basel II.5, which equals the VaR in 2009.

The third column reports the minimum total capital ratio for U.S. banks. Finally, the fourth column presents the total capital charges against the CIP trade. It is obtained by multiplying the sum of VaR and SVaR by the minimum capital ratio and scaling by a factor of 12.5 times 3, as specified by the Basel rules. Capital charges against the five-year CIP trade increase dramatically from less than 0.4% before the crisis to more than 4% of the trade notional after both Basel II.5 and Basel III went into effect. In a nutshell, banks engaging in CIP arbitrages could trade a volume equal to 250 times their equity before the crisis; now, they can only trade a volume equal to 25 times their equity. While the RWA appears to be very small for short-term CIP arbitrage, it stands as a significant concern for long-term CIP arbitrage. Finally, if we focus on other banking regulations we observe that a bunch of them have also reduced banks' willingness to engage in CIP arbitrage.

As a result, banks can only participate in market making or assist arbitrage activities of their clients in the exchange rate derivative markets. Moreover, the over-the-counter derivatives' reform sets higher capital and minimum margin requirements for cross-currency swaps, which further increases the capital required to implement the CIP trade. The Basel III other than risk-weighted capital requirements and the leverage ratio, introduced also the Liquidity Coverage Ratio, which requires banks to keep High Quality Liquidity Assets (HQLA) against potential cash outflows during the 30-day stress period. Since the CIP trade goes long and short in funding of the same tenor, it generally has no effect on the Liquidity Coverage Ratio. However, also if the funding and investing legs of a short term CIP trade belong to different categories of instruments, for example, funding in the interbank market and depositing at the central bank, the Liquidity Coverage Ratio can be affected. Banks may engage in CIP arbitrage using the deposit facility at the central banks for the Liquidity Coverage Ratio consideration as central bank reserves are considered HQLA.

This regulatory reforms on banks certainly have some spill over effects on the cost of leverage faced by non-regulated institutions, such as hedge funds. That is because hedge funds need to obtain funding from their prime brokers, which are regulated institutions. In order to sell the CIP arbitrage strategy to their clients, hedge funds need to lever up the arbitrage strategy ten or twenty times to make it attractive to them. When they borrow large amounts, their borrowing costs may increase considerably as their positions show up in their prime brokers' balance sheets and consequently making primer brokers' capital requirements more binding. U.S. prime money market funds (MMFs) hold large amounts of commercial paper and certificates of deposits issued by foreign banks and act as an important alternative source of dollar funding to foreign banks. The recent MMF reform has had a substantial impact on the intermediation capability of the prime MMFs. The reform requires a floating Net Asset Value for prime MMFs and allows gates and fees to limit redemptions for prime funds, which led to large outflows of funds from prime MMFs to government MMFs.

Government MMFs do not hold bank commercial papers or credit deposits. On October 14, 2016 the new MMF reform was implemented, making dollar funding from U.S. prime MMFs scarcer and more expensive, which brought to a significant increase in the cross-currency basis.
Not only MMFs, but also FX reserve managers with large holdings of dollar-denominated dollar are in the good positions to arbitrage CIP deviations. For example, the People’s Bank of China recently increased their holdings of Japanese Treasury bills, which, on the swapped basis, quadrupled yields on U.S. Treasury bills. However, the persistence of CIP deviations between Treasury bills despite potential arbitrage suggests that the arbitrage position is not large enough.
Finally, also corporate issuers and bank treasuries can also arbitrage long-term CIP deviations by issuing long-term debt in different currencies and then swap them into their desired currency composition. In summary, the banking centre has a key role in the CIP arbitrage, because as we said CIP deviations can persist due to constraints on bank balance sheet capacity.
To conclude we can observe that CIP deviations are larger when the banks’ balance sheet costs are higher, particularly towards quarter-end financial reporting dates. In addition to this, CIP deviations usually are of similar magnitude as the balance sheet costs associated with wholesale dollar funding and finally CIP deviations should be correlated with other near-risk-free fixed-income spreads.
Costly financial intermediation is a likely cause of the overall increase in CIP deviations post-crisis. Nevertheless, in the absence of currency-specific trading costs, frictions to financial intermediation would likely affect all currencies similarly anyway. Yet, large cross-currency differences exist, pointing to hedging demand arising from international imbalances in funding and investment opportunities across currencies.

3.2.2 International Imbalances

The other element to consider in the analysis of the possible causes of CIP deviations are the international imbalances. Search-for-yield and carry trade motives create a large customer demand for investments in high-interest-rate currencies, such as the Australian and New Zealand dollars, and a large supply of savings in low-interest rate currencies, such as the Japanese yen and the Swiss franc. This imbalance brings to customer currency hedging demand to sell high-interest-rate currencies and buy low-interest rate currencies in the foreign exchange forward and swap markets, for example, Japanese pension funds need to sell dollars and buy yen forward to hedge their U.S. corporate bond portfolios. The problem is that financial intermediaries, such as foreign exchange swap market makers, supply currency hedging but do not want to bear the currency risk.

To achieve that, the financial intermediaries can hedge the currency exposure of their forward and swap positions in the cash market by going long in low interest rate currencies and short in high interest rate currencies. The profit per unit of notional is equal to the absolute value of the cross-currency basis, which justifies for the cost of capital associated with the trade.

The cross-currency basis is increasing in the nominal interest rate differential between the foreign currency and the dollar. The intuition behind the prediction is that the lower the interest rate, the higher the excess demand to sell U.S. dollar and buy foreign currency in the forward and swap market. A capital-constrained arbitrageur charges higher excess returns for taking the opposite of the trade due to diminishing returns to investment, which corresponds to a more negative basis. With the two-factor hypotheses in mind, we turn now to additional empirical evidence on CIP deviations.

3.3 Characteristics of the Basis

In the following part, we will discuss about the main characteristics of the basis and its systematic nature. First of all, we can observe that the basis is particularly high at the end of the quarter since the crisis. Second, we show that the average CIP deviations is of the same order of magnitude as an independent proxy for the cost of wholesale dollar funding. Then, we will see that the currency basis is correlated with other liquidity premium in fixed-income markets. Finally, we analyse how the basis increases with the level of interest rates in the cross section and in the time series.

3.3.1 Quarter-End Dynamics

Usually financial intermediaries face greater balance sheet constraints at the end of quarters due to quarterly regulatory filings, like key balance sheet variables, risk metrics, and leverage ratios which are reported at the quarterly frequency and analysed by regulators and investors.

As the banking regulation increased, and consequently investors' attention, since the global financial crisis apparently makes quarter-end balance sheet constraints more predominant than before. More specifically, the short-term CIP arbitrage has very little mark-to-market risk and the Leverage Ratio requirement is one important regulatory constraint. The Leverage Ratio is required by the Basel Committee to be disclosed on the quarter-end basis, at minimum. The actual calculation method of the Leverage Ratio is different across jurisdictions. The European Leverage Ratio Delegated Act, which is effective from January 2015, changes the definition of this ratio for European banks from the average of the month-ends over a quarter to the point-in-time quarter-end ratio.

Since European banks play an important role in intermediating U.S. dollars offshore, it is expected that the quarter-end dynamics should be particularly pronounced since January 2015 in the post-crisis period. In this section, we examine the effects of quarter ends on the level and term structure of CIP deviations. Since the crisis, we observe that one-week and one-month CIP deviations tend to increase at the quarter ends for contracts that would cross quarter-end reporting dates. The quarter-end anomalies became more intensified since January 2015, which coincides with the change in the leverage ratio calculation method for European banks. These discoveries are consistent with the view that strengthened balance sheet constraints at quarter ends translates into wider CIP deviations in the post-crisis period.

3.3.2 Quarter-end Effects on the Level of CIP Deviations

The effect previous mentioned was tested by Wenxin Du, Alexander Tepper and Adrien Verdelhan in their paper where they showed that CIP deviations are more pronounced at the end of the quarters respect to any other point in time, and especially so since the global financial crisis and since 2015. The difference-in-difference test for the one-week contract takes the following form:

$$\left|x_{1w,it}\right| = \alpha_i \beta_1 QendW_t + \beta_2 endW_t \times Post07_t + \beta_3 QendW_t \times Post15_t + \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it}$$

where $\left|x_{1w,it}\right|$ is the absolute value of the one-week basis for currency i at time t, α_i is a currency fixed effect. $Post07_t$ is an indicator variable equal to one after January 1, 2007 and zero otherwise, and $Post15_t$ is an indicator variable equal to one after January 1, 2015 and zero otherwise. The variable $QendW_t$ is an indicator variable that equals one if the settlement date for the contract traded at t is within the last week of the current quarter and the maturity date is within the following quarter. These one-week contracts crossing the quarter ends would show up on the bank balance sheet on quarter-end reporting dates.

The regression is estimated on the daily sample from 01/01/2000 to 09/15/2016 on one week Libor, OIS and repo bases. The coefficients β_2 and β_3 are the ones they have focused on, where β_2 captures the change in the quarter-end effect in the post-crisis 2007-2016 sample compared to the quarter-end effect in the 2000–2006 pre-crisis sample, and β_3 captures the additional changes in the quarter-end effect during the past two years relative to the post-crisis average effect.

Similarly, they also tested the quarter-end effect for the monthly CIP deviation as follows:

$$|x_{1w,it}| = \alpha_i \beta_1 QendM_t + \beta_2 endM_t \times Post07_t + \beta_3 QendM_t \times Post15_t + \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it}$$

where $QendM_t$ is a binary variable indicating if the settlement date and maturity date of the monthly contract spans two quarters. In the following table we can see the results of their regression.

(Table 2) Regression Results

Panel A	(1) 1w Libor	(2) 1w OIS	(3) 1w Repo	(4) 1m Libor	(5) 1m OIS	(6) 1m Repo
$QendW_t$	1.585*	2.446	6.624**			
	(0.963)	(2.851)	(2.675)			
$QendW_t \times Post07_t$	9.545***	11.23***	22.42***			
	(1.297)	(3.191)	(3.864)			
$QendW_t \times Post15_t$	37.30***	31.35***	38.48***			
	(2.257)	(3.406)	(7.014)			
$QendM_t$				-0.523	-0.397	0.331
				(0.598)	(1.407)	(1.928)
$QendM_t \times Post07_t$				4.748***	4.419**	13.01***
				(0.822)	(1.748)	(2.689)
$QendM_t \times Post15_t$				7.561***	8.154***	1.792
				(1.371)	(2.493)	(5.620)
$Post07_t$	11.00***	18.33***	21.71***	12.64***	13.55***	22.00***
	(1.036)	(2.737)	(2.301)	(1.062)	(2.057)	(2.587)
$Post15_t$	4.344***	4.838*	-8.259**	6.228***	5.795**	3.026
	(1.602)	(2.554)	(4.000)	(1.706)	(2.828)	(5.449)
Observations	32,102	22,664	9,921	41,577	31,765	9,262
R-squared	0.168	0.101	0.112	0.200	0.129	0.162

Columns 1, 2 and 3 consider the one-week CIP deviations based on Libor, OIS, and repos. The slope coefficients β_2 and β_3 are positive and statistically significant across all three instruments. The quarter-end CIP deviation relative to the mean deviation in the rest of the quarter is on average 10 to 22 basis points higher in the post-2007 sample than over the pre-2007 sample for the one-week contracts.

Additionally, compared to the post-2007 sample, the quarter-end weekly CIP deviation increases by another 30-40 basis points on average since January 2015. Columns 4, 5 and 6 consider the one-month CIP deviations. Still, the results show that β_2 and β_3 are all significantly positive except in one case. For CIP deviation based on Libor and OIS rates, the month-end deviation relative
to the rest of the quarter is on average 4 to 5 basis point higher post-crisis than the level pre-crisis and increases by another 8 basis point in the post-2015 sample. For one-month repo, even though β_3 is not significant, β_2 is highly significant and equals 13 basis points.
Moreover, they noted that coefficients on $QendW_t$ and $QendM_t$ are very small and largely insignificant, which suggests that there is very little quarter end effect before 2007.

3.3.3 Quarter-end Effects on the Term Structure of CIP Deviations

The quarter-end balance sheet constraints are also reflected in the term structure of the basis. We have seen that the one-week basis widens significantly as the one-week contract crosses quarter ends and one-month basis widens significantly as the one-month contract crosses quarter ends. On the other hand, since a three-month contract always shows up in one quarterly report regardless of when it is executed within the quarter, we should not expect isolated price movement one week or one month prior to the quarter end. Thus, the quarter-end balance sheet constraint has effects on the term structure of the basis.
More specifically, the difference between three-month and one-month CIP deviation ($ts_{t,3M-1M} \equiv |x_{t,3M}| - |x_{t,1M}|$) is expected to drop significantly once the one-month contract crosses the quarter-end. At the same time, the difference between one-month and one-week CIP deviation ($ts_{t,1M-1W} \equiv |x_{t,1M}| - |x_{t,1W}|$) is expected first to increase significantly as the one-month contract crosses the quarter end and then decreases significantly once the one-week contract crosses the quarter end.
Wenxin Du, Alexander Tepper and Adrien Verdelhan confirmed the characteristics previously observed with these panel regressions:

$$ts_{t,3M-1M} = \alpha_i \beta_1 QendM_t + \beta_2 endM_t \times Post07_t + \beta_3 QendM_t \times Post15_t + \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it}$$

This regression, similar to the one previously explained, used $ts_{t,3M-1M}$ based on Libor, OIS and repo.

(Table 3) Regression results

	(1) ts^{Libor}_{3M-1M}	(2) ts^{OIS}_{3M-1M}	(3) ts^{Repo}_{3M-1M}	(4) ts^{Libor}_{1M-1W}	(5) ts^{OIS}_{1M-1W}	(6) ts^{Repo}_{1M-1W}
$QendM_t$	0.565	0.565	0.565			
	(0.414)	(0.414)	(0.414)			
$QendM_t \times Post07_t$	-2.390***	-2.390***	-2.390***			
	(0.567)	(0.567)	(0.567)			
$QendM_t \times Post15_t$	-9.476***	-9.476***	-9.476***			
	(0.934)	(0.934)	(0.934)			
$\mathbb{I}_{QendM_t=1,QendW_t=0}$				-0.625	0.543	0.827
				(0.577)	(1.315)	(1.020)
$\mathbb{I}_{QendM_t=1,QendW_t=0} \times Post07_t$				4.242***	2.392	8.270***
				(0.773)	(1.466)	(1.505)
$\mathbb{I}_{QendM_t=1,QendW_t=0} \times Post15_t$				12.76***	11.05***	19.84***
				(1.226)	(1.426)	(3.635)
$QendW_t$				-3.217***	-3.782**	-5.618***
				(0.809)	(1.743)	(1.525)
$QendW_t \times Post07_t$				-1.404	-5.725***	-8.307***
				(1.085)	(1.950)	(2.353)
$QendW_t \times Post15_t$				-33.39***	-25.22***	-77.10***
				(1.849)	(2.057)	(6.177)
$Post07_t$	5.925***	5.925***	5.925***	0.843	-0.524	1.087
	(0.553)	(0.553)	(0.553)	(0.657)	(1.097)	(0.912)
$Post15_t$	-2.591***	-2.591***	-2.591***	0.444	1.594	5.516**
	(0.890)	(0.890)	(0.890)	(1.022)	(1.030)	(2.160)
Observations	41,553	41,553	41,553	32,045	22,491	7,337
R-squared	0.104	0.104	0.104	0.095	0.091	0.131

From the first three column of the table we can see that β_1 is small and insignificant, and β_2 and β_3 are both significantly negative. Compared to the pre-crisis sample, $ts_{t,3M-1M}$ is 2.4 basis point lower relative to its mean in the rest of the quarter when the one-month contract crosses the quarter ends in the post crisis sample. In the post-2015 sample, the quarter-end effect corresponds to another 9.5 basis point reduction in $ts_{t,3M-1M}$ compared to its post-crisis mean. The remaining three columns show similar tests for $ts_{t,1M-1W}$:

$$ts_{t,1M-1W=}\alpha_i + \beta_1\, \mathbb{I}_{QendM_t=1,QendW_t=0} + \beta_2\, \mathbb{I}_{QendM_t=1,QendW_t=0} \times \text{Post07}_t + \beta_3\, \mathbb{I}_{QendM_t=1,QendW_t=0} \times \text{Post15}_t + \beta_4 QendW_t + \beta_5 QendW_t \times \text{Post07}_t + \beta_6 QendW_t \times \text{Post15}_t + \gamma_1 Post07_t + \gamma_2 Post15_t + \epsilon_{it}$$

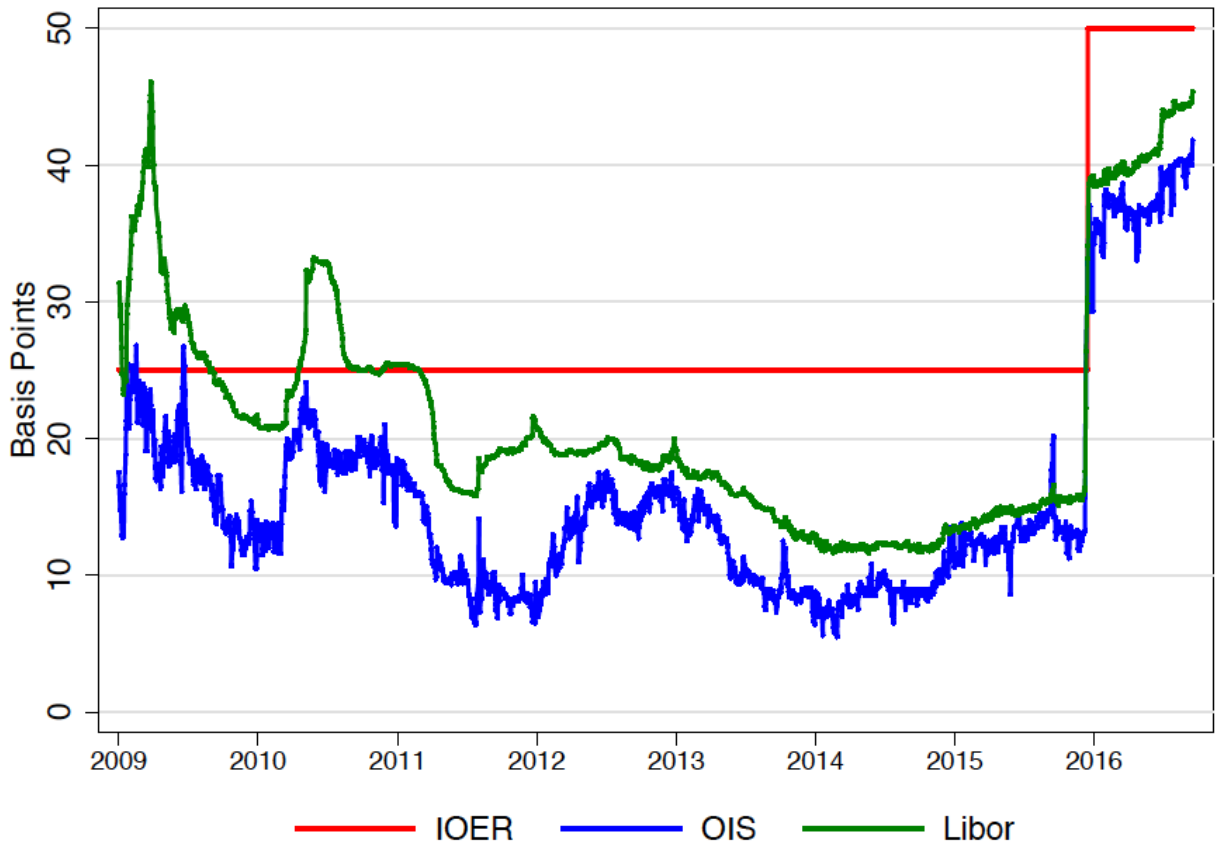
The variable $\mathbb{I}_{QendM_t=1,QendW_t=0}$ is an indicator that equals 1 if a one-month contract traded at t crosses the quarter end, but the one-week contract traded at t does not cross the quarter end. As expected, the coefficients β_2 and β_3 are significantly positive while β_5 and β_6 are significantly negative, which suggests that the difference between one-month and one-week CIP deviation first increases as the once-month contract crosses the quarter end, but the one-week contract does not, and then decreases as the one-week contract crosses the quarter end. Like in the previous results we can observe that these quarter-end effects are larger in the post-crisis period and especially since 2015. In a nutshell, consistent with the key role of banks' balance sheets on quarter-end reporting dates, we observe that CIP deviations are systematically higher for contracts that cross quarter end reporting dates post the crisis.

3.4 CIP Arbitrage Based on Excess Reserves at Central Banks

During the great financial crisis, major central banks implemented unconventional monetary policies, which brought global depositary institutions to have held large amounts of excess reserves at major central banks, for example the $2.4 trillion at the Fed and $0.5 trillion at the ECB.

As we know, excess reserves are compensated at an interest rate set by the central bank, which is known as the interest rate on excess reserves (IOER). The main feature of the IOER at the Fed is that it is often above interest rates paid on private money market instruments, for example, the Fed Fund rate. The main reason that the Fed fund rate stays persistently below the IOER in the United States is that government-sponsored enterprises (GSEs), such as Federal Home Loan Banks, do not have access to the IOER deposit facility and are willing to lend at rates below the IOER in the Fed Fund market. This creates the well-known IOER-Fed Fund arbitrage for depositary institutions with access to the IOER deposit facility, in which banks borrow in the Fed Fund market from the GSEs and deposit the proceeds in the forms of excess reserves at the Fed, earning the IOER-Fed Fund spread. The trade is risk-less as central bank cash is risk-free and dominates private money market instruments in terms of liquidity and unviability. We can better understand this concept by looking at the following chart which shows the IOER, one-week OIS and Libor rates for the U.S. dollar since 2009.

(Chart 3) IOER, one-week OIS and Libor rates for the U.S. dollar since 2009



We can observe that the IOER is always greater than the one-week OIS rate over the entire sample and is also greater than the one-week Libor rate starting in 2011. If borrowing funds at the Fed fund or Libor rate did not carry additional costs, banks would accumulate even more reserves at the Fed in order to exploit this arbitrage opportunity, and the interest rate gap between IOER and OIS would become zero.

Thus the spread earned on the IOER-Fed Fund (Libor) arbitrage gives a distinct measure of the cost of balance sheet expansion for depository institutions that participate in risk-free arbitrage opportunities. This cost is composed by two parts, which are for U.S. and foreign banks, the cost of leverage, summarized in leverage ratios, which is likely to be the most important part, since the trade is a risk-free one. For U.S. banks, an additional cost arises: the deposit insurance fees paid on wholesale funding. Thus, the gap between the IOER and OIS/Libor in the U.S. can explain about one-third of the one-week CIP deviations, however, since central bank reserves are considered HQLA for the Liquidity Coverage Ratio calculation, but interbank lending is not, the CIP arbitrage based on interbank rates has less favourable implications on the Liquidity Coverage Ratio than the IOER-Fed Fund arbitrage.

3.5 KfW Basis

We consider now the CIP deviations at the long end of the yield curves. General collateral repo contracts do not exist for long maturities, but we can focus on an alternative long-term cross–currency basis free from credit risk if we compare direct dollar yields on dollar denominated debt and synthetic dollar yields on debt denominated in other currencies for the same risk-free issuer and the same maturity in years. For this purpose, we consider bonds issued by the KfW, an AAA-rated German government-owned development bank, with all its liabilities fully backed by the German government. The KfW is a very large multi-currency issuer, with an annual issuance of around $70 billion and $370 billions of bonds outstanding. In their research, Wenxin Du, Alexander Tepper and Adrien Verdelhan compared KfW bonds of similar maturity issued in different currencies, assuming for simplicity, zero-coupon yield curves and swap rates.

Similar to the general definition of the basis, the KfW cross-currency basis is the difference between the direct borrowing cost of KfW in U.S. dollars and the synthetic borrowing cost of KfW in a foreign currency j:

$$x_{t,t+n}^{KfW} = y_{t,t+n}^{\$,KfW} - (y_{t,t+n}^{j,KfW} - \rho_{t,t+n}^{j})$$

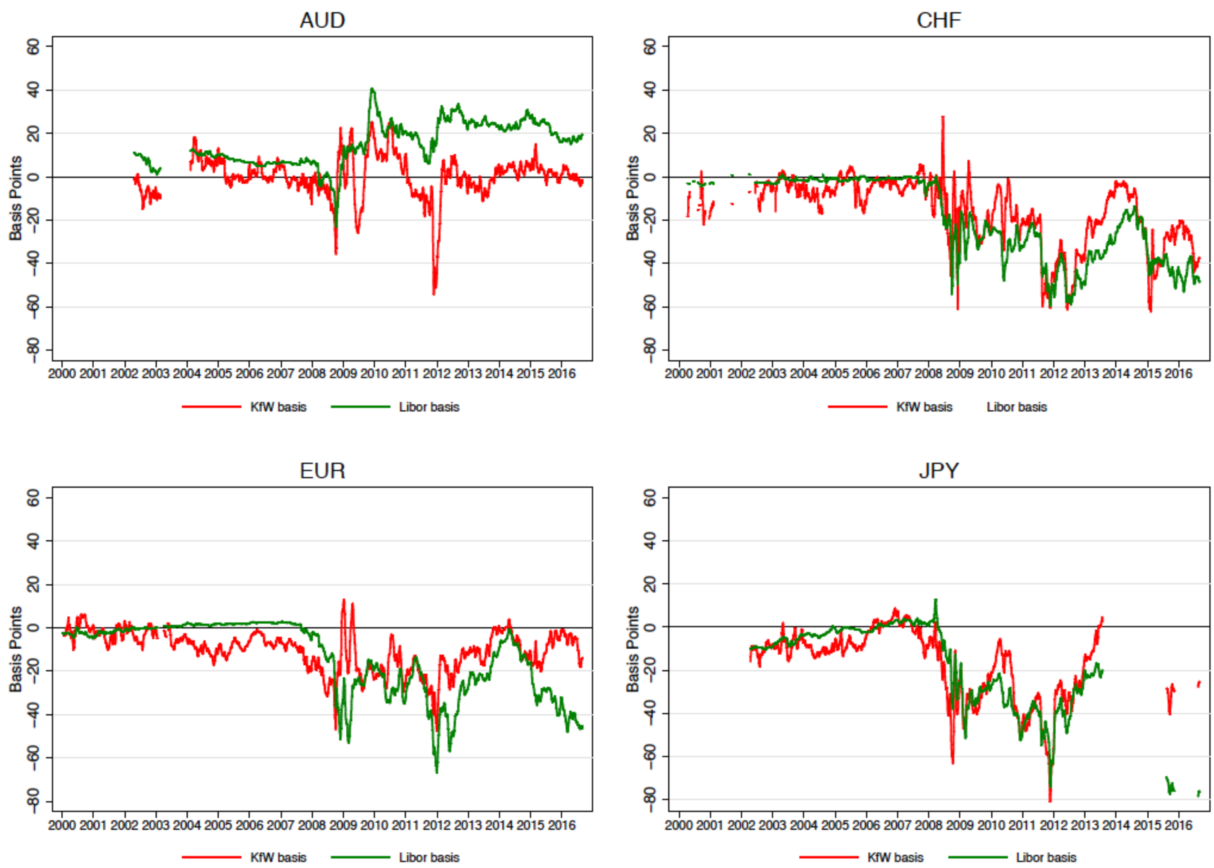
where $y_{t,t+n}^{\$,KfW}$ and $y_{t,t+n}^{j,KfW}$ refer to the zero-coupon yields on KfW bonds denominated in U.S. dollars and foreign currency j. We can see the results they obtained in the following table:

(Table 4) KfW basis

		Basis full sample	Basis conditional	Pos. Profits ex. shorting fee	Pos. Profits 25 pct fee	Pos. Profits median fee
AUD	Mean	0.1	6.9	4.3	6.1	5.8
	S.D.	(11.5)	(6.1)	(4.2)	(3.1)	(3.4)
	% sample		57%	10%	4%	2%
CHF	Mean	-23.5	-24.3	15.0	5.6	15.2
	S.D.	(15.7)	(15.0)	(10.7)	(10.0)	(8.9)
	% sample		97%	72%	50%	33%
EUR	Mean	-13.6	-14.7	9.3	2.5	8.7
	S.D.	(9.7)	(8.8)	(6.7)	(6.9)	(5.4)
	% sample		94%	68%	34%	23%
JPY	Mean	-30.2	-30.8	21.6	13.1	20.2
	S.D.	(15.2)	(14.6)	(13.5)	(13.1)	(11.3)
	% sample		98%	90%	75%	63%

The first column of the table shows summary statistics on the KfW basis during the January 2009 to August 2016 period. The mean post-crisis KfW basis is very close to zero for the Australian dollar (0.1 basis points) but is significantly negative for the other three currencies: -24 basis points for the Swiss franc, -14 basis points for the euro, and -30 basis points for the yen. The second column of the table, instead, shows similar summary statistics for the basis conditional on a positive basis for the Australian dollar and a negative basis for the other three currencies: while the Australian dollar basis is only positive 59% of the time, the other bases are negative at least 94% of the sample. As a result, the average conditional basis is 9 basis points for the Australian dollar, and close to their unconditional values for the other currencies: -24 basis points for the Swiss franc, -15 basis points for the euro, and -31 basis points for the yen. These results suggest that potential arbitrage strategies could be implemented. In the following chart we can see the time series of the KfW basis by currency.

(Chart 4) Time series of the KfW basis



When the KfW basis is negative, a potential arbitrage strategy would be to invest in the KfW bond denominated in foreign currency, pay the cross-currency swap to swap foreign currency cash flows into U.S. dollars, and short-sell the KfW bond denominated in U.S. dollars. When the KfW basis is positive, instead, the arbitrage strategy would be the opposite.

In summary the effect of cross-country differences in the liquidity of KfW bonds on the CIP deviations depends on the currencies. For example, the euro and the U.S. dollar are the most important funding currencies for KfW, followed by the British pound and the Australian dollar. Currently, there are about $170 billion euro-denominated KfW bonds outstanding and $130 billion dollar-denominated bonds outstanding. The liquidity of euro-denominated KfW bonds is more or less the same of the liquidity of dollar-denominated bonds. Thus, liquidity differential cannot explain the positive arbitrage profits of going long in the euro bonds and shorting the U.S. dollar bonds. At the same time, the Australian dollar market, with the amount outstanding around $21 billion, is considerably less liquid than the U.S. dollar and euro market. Therefore, the lower liquidity in the KfW Australian market may explain the finding of positive CIP arbitrage opportunities of going long in U.S. dollar-denominated KfW bonds and shorting Australian-dollar denominated KfW bonds, despite sizeable potential arbitrage opportunity implied by Libor. Instead, the Swiss franc and the Japanese yen markets are relatively small with total amounts outstanding of less than $5 billion, thus resulting in a liquidity differential that can potentially explain the positive profits of going long in the more illiquid yen and Swiss franc KfW bonds and shorting the more liquid dollar KfW bonds.

To conclude, deviations from CIP are present in many currency and fixed income markets, often representing significant arbitrage opportunities.

Chapter 4

Conclusions

In this paper we have examined persistent and systematic failure of the CIP conditions in the post crisis period and we have provided evidence that short-lived arbitrage opportunities arise in the major FX and capital markets. The size of CIP arbitrage opportunities can be economically significant for different exchange rates examined and across different maturities of the instruments involved in arbitrage. The duration of arbitrage opportunities is, on average, high enough to allow agents to exploit deviations from the CIP condition. However, duration is low enough to suggest that markets exploit arbitrage opportunities rapidly. These results, coupled with the unpredictability of the arbitrage opportunities, imply that a typical researcher in international macro-finance can safely assume arbitrage-free prices in the FX market when working with daily or lower frequency data.

We also saw that there is not a specific time during the day or during the week when arbitrage opportunities arise, making it more difficult to identify and exploit these deviations.

Finally, we showed that these arbitrage opportunities can be explained by the interaction between costly financial intermediation and international imbalances in funding supply and investment demand across currencies. Consistent with this two-factor hypothesis, we showed some characteristics of CIP deviations. First of all, CIP deviations increase at the quarter ends post crisis for short-term contracts, reflecting the impact of the Leverage Ratio on asset prices. Second, CIP deviations can be softened once we take into account the balance sheet cost associated with wholesale dollar funding.

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