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Covered Interest Parity in long-dated securities

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Covered Interest Parity in long-dated securities

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Abstract This paper investigates the validity of Covered Interest Rate Parity (CIP) in long-dated fixed income securities. I show that common measures of CIP rely on trading strategies subject to rollover risk and credit risk, or fail to fully account for the trading costs. Hence, round-trip CIP profit is generally not possible to reap when the trade is risk-free and all costs are taken into account. In particular, short-selling costs (haircuts and lending fees) and differences in funding spreads across currencies allow for substantial deviations from common measures of CIP without implying arbitrage opportunities. In contrast to recent research, my results lend little support to the view that stricter banking regulations have led to persistent arbitrage opportunities in long-dated fixed income markets.

Keywords: Covered Interest Parity, FX-swaps, Libor, Corporate bonds, Arbitrage, Securities Lending

JEL: E43, F31, G15

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1 Introduction

Covered Interest Parity (CIP) has been known as one of the most reliable no-arbitrage conditions in international finance. According to CIP it should not be possible to earn risk free profit by borrowing in one currency and investing in another with the foreign exchange rate fully covered. Since the global financial crisis (2008-2009), seemingly large deviations from CIP have puzzled academics, policy makers and market participants alike. Despite several years of tranquil financial conditions, recent work indicates persistent and sizeable arbitrage opportunities in some of the most liquid long-dated fixed income and currency markets in the world (Du et al. [2019], Liao [2020], Sushko et al. [2016], Avdjiev et al. [2019]).

The failure of CIP is commonly ascribed to the post-crisis tightening of banking regulations.[1,2] According to this view, tighter balance sheet constraints make it more costly for banks to step in as arbitrageurs. In turn, this may lead to unexploited arbitrage opportunities, less efficient markets and a breakdown of CIP. If proven correct, stricter banking regulations have broad implications for market efficiency and the relative pricing of fixed income securities across currencies.

This paper revisits the validity of CIP across a range of long-dated fixed income securities for three major currency pairs; EUR, JPY and GBP, against USD.[3] An important premise for CIP arbitrage is that the profit is riskless and adjusted for trading costs. To this end, I look into various trading strategies to ensure that the strategy is truly risk-free and that all costs are identified. I examine Libor swaps (fixed-for-floating interest rate swaps), corporate bonds and government bonds and refer to deviations between the synthetic and direct interest rate as the basis, i.e. the Libor basis, the government bond basis and the corporate bond basis. My results suggest that CIP arbitrage is difficult to reap and that common measures of CIP rely on trading strategies subject to rollover risk and credit risk, or fail to fully account for the trading cost.

As a point of departure, Figure 1 depicts the 5-year EUR/USD basis for Libor swaps, high quality corporate bonds and risk-free government bonds in two tranquil periods before and after the global financial crisis. Prior to the crisis (2004-2006), the corporate bond basis and the Libor basis were close to zero. In the same period, the government bond basis hovered between -30 and -40 basis points. Seen from the perspective of an U.S. investor, this means that U.S. Treasuries yield less than German government bonds with the exchange rate risk fully covered. After the crisis (2015-2017), the Libor basis has moved into negative territory. In contrast, the corporate bond basis has been near zero in both periods.

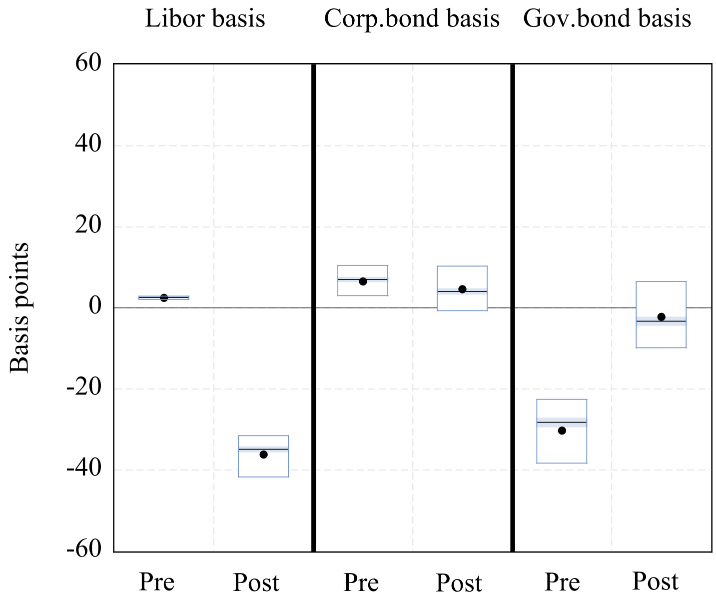
Figure 1 raises several questions. Why has the Libor basis widened so much after the financial

[1] See for instance Du et al. [2019], Liao [2020], Sushko et al. [2016], Avdjiev et al. [2019]

[2] The Basel III framework introduces new capital and liquidity standards. This includes higher capital requirements for banks, a strengthening of banks liquidity coverage (Liquidity Coverage Ratio - LCR) and a more stable funding structure (Net Stable Funding Ratio - NSFR). Moreover, some jurisdictions have introduced Leverage Ratios limiting the amount of bank leverage independent of the risk profile of the asset side of the bank. These regulations have been gradually implemented since the global financial crisis.

[3] Long-dated is defined in this paper as 1 year to maturity and beyond.

Figure 1
Deviations from CIP before and after the global financial crisis (EUR/USD)



Note: The graph depicts a boxplot of the 5-year Libor basis, corporate bond basis and government bond basis for EUR/USD in two tranquil periods prior to the financial crisis(Pre=2004-2006) and after the global financial crisis (Post=2015-2017). The figure shows median (black horizontal line), average (dot), and ranges between the 25 per cent and 75 per cent quantiles (box). The corporate bond basis is calculated based on zero coupon bonds of high quality (AA) issued by financial institutions. The Government bond basis is calculated based on US and high quality European government zero coupon bonds (AAA). The Libor basis is the deviations from CIP using on Libor interest rate swaps. Negative values indicate that the US denominated security yields lower return (higher price) than the European denominated security swapped into USD, i.e. after the exchange rate risk is fully covered.

crisis? Why was the (risk-free) government bond basis well below zero already prior to the post-crisis tightening of banking regulations? A challenge for the explanation related to tighter banking regulations is that a wide range of bond market participants are not subject to these regulations. For instance, why would a relatively unconstrained hedge fund leave risk-free profit on the table? These questions call for further analysis on the impediments to cross currency arbitrage in long-dated securities.

I first turn to the Libor basis - the difference between the direct and the synthetic Libor swap rate.[4] The Libor basis is a frequently applied measure of long-dated CIP deviations and has traded at unprecedented levels ever since the global financial crisis.[5] However, the Libor basis is not suited to measure CIP deviations due to substantial roll-over risk and the failure of the Libor swap rates to accurately reflect the costs of avoiding this roll-over risk - which I refer to as the term funding liquidity premium. The Libor swap is a derivative reflecting the expected path of the underlying short-term floating rate. Hence, to take advantage of the 5-year Libor basis, for instance, the investor has to raise funding every quarter exactly at the 3-month Libor rate over the next 5 years.[6]

Although the roll-over risk is always inherent in the Libor basis trade, it only shows up in the Libor basis if the costs of avoiding roll-over risk differ across currencies. Indeed, the Libor basis is basically a necessary compensation for such differences as the Libor swap rate in the two currencies does not reflect the true cost for borrowing and lending at the respective tenor. My empirical results suggest that cross-currency differences in the relative costs of locking in funding over longer periods - the term funding liquidity premium - is an important driver of the Libor basis after the global financial crisis. Divergence in the timing, scale and composition of central bank asset purchases contribute to the differences in the term funding liquidity premium. Furthermore, trading the Libor basis exposes the trader to credit risk in the investment leg. The considerations above substantiate that the Libor basis is not an adequate measure of CIP deviations.

To avoid the roll-over risk in Libor swaps, one may turn to corporate bonds where the principal is exchanged at the same tenor as the FX forward agreement. Hence, corporate bond rates should embed the full term funding liquidity premium at the relevant tenor and the corporate bond basis is expected to be significantly closer to zero than the Libor basis. To verify this, I construct the deviations between the synthetic and direct corporate bond rate for similar bonds. I find that the corporate bond basis is substantially closer to zero and less persistent than the corresponding deviations based on Libor swap rates. Moreover, empirical tests indicate that the long run relationship between corporate bond spreads and the Libor basis is in line with the CIP-condition. These results are consistent with the hypothesis that corporate bond rates indeed account for differences in the

[4]The Libor swap rate is often referred to as Interest Rate Swaps (IRS). The Libor basis is equivalent to a Cross Currency Basis Swaps (CCBS) which is quoted directly on data vendors like Bloomberg and Thomson Reuters.

[5]Several studies have shown the tight correspondence between the Libor basis and CCBS, see for instance Du et al. [2019].

[6]The underlying short-term rate in Libor swaps are typically 3-month or 6-month Libor. In this paper I use 3-month Libor rates. In currencies where Libor is not quoted, an equivalent interbank benchmark rate acts as the underlying floating rate. Although Libor is quoted in EUR, the market convention is Euribor.

term funding liquidity premium across currencies.[7]

Corporate bonds are typically not risk-free. Hence, the corporate bond basis can be exploited by bond issuers, but deviations do not represent round-trip arbitrage opportunities.[8] To eliminate the credit risk embedded in the corporate bond basis, a risk-free option is government bonds. Du et al. [2019] suggest that deviations between the synthetic and direct risk-free bond rate - e.g. the government bond basis - can be arbitraged by going short the "expensive" bond denominated in one currency and investing in the "cheap" bond denominated in another currency with the exchange rate risk fully covered (the short/long strategy).[9,10] The authors argue that the persistent deviations between the synthetic and direct risk-free bond rate - in their case bonds issued by the German government sponsored bank KfW - are due to stricter banking regulations introduced in the aftermath of the financial crisis.

The short/long strategy incurs substantial shorting costs in the form of haircuts and lending fees. My estimations of the shorting costs suggest that the post-crisis CIP deviations for government bonds generally are below the costs of employing a short/long strategy. The costs of haircuts and lending fees stemming from the short position effectively limit round-trip arbitrage in bonds.[11] The funding required to trade the CIP deviations in government bonds has to be raised by short selling. To obtain the security to sell short, the arbitrageur has to pledge collateral with the lender of the security. In the CIP trade, the value of the foreign denominated bond (long position) is not sufficient when the security lender requires a haircut. Typically, security lenders require a 5 per cent haircut when the collateral is denominated in foreign currency due to the substantial currency risk such collateral pose to the securities lender, see for instance Grohowski [2014], Duffie et al. [2002], Bassler and Oliver [2015] and Brunnermeier and Pedersen [2009]. On the top of the cost of haircut the arbitrageur faces a lending fee of at least 15 basis points (Baklanova et al. [2016]).[12]

Moreover, as shown in figure 1, the government bond basis persistently traded below zero prior to the introduction of new banking regulations. This simple observation, also carefully documented in Du et al. [2018], substantiates that shorting costs is a more plausible explanation for the observed deviations in risk-free bonds than stricter banking regulations. It also explains why market participants not subject to banking regulations, like hedge funds, are not able to close the government bond basis.

[7] These results are also consistent with the findings in Liao [2020]. However, this paper conducts a more granular comparison of corporate bond rates across currencies for instance by comparing bonds issued by financial corporations domiciled in the same country.

[8] This is because, conditional on default, the payoff from the claim in the two currencies differs.

[9] Du et al. [2019] employ bonds issued by the government owned bank KfW. This means that they can compare bonds issued by the same issuer across currencies. However, as long as the bonds are risk-free it does not matter if the issuer is different. Hence, I examine the government bond basis as government bonds are traded in much deeper markets (better market liquidity), with large outstanding volume and are easier to obtain in the securities lending market - a precondition for the short/long strategy.

[10] Note that it is not possible to employ the short/long strategy to take advantage of the Libor basis as Libor swaps are derivatives with no exchange of the principal.

[11] Note that haircut applies to all types of bonds, not only government bonds.

[12] Given that these 15 basis points are based on collateral denominated in the same currency as the borrowed security it is likely a conservative estimate when the collateral is of foreign currency denomination.

Despite not representing round-trip arbitrage, investors with a portfolio of US government bonds can indeed enhance their return by selling U.S. government bonds and buying foreign government bonds with the foreign exchange rate risk fully covered when the basis is negative. Textbook representations of CIP suggest that with such return-enhancing opportunities available, investors will push the government bond basis towards zero by reallocating their portfolios. However, such return-enhancing opportunities were equally large prior to the introduction of new banking regulation. Hence, a more plausible explanation is a USD specific premium: investors value USD liquidity highly due to its status as the main settlement, funding and investment currency in the world. U.S. government bonds can easily be turned into USD cash (via the repo market for instance), while the costs of turning foreign denominated bonds into USD cash is much more difficult and costly - in particular in distressed markets when the demand for liquidity is high. This argument is in line with U.S. Treasuries being subject to a convenience yield. Note that the convenience yield hypothesis cannot explain why market participants are not employing the short/long strategy, but serves as an explanation for real money investors preference for U.S. Treasuries.

Finally, I test for round-trip arbitrage opportunities in international bond markets based on actual unsecured funding costs for high quality financial corporations in the funding leg and the risk-free government bond rate in the investment leg. This strategy captures the funding costs of potential arbitrageurs of high credit quality.[13] The trading strategy I propose assumes that one can borrow unsecured in USD and invest in a risk-free asset in one of the foreign currencies (EUR, GBP or JPY), or borrow unsecured in foreign currencies and invest in a risk-free asset in USD. I find no evidence of persistent risk-free profit opportunities in major bond markets based on this measure.

Overall, my analysis lend little support to the hypothesis that stricter banking regulation has distorted long-dated fixed income and currency markets. Although the cross currency basis is sizeable for risk-free bonds, this was also the case prior to the post-crisis tightening in banking regulations. Moreover, round-trip arbitrage in risk-free bonds is difficult to reap due to substantial costs associated with shorting bonds or due to the direct funding costs that apply when financing the trade. Real-money investors that can increase portfolio returns without adding credit risk by reallocating out of US government bonds seem to prefer securities that can easily be turned into USD liquidity. Holding liquid assets in USD is particularly valuable during a crisis and consequently act as an insurance against market volatility.

The rest of this paper is organized as follows. Section 2 provides an overview of related literature, Section 3 defines relevant concepts, Section 4 examines the Libor basis, Section 5 takes a closer look at the relation between the Libor basis and the corporate bond basis, while Section 6 discusses costs and risks associated with taking advantage of cross currency deviations between risk-free government bonds. In Section 7 I assess arbitrage opportunities in bonds after accounting for actual funding costs. Section 8 concludes.

[13] This strategy is in line with the one Rime et al. [2019] examine for short-term maturities and can be interpreted as a way to incorporate the practice of Funding Value Adjustment (FVA).

2 Related literature

This paper is closely related to a growing body of literature investigating deviations from Covered Interest Parity in long-dated fixed income markets, in particular Du et al. [2019] and Liao [2020]. Du et al. [2019] suggest a short/long strategy to take advantage of deviations between the synthetic and direct bond spreads in risk-free bonds. The authors show large and persistent deviations between the direct and synthetic USD rate for bonds issued by the German government sponsored bank KfW. They argue that these deviations represent potential arbitrage opportunities and ascribe its existence to the introduction of new banking regulation. My results indicate that the long/short strategy is more costly than assumed by Du et al. [2019] due to haircut in the securities lending market. Liao [2020] looks at corporate bond spreads and establishes that the spreads are different across currencies and co-move with the Libor basis. This is consistent with my findings for the corporate bond basis. Liao [2020] links the differences in bond spreads across currencies and the Libor basis to limits of arbitrage in the two market segments and highlights regulatory constraints as a reason for the lack of arbitrage activity.

Sushko et al. [2016] investigate the Libor basis and relates the widening of the basis to hedging demand caused by currency mismatch between assets and liabilities on banks' balance sheets. The authors argue that the persistent non-zero Libor basis is due to new regulatory costs for banks limiting the arbitrage flows. Avdjiev et al. [2019] also look at the long-term Libor basis and relate the widening to the USD exchange rate. They argue that the cross currency basis widens when the USD strengthens.

Although my paper examines CIP-deviations at longer maturities, it is also closely related to a large literature on the validity of CIP in money markets. The first wave of literature on short-term CIP-deviations emerged shortly after the outburst of the global financial crisis, see e.g. Baba et al. [2008], Baba and Packer [2009a], Baba and Packer [2009b], Coffey et al. [2009], Gârleanu and Pedersen [2011], Goldberg et al. [2011], Griffoli and Ranaldo [2010] and McGuire and von Peter [2012]. Common for these studies is the focus on market frictions arising as a result of the financial crisis.

As market conditions stabilized from 2014 another wave of interest in the CIP-condition and the seemingly large violations of CIP emerged, i.e. Du et al. [2019], Rime et al. [2019], Cenedese et al. [2019], Iida et al. [2016], Wong et al. [2016] and Pinnington and Shamloo [2016]. Du et al. [2019] look at the deviations in repo rates arguing that regulatory constraints are the main reason for these deviations. In contrast, Rime et al. [2019] focus on differences in funding liquidity and unconventional monetary policy. The authors show that a narrow group of global banks face arbitrage opportunities, but that the scalability of this arbitrage is limited due to funding constraints. Cenedese et al. [2019] argue that dealers with higher leverage ratio charge less attractive FX forward prices to their customers.

Finally, my paper is also related to research on the effect of central bank balance sheet policies on bond prices and the funding liquidity premium. Specifically, it adds to an emerging literature on the balance sheet composition of private banks caused by central bank operations. For instance, Christensen and Krogstrup [2016] explain how an increase in the central bank balance sheet increases private banks' deposit ratio, while Haldane et al. [2016] and Butt et al. [2014] discuss the bank credit channel of central bank balance sheet policies. Moreover, Abidi and Miquel-Flores [2018] find that corporate bonds eligible under the ECB's corporate asset purchase program experienced a significant yield reduction compared with those not eligible. In this paper I relate central bank balance sheet policies to funding liquidity through higher demand for bonds and an improvement in the deposit base for banks.

3 Covered Interest Parity

This section clarifies the main concepts in the paper - Covered Interest Parity, the cross currency basis and the requirements for arbitrage.

Covered Interest Parity (CIP) Generally, CIP can be expressed by the following equation:[14]

$$\left(1 + r_{m;\$}\right) = \frac{F_m}{S}\left(1 + r_{m;\star}\right), \tag{1}$$

that is, the direct interest rate ($r_{m;\$}$) equals the synthetic FX swap implied rate $\frac{F_m}{S}\left(1 + r_{m;\star}\right)$, where F_m is the forward exchange rate, m is the maturity and S is the spot exchange rate. The subscript t for time is suppressed for simplicity.

Equation 1 holds if the forward and the spot rate (the hedging cost) is equal to the interest rate differential. By applying log approximation equation 1 can be written as:

$$f_m - s \approx r_{m;\$} - r_{m;\star} \tag{2}$$

At a given tenor m, the FX hedging component, i.e. $f_m - s$, is homogenously priced in the interdealer market and can easily be obtained through data vendors like Bloomberg and Thomson Reuters.[15] In contrast, one can compute a plethora of interest rate differentials ($r_{m;\$} - r_{m;\star}$) by using the interest rates on various fixed income securities. Consequently, two important questions arise. First, which interest rate differential corresponds to the hedging cost (interest rate differential) in the foreign exchange market? Second, which instruments can be used to construct proper arbitrage strategies? The answers to these questions are crucial when analyzing deviations from CIP. Since a cross currency trade necessarily involves the exchange of currencies, the interest rate

[14] Subscript t for time is dropped for simplicity.

[15] Interdealer transactions as quoted on Bloomberg and Thomson Reuters are typically subject to two-way variation margins leading to low degree of price dispersion.

differential priced in the FX swap market must correspond to an interest rate differential composed by instruments where funding can be raised and money can be invested at the relevant tenor.

The cross currency basis In line with the recent literature on CIP, I refer to the deviation from the general CIP-equation (equation 1) as the cross currency basis. Hence, the cross currency basis (ρ_m) is defined as follows:

$$\rho_m = \left(1 + r_{m;\$}\right) - \frac{F_m}{S}\left(1 + r_{m;\star}\right) \tag{3}$$

I examine three cross currency bases based on the following fixed income instruments; Libor swaps (interest rate swaps), corporate bonds and government bonds. I refer to the three bases as the Libor basis, the corporate bond basis and the government bond basis, respectively. It is important to stress that each basis potentially can be traded with profit when it deviates from zero, but this does not necessarily imply viable *arbitrage* opportunities.

Covered Interest Rate Arbitrage The requirements for an implementable round-trip arbitrage trade imply that i) the trade is adequately adjusted for the transaction costs; (ii) the instruments involved need to be tradeable; and (iii) the sequence of trades involved is free of risk for the arbitrageur.

Taking bid/ask spreads into account, and both from the perspective of U.S. and foreign borrowing, the CIP-trade is *not* profitable under the following conditions:

$$\left(1 + r^a_{m;\$}\right) \geqslant \frac{F^b_m}{S^a}\left(1 + r^b_{m;\star}\right) \tag{4}$$

$$\left(1 + r^a_{m;\star}\right) \geqslant \frac{S^b}{F^a_m}\left(1 + r^b_{m;\$}\right) \tag{5}$$

where the superscripts a and b symbolize ask and bid rates, respectively, and $r^a > r^b$. Equation (4) implies that the funding rate (ask) in USD has to be equal to or higher than the synthetic investment rate (bid) measured in USD for the no-arbitrage condition to hold. Similarly, Equation (5) implies that the funding rate (ask) in the foreign currency has to be equal to or higher than the synthetic investment rate (bid) measured in foreign currency for the no-arbitrage condition to hold.[16]

As I will discuss later, the bid/ask spreads constitute a small part of the trading costs in the CIP trade. The largest part is associated to the costs of obtaining the necessary funding at the relevant maturity and potential short-selling costs. It is also important that the security in the investment leg is risk-free.

[16]Note that the currency convention, i.e. if it is EUR/USD or USD/EUR, matters for the exact specification of the equations. Equation (4) and (5) are based on USD as the base currency.

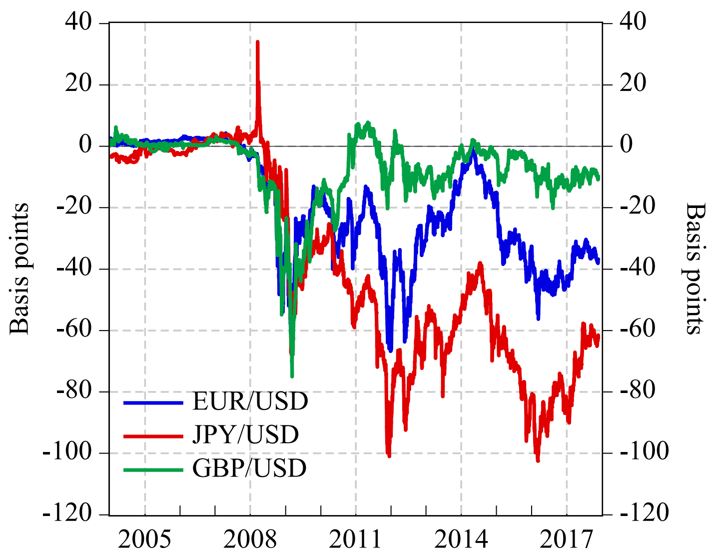
4 The Libor basis

This section examines a frequently reported measure of long-dated CIP deviations - the Libor basis.[17] The Libor basis (ρ_m^{Lib}) is the difference between the direct and the synthetic Libor swap rate:

$$\rho_m^{Lib} = \left(1 + c_{m;\$}\right) - \frac{F_m}{S}\left(1 + c_{m;\star}\right), \tag{6}$$

where $c_{m;\$}$ is the USD Libor swap rate, $c_{m;\star}$ is the foreign currency Libor swap rate, while F_m and S are the forward exchange rate and the spot exchange rate, respectively. Subscript m refers to the maturity. Figure 2 depicts the evolution in the 5-year Libor basis for EUR, GBP and JPY, against USD. The Libor basis traded fairly close to zero across all three currency pairs prior to 2008. Since the onset of the global financial crisis, the Libor basis has been volatile and persistently below zero across the currency pairs.

Figure 2
The 5-year Libor basis



Note: The graph shows the 5-year Libor basis for three currencies - EUR, JPY and GBP - against the USD. The series are showing mid prices extracted from Bloomberg. A negative value means that the direct Libor swap rate in USD is lower than the synthetic Libor swap rate based on foreign currency.

At first glance it may seem like the post-crisis widening of the Libor basis convincingly represents large and persistent deviations from CIP and consequently opportunities to reap arbitrage profit. However, the properties of the underlying Libor swap rates in the Libor basis challenge this interpretation. If the 5-year Libor basis is minus 35 basis points between EUR and USD, a number close

[17] The focus in this analysis is on maturities ranging from 2 to 10 years. The Libor basis is effectively quoted in the market as the cross currency basis swaps. Several papers have shown the correspondence between the Libor basis calculated as the Libor swap rate plus the FX implied interest rate differential and the cross currency basis swap, see for example Du et al. [2019]. In order to stick to a fixed terminology, I consistently refer to the "Libor basis".

to the post-crisis average for the 5-year EUR/USD Libor basis, it means that the 5-year Libor swap rate in USD is 35 basis point lower than the comparable alternative in EUR after the EUR/USD exchange rate risk is fully covered. Theoretically, one would expect market participants to pay the Libor swap rate in USD, receive the Libor swap rate in EUR and hedge the FX risk in order to take advantage of the basis. The problem is that the Libor swap is *not* a security where cash can be raised or placed at the 5-year tenor.

Given a negative Libor basis of 35 basis points, market participants that are able to borrow funds exactly at 3-month Libor in USD and invest exactly at 3-month Libor in EUR on a rolling basis over the next five years and simultaneously exchange currencies and hedge the foreign exchange rate risk for 5 years will earn an annual profit of 35 basis points. However, a non-zero Libor basis should not be interpreted as an arbitrage opportunity as taking advantage of the basis implies both rollover risk in the funding leg and credit risk in the investment leg. Hence, there is no reason to expect the Libor basis to be zero at all times. Even though a non-zero Libor basis does not indicate arbitrage, the post-crisis evolution in the Libor basis has been unprecedented. The next subsection examines potential drivers of the Libor basis.

The main reason for the inadequacy of the Libor basis as a measure of CIP-deviations stems from the fact that the Libor swap rate is a derivative connected to a short-term interest rate and not a cash instrument. In a Libor swap the counterparts exchange a fixed coupon rate for a variable coupon rate equal to the 3-month Libor rate over the term of the swap.[18] At initiation, the value of the Libor swap is zero. The Libor swap rate is therefore the yield to maturity the market is willing to pay in order to receive a path of unknown 3-month Libor interest rate payments throughout the term of the Libor swap contract. To take advantage of a negative Libor basis the trader needs to obtain funding in USD and invest the proceeds in EUR since the participants in the foreign exchange market require that USD is exchanged and delivered against EUR. However, as the Libor basis is based on Libor swaps - a derivative with no exchange of the principal - it is not straight forward to borrow or invest at the interest rates used to compute the Libor basis.

To obtain the necessary funding to exploit a negative Libor basis, market participants have to roll over 3-month Libor borrowing in USD throughout the term of the Libor swap (in this example 5-year). The Libor swap rate in USD can then be locked in by paying the fixed rate and receiving the 3-month U.S. Libor throughout the lifetime of the Libor swap contract. The interest rate payments (equal to the 3-month U.S. Libor rate) on the funding will be canceled out by the incoming 3-month U.S. Libor rate from the Libor swap and the trader is left paying the fixed Libor swap rate in USD. On the investment side, the Libor basis assumes an unsecured investment in a representative Libor panel bank in the investment currency, for instance EUR. The trader then rolls over the unsecured deposit at 3-month EUR Libor (or an equivalent rate like Euribor), pays the 3-month EUR Libor in the Libor swap and receives the Libor swap rate in EUR. The trader is then left with the EUR

[18] In some currencies the underlying interest rate in the swap is the 6-month rate. In main currencies swap rates with both 3-month and 6-month rates as underlying are quoted. The Libor basis that corresponds to cross currency swaps is based on 3-month Libor swap rates.

Libor swap rate on its investment.

4.1 Determinants of the Libor basis

The rollover risk in the Libor swap serves as a natural starting point when searching for potential drivers of the Libor basis. The Libor swap rate represents the expected average of 3-month Libor over the term of the Libor swap, but not the actual term funding cost at longer tenors. This implies that cross currency differences in the term funding liquidity premium not embedded in the Libor swap rates may influence the Libor basis. To see this, imagine a trader who wants to take advantage of the Libor basis. Since there is no exchange of the principal, only interest rate payments in a Libor swap the trader of the Libor basis has to raise funding every third month while the cash proceeds are exchanged and locked in another currency for a long period of time. Moreover, the trader place the funds in the new currency at 3-month Libor. The trader has now basically traded one currency for another at a long tenor, while paying and receiving the expected path of short term rates in the respective currencies. If the compensation for locking in funds for a long term - the term funding liquidity premium - in the currency the trader gave up is higher than in the currency she receive, a similar compensation must be given in the FX forward market. Such compensation shows up as a Libor basis.

To test this hypothesis, I resort to the relative size of the central bank balance sheets as a proxy for differences in the term funding liquidity across currencies. This implicitly assumes that central bank balance sheet policies have an effect on the term funding liquidity premium.

To justify this assumption, I start with the stylized fact that the central bank has the power to influence the short-term funding liquidity premium in its own currency due to its control over the supply of the most liquid asset in the economy - central bank reserves. It is already well established that standard central bank operations affect the funding liquidity premium at short horizons, see for instance Hamilton [1997] and Carpenter and Demiralp [2008]. Furthermore, in their seminal paper, Kashyap and Stein [2000] establish that even relatively small asset purchases by the Federal Reserve - conducted as part of the regular implementation of monetary policy prior to the financial crisis - affect banks' liability composition through relative changes in the deposit base. Such changes in the liability composition consequently affects lending. One important lesson from Kashyap and Stein [2000], further supported in Drechsler et al. [2017], is that deposits is a special source of funding for banks which may not be easily replaced by market funding and that many types of deposits, independent of the maturity, can be regarded as long-term funding for banks.

Large-scale asset purchases may have a similar effect on the long-term funding liquidity premium as standard central bank operations have on the short-term funding liquidity premium. One potential channel is through an increase in non-bank deposits. For instance, when the central bank purchases assets held by the non-bank sector, the central bank prints money to finance its purchases and thereby induces an increase in non-bank deposits at commercial banks. The new non-bank deposits show up on the liability side on commercial banks' balance sheets and are matched by highly liquid central bank reserves on banks' asset side. Additional deposits and a higher level of central bank reserves improve banks' funding and liquidity position[19]

Indeed, deposits relative to non-cash assets have increased significantly after the introduction of large-scale asset purchases in the US, UK, Japan and the euro area.[20] Normally, non-cash assets and deposits grow at a fairly similar pace. However, in the aftermath of central bank asset purchases the deposit growth has outpaced the non-cash asset growth.[21] Higher growth in deposits than in non-cash assets may lead to lower demand for long-term market funding (bond issuances) and improved term funding liquidity for banks as banks' less liquid assets can increasingly be financed by deposits.

Hence, large-scale asset purchases may reduce the term funding liquidity premium for banks in the respective currency through the deposit channel. In turn, this affects the relative term funding liquidity premium across currencies for all market participants and it becomes relatively cheaper to obtain long-term funding in the respective currency. However, because the Libor swap rate does not embed the term funding liquidity premium, the interest rate differential based on Libor swap rates does not change while the hedging cost adjusts to the fact that the relative price of the currencies changes (because the notional in the two currencies changes hands when exchanging from one currency to another). Consequently, the Libor basis widens.

The Libor basis may also be effected by discrepancies between the underlying Libor benchmark rates across currencies. The Libor swap rate inherits the characteristics of the underlying 3-month Libor benchmark rate. Differences across benchmark rates, e.g. the panel composition, transmit to the Libor basis through the Libor swap rates in the two currencies. If the Libor swap rates are not comparable due to differences in the underlying instrument, a compensation is needed. Such a compensation shows up as a Libor basis.

Libor benchmark rates have been under scrutiny, evidently manipulated and subject to various reforms over the past 10 years. Since Libor is based on quotes rather than actual transactions, these rates are sensitive to the panel banks' own assessment. The various reforms and the touch of banks' own judgement may cause differences in the benchmark rates across currencies. I proxy such cross currency discrepancies by the spread between 3-month Libor rates and actual funding costs for similar issuers in the commercial paper market. In cases where the spread between the benchmark rate and actual funding costs for banks with a specific rating differs across currencies, this is a sign that the benchmark rates contain different information, for instance in terms of methodology or credit quality of the panel banks.[22] I use these cross currency differences as a proxy for benchmark rate discrepancies.[23]

[19]There may also be other channels like the direct price impact of central bank purchases of corporate bonds, see for instance Abidi and Miquel-Flores [2018].

[20]This can be seen in figure 9 in Appendix B.

[21]See Appendix B and Christensen and Krogstrup [2016] for a detailed discussion of how asset purchases may affect the deposit base.

[22]Figure OA.1 in the online appendix illustrates the relevant 3-month Libor rates and the non-bank funding cost measured by the 3-month commercial paper rate (CP rate) for high quality banks (A1/P1 short-term rating) differ across currencies.

[23]Libor and other Ibor panel banks have generally A1/P1 rating. After the financial crisis, some panel banks have

Empirical strategy I examine the Libor basis and the potential determinants laid out above by employing a panel regression on three currency pairs - EUR/USD, GBP/USD and JPY/USD.[24] I investigate the Libor basis for 2, 5 and 10 years maturity and my sample runs from 2010 to 2017 with weekly frequency due to data availability for the central bank balance sheets. The regression is specified as follows:

$$\Delta LB^m_{i,t} = \beta_0 + \beta_1 \Delta LB^m_{i,t-1} + \beta_2 \Delta(Bal_{i,t}/Bal_{fed,t}) + \beta_3 \Delta CDSsprFR_t \\ + \beta_4 \Delta(LIBCPspr_{i,t} - LIBCPspr_{US,t}) + \beta_5 LB^m_{i,t-1} + \epsilon_{i,t} \quad (7)$$

where Δ is the first difference operator, $LB^m_{i,t}$ is the Libor basis for currency i (against USD) at time t with maturity m, $Bal_{i,t}$ is the indexed balance sheet for currency i, $Bal_{fed,t}$ is Federal Reserve's indexed balance sheet, $CDSsprFR_t$ is the difference between the 5-year French CDS price denominated in USD and EUR added as a control variable in order to account for the impact of the European sovereign debt crisis and the euro break-up risk.[25] The Euro crisis increased the political risk of holding euro assets in addition to a general surge in market uncertainty. The sovereign debt crisis in the euro area can be characterized as a period with severe turmoil across financial markets and large heterogeneity in banks' funding costs depending on the country of incorporation and the asset composition of the bank. Finally, $LIBCPspr_{i,t}$ is the spread between 3-month Libor and commercial paper rate in currency i and $LIBCPspr_{US,t}$ is the corresponding spread in USD.

The model is specified on first differences, solely focussing on short-run effects, because of non-stationarity of some variables on levels. Standard unit-root tests indicate that all variables are stationary after differencing. Johansen cointegration tests show mixed results across currencies and lack of cointegration between the main variables. The lagged dependent variable on first differences is included to shed light on the persistence of the effects. A positive coefficient estimate on this variable would suggest that the price adjustment in the previous period is not reversed.

Finally, the lagged dependent variable on levels act as an "error correction" term as the Libor basis is potentially a stationary variable. Note that the focus on short-run effects means that the change in the relative central bank balance sheet has to be interpreted as a flow rather than a stock effect.

been downgraded. However, the effect of lower rated banks in the Libor fixing should be minimal as the methodology ensures that outliers are removed, e.g. the four lowest and highest contributions. See the online appendix for further details about benchmark rates.

[24]Table OA.I in the online appendix shows the results from a seemingly unrelated regression (SUR), an alternative to the panel regression allowing currency specific coefficients. By employing a SUR model, potential correlation between the residuals across currencies is taken into account.

[25]I use French government CDS prices due to data quality. German CDS prices show the same pattern, but suffer from more frequent data gaps.

Regression results Table 1 depicts the results from the panel regression specified in equation 7 for three different maturities - 2, 5 and 10 years. The results indicate that the relative central bank balance sheet affects the Libor basis. An increase in the non-US central bank balance sheet relative to the Federal Reserves balance sheet (β_2) is associated with a decline in the Libor basis, consistent with asset purchases improving the funding liquidity and consequently affect the Libor basis. Specifically, a one standard deviation change in the relative central bank balance sheet (β_2) is followed by a 0.15 basis point change in the 5-year Libor basis.

As expected, the results also suggest that a higher spread between the French CDS price denominated in USD and Euro (β_3) leads to a more negative Libor basis, i.e. an increase in the break-up risk is associated with a higher cost of synthetic USD funding. Specifically, during the height of the sovereign debt crisis in Europe USD investors worried about the health of some banks balance sheets - especially those exposed to European sovereign debt - and many globally active banks were forced to obtain USD through the FX swap market. This put a downward price pressure on the Libor basis.

Finally, a higher Libor-CP spread in non-US currencies compared to the US Libor-CP spread (β_4) leads to a lower Libor basis. The relative Libor-CP spread between non-US currencies and the US dollar measures the contemporaneous discrepancies in the benchmark rates relative to the actual non-bank funding rate across currencies. These discrepancies are compensated by a widening of the Libor basis. Interestingly, the regression coefficients across the term structure indicates a declining importance of the benchmark rate discrepancies. A one basis point increase in the non-US Libor-CP spread versus the US leads to a 0.12 basis point decline in the 2-year Libor basis. The corresponding decline in the 10-year Libor basis has been 0.073 basis points. The striking pattern observed in the benchmark rate coefficients is consistent with market participants interpreting a share of the benchmark rate discrepancies as transitory (declining effect along the term structure). For example, the strains in US money markets due to the European sovereign debt crisis may have been considered to be transitory and benchmark rates in different currencies may react differently to the underlying market stress. If this effect was perceived to be a short lived the coefficients should indeed be smaller than one and declining along the term structure since the transmission from the 3-month Libor to the longer term Libor swap rates and further to the Libor basis depends on the expected persistence of the discrepancies between the 3-month Libor rates.

5 The corporate bond basis

The discussion above suggests that the Libor basis is not an accurate measure of CIP deviations because Libor swap rates do not adequately capture the full funding costs across currencies. To avoid this problem I turn to the corporate bond basis by obtaining granular corporate bond data

Table 1
Determinants of the Libor basis

	(1) 2-year	(2) 5-year	(3) 10-year
$\Delta LB_{t-1}(\beta_1)$	0.248***	0.245***	0.250***
	(3.75)	*(4.36)*	*(6.14)*
$\Delta RelCBbal(\beta_2)$	-15.75**	-14.23**	-14.77***
	(-2.47)	*(-2.17)*	*(-2.61)*
$\Delta CDSsprFR(\beta_3)$	-0.162***	-0.156***	-0.106***
	(-4.49)	*(-4.43)*	*(-3.99)*
$\Delta LIBCPdiff(\beta_4)$	-0.124***	-0.095**	-0.073***
	(-2.87)	*(-2.57)*	*(-2.81)*
$LB_{t-1}(\beta_5)$	-0.021***	-0.021***	-0.018***
	(-2.59)	*(-3.14)*	*(-3.73)*
$Constant$	-0.657***	-0.704***	-0.589***
	(-3.04)	*(-3.60)*	*(-3.96)*
$CurrencyFE$	Yes	Yes	Yes
Adj R^2	0.149	0.134	0.113
Number of Observations	1119	1119	1119

*Note: The table depicts the results from the panel regression specified in equation 7 for EUR/USD, GBP/USD and USD/JPY. LB is the Libor Basis, RelCBbal is the ratio between the indexed foreign central bank balance sheet and the indexed Federal Reserve balance sheet, CDSsprFR is the difference between the 5-year CDS price on France denominated in EUR and USD and LIBCPdiff is the difference between 3-month Libor CP spread in foreign currency and USD. The dependent variable is the Libor basis. Results are reported with White cross section standard errors. *** denote a statistical significance level of 1 per cent, ** 5 per cent and * 10 per cent. The sample runs from 2010 to 2017.*

from Barclays/Bloomberg running from 2010 to the end of 2017.[26] This allows the calculation of zero coupon corporate bond spreads based on country of incorporation, rating of the bond, issuance currency and maturity.[27] I compute the corporate bond basis (ρ_m^{Corp}) for issuers with similar characteristics as follows:

$$\rho_m^{Corp} = \left(1 + y_{m;\$}\right) - \frac{F_m}{S}\left(1 + y_{m;\star}\right), \tag{8}$$

where $y_{m;\$}$ is the direct zero-coupon corporate bond rate denominated in USD, $y_{m;\star}$ is the zero-coupon corporate bond rate in foreign currency and $\frac{F_m}{S}$ is the hedging cost. That is, $\frac{F_m}{S}\left(1 + y_{m;\star}\right)$ is the synthetic zero-coupon corporate bond rate based on foreign currency at maturity m.[28]

As a starting point, it is useful to look at the relation between the corporate bond basis and the Libor basis. Corporate bond rates are typically compared to the Libor swap rate (interest rate swap) as a measure for the bond spread.[29] In contrast to Libor swaps, corporate bonds are cash instruments where the principal is exchanged over the full maturity of the bond. Corporate bond rates should therefore embed the term funding liquidity premium. Hence, the corporate bond spread is expected to be positive. However, there is nothing that prevents bond spreads for the similar corporations to differ across currencies. For instance, in the presence of differences in the term funding liquidity premium, the spread between the corporate bond rate and the Libor swap rate (the corporate bond spread) should also differ across currencies. If the Libor basis exactly compensates for potential differences in corporate bond spreads the corporate bond basis is zero.

To show the relationship between bond spreads and the Libor basis I decompose the zero coupon corporate bond rate, y, into the zero coupon Libor swap rate, c, and the corporate bond spread, b:

$$y_m = c_m + b_m, \tag{9}$$

Hence, the bond spread, b_m, is the difference between the corporate bond rate, y_m, and the Libor swap rate, c_m, at maturity m. For a given issuer, differences in the term funding liquidity premium show up in differences in corporate bond spreads across currencies. By combining equation 8 and 9, the corporate bond basis (in logs) can be expressed as a function of corporate bond spreads and

[26] It is important to note that the corporate bond market is highly fragmented. In my analysis of the corporate bond basis the Barclays/Bloomberg data are restricted to bonds with the minimum outstanding volume of around 200 million USD. After the financial crisis both market liquidity and funding liquidity have been gained importance and the price differences between bonds with different outstanding volume but otherwise similar/equal may be substantial. Moreover, among more standard features of the bond as rating and remaining maturity, I condition on the country of incorporation of the bond issuer.

[27] More details regarding the data and the calculation of bond spreads can be found in Appendix A.

[28] Subscript t for time is dropped for simplicity. Mid prices from the foreign exchange market are applied to simplify the illustration as deviations between the synthetic and direct corporate bond rate do not represent arbitrage opportunities due to the credit risk in corporate bonds. Table OA.VI in the online appendix illustrates the bid/ask spreads in the FX hedging market and shows these spreads would only account for a couple of basis points.

[29] Bond spreads are commonly referred to as credit spreads or z-spreads. However, since a main point in this analysis is that bond spreads across currencies may vary due to differences in the term funding liquidity premium, the terminology bond spreads is used in this paper.

Libor swap rates:

$$\rho_m^{Corp} \approx c_{m;\$} + b_{t;\$} - (f_m - s) - c_{m;\star} - b_{m;\star} \tag{10}$$

A zero corporate bond basis implies that the difference between the corporate bond spreads equals the Libor basis. Equation 10 illustrates that the corporate bond basis is basically the Libor basis plus the cross currency bond spread differential. After isolating the bond spreads, the remaining elements constitute the Libor basis (i.e. the log version of equation 6):

$$\rho_m^{Corp} \approx \rho_m^{Lib} + (b_{m;\$} - b_{m;\star}) \tag{11}$$

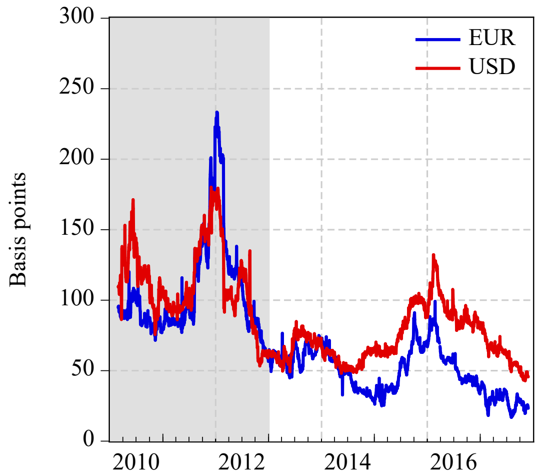
Figure 3 illustrates the empirical relationship between the bond spread differential, the Libor basis and the corporate bond basis. As expected, and consistent with the term funding liquidity premium hypothesis, corporate bond spreads differ substantially across currencies. The left hand side of the panel, graph a and c, depicts the corporate bond spreads for high quality financial corporations in EUR and USD, and JPY and USD, respectively. Moreover, the difference between the bond spreads corresponds closely to the Libor basis as shown in graph b and d in figure 3. This means that the corporate bond basis is relatively close to zero. The exception is during the European sovereign debt crisis, a period characterized by high political risk and generally high degree of uncertainty in financial markets, highlighted by the grey shaded area in the graphs.

Overall, the data suggest that the discrepancies in the funding liquidity premium are embedded in corporate bond prices. This observation supports the hypothesis that the Libor basis expresses cross currency differences in the term funding liquidity premia that are not reflected in Libor swap rates.[30] The co-movement between the Libor basis and the corporate bond spread differential sheds light on the development in bond markets. The differences in corporate bond spreads for similar issuers mean that the funding liquidity premium in bonds varies across currencies as the credit risk component should be fairly similar. The widening of the Libor swap basis is necessary to equalize the synthetic and direct corporate funding costs.

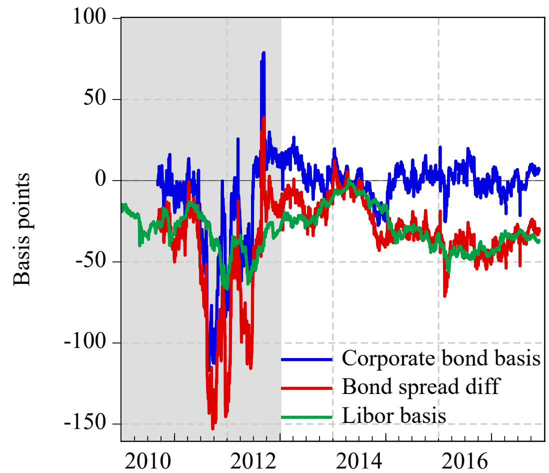
A natural implication of the discussion above is that bond spreads should be similar across currencies prior to the financial crisis as the Libor basis was close to zero in the pre-crisis period. Figure 4 shows the senior bond spreads in EUR and USD for investment grade financial issuers in two periods - 2004-2007 and 2015-2017 obtained from the Barclays/Bloomberg global financial indices for EUR and USD. The average maturity of the bonds included varies slightly and the credit quality of the included bonds can vary within the investment grade environment. Despite being a crude measure, figure 4 confirms that bond spreads were very close prior to the crisis. The right-hand panel depicts the difference between the bond spreads (EUR minus USD) in two periods, the first

[30] I do not adjust for so-called quanto spreads connected to potential jump risk in the foreign exchange rate in the case of default. The existence of quanto spreads implies a room for the corporate bond basis to deviate from zero without violating CIP.

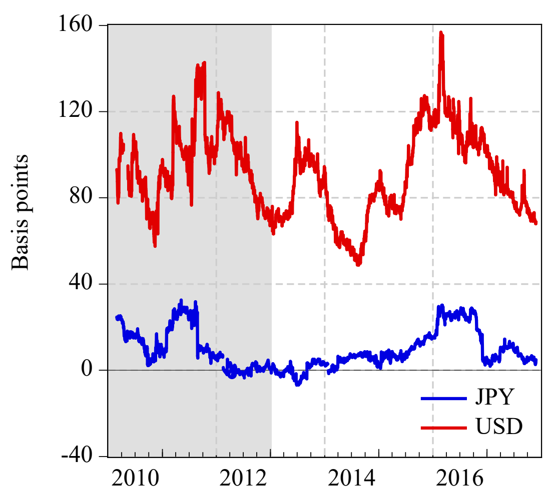
Figure 3
Bond spreads and the Libor basis, 5-year maturity



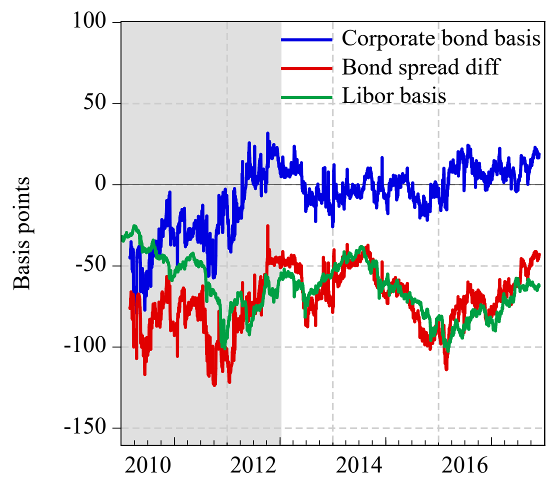
(a) Bond spreads in EUR and USD



(b) Corporate bond basis EUR/USD



(c) Bond spreads in JPY and USD

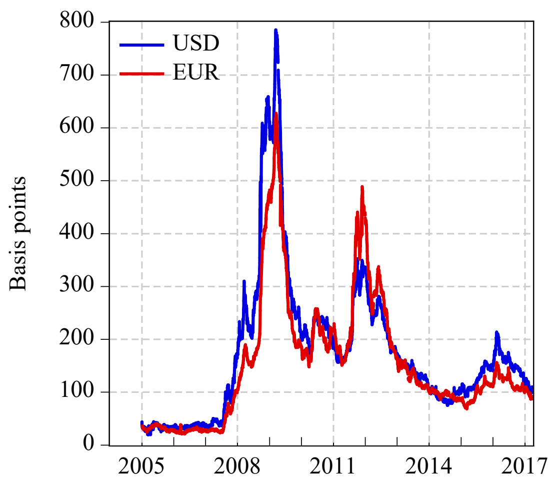


(d) Corporate bond basis JPY/USD

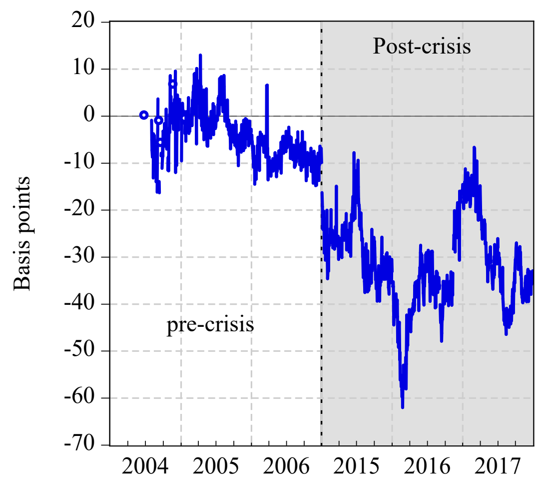
Note: The left-hand graphs (a and c) show the corporate bond spread for a basket of corporate issuers with the same rating and domiciled in the same country in EUR, JPY and USD. The right hand graphs (b and d) show i) the corporate bond spread differential (EUR or JPY minus USD) based on the corporate bond spreads depicted in graph a and c, ii) the Libor basis which is the difference between the synthetic and direct Libor swap rate, and iii) the corporate bond basis for similar issuers which is the difference between synthetic and direct corporate bond rate. Negative values of the basis mean that the direct corporate bond rate in USD is lower than the synthetic corporate bond rate implied from foreign currency denominated bonds. The corporate bond basis is zero if the Libor basis and the bond spread differential are equal. The shaded area illustrates the European sovereign debt crisis from 2010 to 2012. Similar graphs for GBP can be found in figure OA.2 in the online appendix.

from 2004 to 2007 and the second from 2015 to 2017. Between 2004 and 2007 the difference in bond spreads never exceeded 10 basis points. In contrast, between 2015 and 2017 the difference between the bond spreads in the two currencies increased substantially. This happened in tandem with the widening of the Libor basis. It is worth noting that a zero Libor basis implies that the bond spreads across currencies have to be equal for the corporate bond basis to hold, i.e. if the Libor basis is interpreted as a measure of CIP it either implies that the central bank has no room to affect *bond spreads* in its own currency or that the ability of one central bank to affect bond spreads will be transmitted to all other currencies as well for CIP to hold in corporate bonds.

Figure 4
Bond spreads



(a) Bond spreads in EUR and USD



(b) Zooming in on differences in bond spreads

Note: The left-hand graph shows corporate bond spreads - the difference between the senior corporate bond rate and the Libor swap rate - for investment grade financial issuers in EUR and USD. The bond rates are from Barclays Bloomberg indices (LEEFYW for EUR and LUAFYW for USD). The right-hand graph zooms in on the difference between the two bond spreads (EUR minus USD) in the period leading up to the financial crisis (2004-2006) and the tranquil period after financial crisis (2015-2017), the grey shaded area. Negative values mean that EUR spreads are lower than the corresponding spread in USD.

The corporate bond basis, however, does not reflect round-trip arbitrage opportunities. The reason is that the investment currency is assumed invested in a risky corporate bond. Despite high rating and relatively good credit quality, most corporations cannot be considered risk-free. However, the corporate bond basis can be exploited by globally active issuers in their search for lowest possible funding cost. This means that the corporate bond basis should be close to zero. I now examine the empirical relationship between the Libor basis and the corporate bond spread differential before turning to risk-free arbitrage strategies in section 6,

5.1 Empirical analysis of the corporate bond basis

This subsection examines the empirical relationship between the 5-year Libor basis and the corresponding corporate bond spread differential in EUR, JPY and GBP against USD.[31] Essentially, I look at how well corporate bond rates are aligned with CIP across currencies.[32] As explained above, the corporate bond basis is zero (no deviations from CIP) when the bond spread differential equals the Libor basis.

The main empirical concern is that corporate bond spreads and the Libor basis are potentially endogenously related as the FX swap price may influence the relative demand for bonds across currencies for given bond prices and vice versa. Hence, I employ a vector error correction framework. An advantage of this approach is that I can test for the long-run relationship between the two. The estimates also give an indication whether it is bond prices or the hedging price (the FX swap price) that adjust most towards the long run equilibrium.

I apply the following Vector Error Correction Model on daily data to shed light on the cointegrating relationship and the speed of adjustment from disequilibrium towards its equilibrium level:[33]

$$\begin{aligned}\Delta bspr_t = \beta_{11}\Delta bspr_{t-1} + \beta_{12}\Delta bspr_{t-2} + \beta_{13}\Delta LB_{t-1} + \beta_{14}\Delta LB_{t-2} + \\ \lambda_{bspr}(bspr_{t-1} - \alpha_1 LB_{t-1}) + v_t^{bspr}\end{aligned} \tag{12}$$

$$\begin{aligned}\Delta LB_t = \beta_{21}\Delta bspr_{t-1} + \beta_{22}\Delta bspr_{t-2} + \beta_{23}\Delta LB_{t-1} + \beta_{24}\Delta LB_{t-2} + \\ \lambda_{LB}(bspr_{t-1} - \alpha_1 LB_{t-1}) + v_t^{LB}\end{aligned} \tag{13}$$

where $bspr_t$ is the 5-year bond spread differential and LB_t is the 5-year Libor basis for the respective currency pair. The λ_{bspr} is the adjustment parameter for the bond spread differential while λ_{LB} is the corresponding adjustment parameter for the Libor basis. After normalizing the coefficient on $bspr_t$ to 1, the cointegrating relationship predicted by the CIP - in order to keep the synthetic corporate bond rate equal to the direct rate - implies a cointegrating vector (1,-1). This means that in the long-run $bspr_t = LB_t$. The error-correction term in each equation above is then $bspr_{t-1} = LB_{t-1}$, meaning that if $bspr$ is above its long-run equilibrium or LB is below. Hence, I expect $\lambda_{bspr} < 0$ and $\lambda_{LB} > 0$.

Table 2 reports the results from both an unrestricted model and a model specification where the cointegrating vector is restricted to (1,-1). The unrestricted model indicates that for EUR/USD and USD/JPY the cointegrating coefficient, α_1, is very close to -1. The adjustment coefficients

[31] I also provide the results for the 2-year and 10-year tenor in the online appendix.

[32] Note that in this section I am not looking for CIP-arbitrage (due to the credit risk in corporate bonds), but deviations from the general CIP equation.

[33] Table OA.II in the online appendix confirms a cointegrating relationship between the Libor basis and the bond spread differential.

for both currencies have the expected sign, have similar magnitude and are statistically significant at conventional significance levels. The major part of the adjustment comes through the bond spread differential (about 2.5 per cent). The adjustment coefficient on the basis swap is about 1 per cent per day. For the GBP/USD cross, α_1 is only - 0.56. Moreover, for GBP the bond spread differential seems to take all the burden of adjusting to long run equilibrium. When restricting the long run relationship to $bspr_{t-1} = LB_{t-1}$, the adjustment parameters are basically unchanged and the Likelihood Ratio test for binding restrictions indicate that this restriction is not binding for any of the currency pairs.

Table 2
Vector Error Correction Model

	(a)Unrestricted					
	EUR/USD		USD/JPY		GBP/USD	
	bspr	LB	bspr	LB	bspr	LB
Coint. Coeff	1	-0.95	1	-0.97	1	-0.56
	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB
Adj. coeff	-0.029	0.011	-0.025	0.011	-0.016	-0.000
t-values	(-2.92)	(4.00)	(-2.83)	(3.02)	(-4.59)	(-0.38)

	(b)Restricted: Coint. relation (1,-1)					
	EUR/USD		USD/JPY		GBP/USD	
	bspr	LB	bspr	LB	bspr	LB
Coint. Coeff	1	-1	1	-1	1	-1
LR test (prob.)	0.39		0.41		0.72	
	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB
Adj. coeff	-0.028	0.011	-0.023	0.010	-0.015	-0.000
t-values	(-2.91)	(4.09)	(-2.72)	(3.01)	(-4.60)	(-0.24)

Note: The table shows the results from a Vector Error Correction Model with two lags, no trend and intercept in the cointegrating relationship. The first model is an unrestricted model (a), while in (b) the cointegrating relationship is restricted to (1,-1) The variables are 5-year bond spread differential (bspr) and 5-year Libor basis (LB). Bond spreads and the Libor basis are measured in basis points. The sample runs from January 2010 to December 2017.

My results indicate that CIP for corporate bond prices issued by similar issuers cannot be rejected in the long run despite the large and persistent non-zero Libor basis. This is due to the joint movement in the bond spread differential and the cross currency Libor basis. Furthermore, the analysis shows that the adjustment from disequilibrium is relatively slow and driven by both the Libor basis and bond spreads. However, the largest part of the adjustment stems from the bond spreads as these are more volatile than the Libor basis.

6 The government bond basis

In this section I investigate risk-free rates. To this end, I compute the government bond basis in the same manner as the Libor and the corporate bond basis. Government bonds, at least for the currencies in this analysis, are close to risk-free and frequently traded in liquid markets. Equation 14 shows the computation of the government bond basis where $g_{m;\star}$ and $g_{m;\$}$ are the zero coupon government bond rates in foreign currency and USD at maturity m, respectively.

$$\rho_m^{GovBasis} = \left(1 + g_{m;\$}\right) - \frac{F_m}{S}\left(1 + g_{m;\star}\right), \tag{14}$$

Figure 5 depicts the difference between the synthetic and the direct US dollar rate based on 2, 5 and 10-year zero coupon government bonds. Negative values indicate that the synthetic bond spread is above the corresponding US Treasury rate, i.e. the USD return on foreign denominated government bonds is higher than for US government bonds after the foreign exchange rate risk is fully hedged.

The figure illustrates substantial deviations between the synthetic and the direct US treasury rate across all currency pairs since 2000. The deviations over the past five years are not *large* in a historical perspective. For instance the average 5-year JPY/USD government bond basis is minus 45 basis points in the period between 2000 and 2006, while the corresponding average is minus 50 basis points between 2014 and 2017 (a tranquil period in the aftermath of the financial crisis and the sovereign debt crisis in the Euro area). Indeed, there is no indication that the deviations can be attributed to the banking regulations implemented after the global financial crisis. Although the synthetic bond spread based on Japanese government bonds is currently above the corresponding US Treasury rate (leading to a negative government bond basis), the deviations were even larger in the period between 2000-2003, a period where the USD/JPY Libor basis traded close to zero. The government bond basis in the two remaining currencies have varied substantially, but have more or less closed the gap towards the end of the sample.

The intention of figure 5 is to illustrate that the cross currency deviations in government bond markets are not a post-crisis phenomenon pointing to impediments to arbitrage beyond the post-crisis tightening of banking regulations. Hence, I turn to an examination of the potential costs of trading the cross currency CIP deviations in bonds, particularly focussing on government bonds.

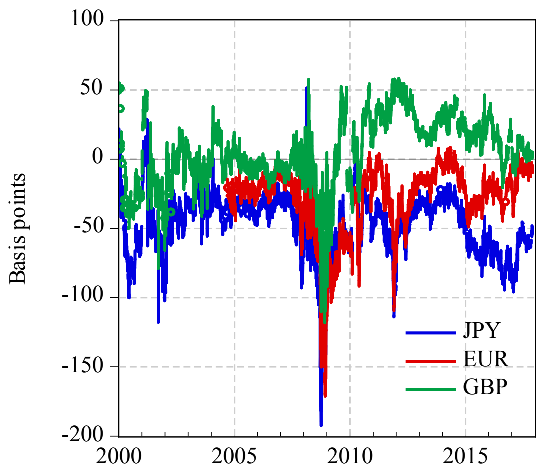
6.1 Trading the government bond basis - costs and risks

Du et al. [2019] propose a short/long strategy to take advantage of the risk-free bond basis, i.e. to short-sell the security denominated in the currency with the highest relative price.[34] The various steps in the strategy are:

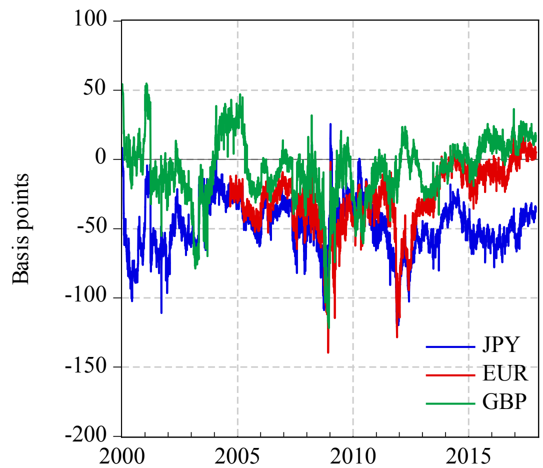
1. Borrow, say, a risk-free US security with m-year remaining maturity from a securities lender,

[34] Short-selling means borrowing the security and subsequently sell the security to raise cash.

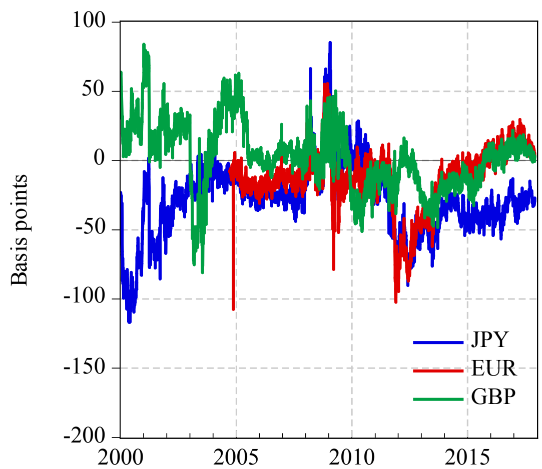
Figure 5
Cross currency deviations in international government bond markets



(a) 2 year maturity



(b) 5 year maturity



(c) 10 year maturity

Note: The figure shows the difference between the direct and the synthetic US dollar government bond rates for 2, 5 and 10-year maturity, respectively. The synthetic yields are implied from EUR, GBP and JPY government bond yields. Negative values of the basis mean that the direct government bond rate in USD is lower than the synthetic government bond rate implied from foreign currency denominated bonds. For the euro area the government bond yields are based on government issuers with AA and AAA rating. The government bond basis is calculated based on mid prices. The government bonds are zero-coupon interest rates collected from either Bloomberg or central bank webpages.

and short-sell this security at rate $r_{m;\$}$

2. With the proceeds of the sale of the security, buy euros spot to obtain $1/S$ euros, and simultaneously enter a forward contract F_m reversing the currency exchange at a predetermined price in m years (effectively entering a FX swap contract),

3. Invest the euro funds at the currently available m-year risk-free euro rate $r_{m;\star}$.

4. Use the euro-denominated bond as collateral for the borrowed security denominated in USD.

Du et al. [2019] find substantial deviations between the synthetic and the direct interest rate on bonds issued by KfW. KfW is a German government sponsored bank and can be considered to be close to risk-free. Hence, the authors suggest persistent arbitrage opportunities in long-dated bond and currency markets. Despite that the government bonds in my analysis are not issued by the same issuer this should not matter as long as the government bonds are considered to be free of risk.[35] Indeed, government bonds are better suited for the short/long trade than for instance KfW bonds as the market liquidity is better and government bonds are more likely to be available by securities lenders. The short/long strategy involves substantial trading costs beyond the bid/ask spreads. Although Du et al. [2019] consider the lending fee in the securities lending market, other important short-selling costs apply. I discuss the costs of short-selling fixed income securities below.

Haircut and lending fees Security lenders typically require over-collateralization (haircut) as risk mitigation mechanism in the case of the default of the security borrower. Haircut is necessary even when the trade is subject to variation margin due to the price and exchange rate risk the security lender is exposed to between the last margin call and the potential liquidation of the collateral.[36] If a default occurs, it may take some time to liquidate the security and the cross currency nature of the collateral increases the risk of a loss due to changes in the price of the collateral relative to the security on loan *and* exchange rate movements between the last margin payment and the liquidation of the collateral.

Unfortunately, data on haircut are scarce. However, several pieces of information collectively provide evidence on both the level and importance of haircut in the repo and securities lending market. For instance, Baklanova et al. [2016], a pilot study conducted by the Office of Financial Research and the New York Fed on the US securities lending market, present data on the last three months of 2015. This study finds that the haircut level ranges from 2 to 5 per cent for government bonds. The average lending fee for US government bonds varied between 15 and 20 basis points during the last three months of 2015, see table 3. The data hide potential differences in the lending

[35] The main risk for the security lender is the fact that the collateral is denominated in another currency which implies that the general interest rate level in the two currencies can develop differently and the exchange rate can move substantially.

[36] Variation margin is additional collateral posted in order to reflect price movements in the underlying security on loan. The exchange rate risk applies only to transactions where the collateral is denominated in foreign currency.

fee and haircut between USD denominated collateral and foreign currency denominated collateral. Most of the transactions in USD are collateralized by USD denominated collateral. The haircut on foreign denominated collateral is therefore likely to be in the high end of the haircut range presented in Baklanova et al. [2016] due to the exchange rate risk connected to foreign currency collateral.

Table 3
Lending fee and haircut in the securities lending market

	Oct 9, 2015			Nov 10, 2015			Dec 31, 2015		
	5th	Mean	95th	5th	Mean	95th	5th	Mean	95th
				a) Lending Fee (bps)					
U.S. Treasury/Agencies	5	13	31	5	15	40	6	20	60
U.S. Corporate Bonds	8	27	38	8	28	25	8	27	25
				b) Haircut (per cent)					
U.S. Treasury/Agencies	0	2	5	0	2	5	0	2	5
U.S. Corporate Bonds	2	2	3	2	2	5	2	2	5

Note: The table shows lending fees and haircut levels based on a survey of securities lenders conducted by the Office for Financial Research and New York Fed. The data are collected on three specific dates in the last quarter of 2015 and taken from Baklanova et al. [2016].

The difference between domestic and foreign currency collateral is emphasized by the Investment Company Institute (ICI). Grohowski [2014] states the following: "A U.S. regulated fund must receive collateral equal to at least 100 percent of the value of the securities on loan. In practice, funds require 102 percent collateral for domestic securities and 105 percent for international securities. Because loaned securities must be available for recall on short notice, the collateral that funds can accept from borrowers must be highly liquid, such as cash, government securities, or bank letters of credit."[37] U.S. regulated funds are not the only player in the U.S. securities lending market, but constitute a large participant together with pension plans and insurance companies, see Adrian et al. [2013]. The practice of requiring a 5 per cent haircut on foreign denominated collateral in securities lending transactions is also pointed out by Duffie et al. [2002] and Bassler and Oliver [2015].[38]

Furthermore, the New York Federal Reserve publishes haircut level data on repo transactions. These data are based on repo only, not on securities lending transactions. However, securities lending is a form of repo meaning that the numbers give an overall picture of the haircut levels. The median level has over the past 6 years hovered between 2 and 5 per cent.[39] Note that a borrower in the tri-party market cannot freely choose the security to be delivered. An important presumption of the short/long trade is that a pre-specified security is delivered. In a special repo where the security lender requires a specific security, both the interest rate (lending fee) and the haircut may be less attractive from the perspective of the cross currency arbitrageur.

Finally, data from EUREX Clearing - a leading clearing house in Europe - suggest a haircut

[37] 102 and 105 per cent collateral are for all practical purposes equivalent to 2 and 5 per cent haircut, respectively.
[38] See also Hu et al. [2019] for a detailed analysis of haircut levels in the U.S Tri-Party repo market.
[39] See figure OA.5 in the online appendix for a time series of the data from New York Federal Reserve.

level of at least 5 per cent on foreign denominated collateral. The numbers suggest the haircut rates applied by EUREX clearing for a range of currencies against the USD. The cross currency haircut rates vary between 4 and 8 per cent.[40] Higher haircut levels for foreign currency denominated collateral is also reflected in most central banks' collateral frameworks, either by a higher haircut (Central Bank of Norway and BoE) or larger mark-down on the valuation of the collateral (ECB).

Overall, the indicative evidence above points in the same direction: consistent with the extensive literature on US repo markets haircut is an important part of the risk mitigation for the securities lender and can be substantial for trades relying on cross currency collateral, see for instance Krishnamurthy et al. [2014], Gorton and Metrick [2012], Copeland et al. [2014]. Essentially, this implies that the short/long strategy needs capital to be deployed in order to cover the haircut. Moreover, the costs of haircut based on standard assumptions of the required return on equity are high. As an example, given a 5 per cent haircut and 10 per cent required return on equity implies an additional cost of the trade equal to 50 basis point. This is around twice the size of the average CIP deviations for long-dated risk-free bonds reported in Du et al. [2019] after accounting for the lending fee, and about four times as large as the reported arbitrage return when the sovereign debt crisis in the Euro area is excluded from the sample.

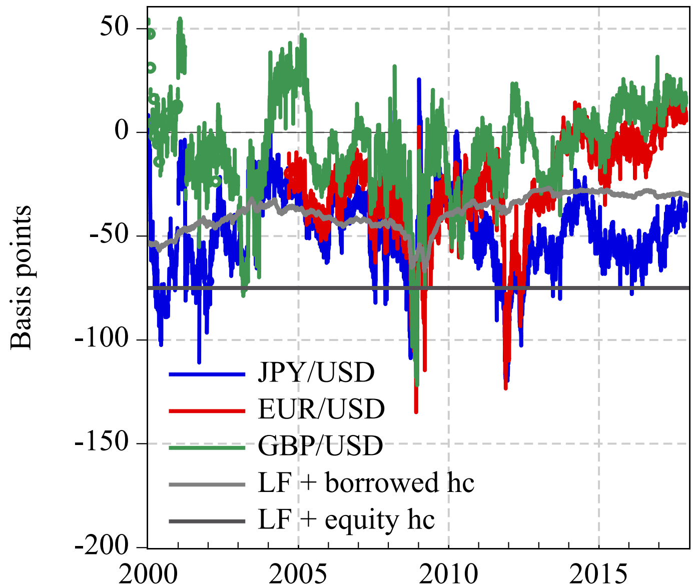
Maturity According to the latest report by the International Securities Lending Association (ISLA), 79 per cent of all government bonds on-loan have open term. This means that the lender can call back the security on short notice. Although it is possible to borrow securities on longer tenors, the large number of securities with open term implies that average lending fees based on historical transactions are likely to be underestimated. The reason is that the lender has to pay (by reducing the lending fee) for the option to call back the security on short notice. Alternatively, the arbitrageur faces roll-over risk.

What are the total costs of haircut and lending fee compared to the size of the government basis? The costs of haircut is difficult to estimate as it depends on the cost of capital for the individual arbitrageur. However, by making some assumptions one can get a good sense of the magnitude of the costs. The arbitrageur may finance the haircut either by debt or equity. Some participants have limited access to bonds markets, like hedge funds, and may have to finance the haircut by equity. Others may resort to the bond market. In figure 6 I have calculated the cost of haircut financed at the unsecured borrowing rate for high quality financial corporations and added a lending fee of 15 basis points. Moreover, the figure also shows the cost of equity financed haircut given 10 per cent required return on equity plus the lending fee. Finally, these numbers are compared to the 5-year government bond basis for the three currency pairs in my analysis. One may think of the two financing alternatives as a lower and a higher end estimate of the shorting costs. Figure 6 illustrates that the government basis across all currencies are generally below the higher end estimate, and that the basis for GBP/USD and EUR/USD have been below the lower end estimate after 2013. Hence,

[40] See table OA.V in the online appendix for an overview.

it seems difficult to reap any profits for most arbitrageurs based on the short/long strategy when the costs of haircut and the lending fee are taken into account.

Figure 6
Estimated costs of round-trip arbitrage: lending fee and haircut



Note: The figure shows the government basis for JPY/USD, EUR/USD and GBP/USD together with the total costs of a 15 basis point lending fee (LF) and two different ways of financing a 5 per cent haircut: i) borrowed financing based on unsecured borrowing costs in USD obtained from Bloomber/Barclays US aggregate index for financial corporations (LF+borrowed hc), and ii) equity financed haircut based on 10 per cent required return on equity (LF+equity hc).

To sum up, the short/long trade exposes market participants to substantial non-regulatory costs that prevent market participants to take advantage of the government bond basis. This point is substantiated by the fact that the government bond basis is currently not particularly large compared with the pre-crisis period.

6.2 Real money investors, portfolio allocation and arbitrage

Haircut and lending fees make it costly to trade the government bond basis without being in possession of an inventory of government securities. However, these costs are not occurring for real money investors with portfolios consisting of USD securities or USD cash. A negative 5-year government bond basis between USD and JPY, for instance, indicates that anyone with a 5-year US government bond can increase their return by selling this bond, lend the USD in the FX swap market for 5 years and invest the proceeds in a 5-year Japanese government bond.

Based on Figure 5 it is difficult to explain the unwillingness of US government bond and cash holders in USD to reallocate into Japanese government bonds by stricter regulation or short-selling costs. There must be other reasons for the preference for US government securities. Although any attempts to explain the preference for U.S. securities necessarily are speculative, specific features of key real money investors may be part of an explanation for the reluctance to fully profit from the government bond basis. First, many real money investors with USD assets have USD liabilities and/or liquidity requirements in USD. An example is a mutual fund facing redemptions in USD. This fund may hold US government bonds exactly because of the ability to convert these into USD cash at short notice. A synthetic USD position is not a liquid asset in USD. Second, some asset managers, like money market funds, are prohibited from investing in foreign currency or do not have the operational capacity to conduct FX swap transactions. Third, government institutions like central banks and foreign governments may strategically prefer USD liquidity due to its status as the main reserve and settlement currency in the world. Even many non-US banks prefer to keep much of their liquid assets in USD. The financial crisis clearly illustrated how important USD liquidity becomes in crisis times and USD liquidity act as an insurance against liquidity squeezes in USD.

Several explanations for the existence and persistence of the government bond basis beyond those mentioned above may exist. Despite that the government bond basis easily can be taken advantage by real money investors equipped with US government bonds or USD cash, investors seem to prefer USD assets over synthetic USD assets. The access to USD liquidity US government bonds are giving the investors together with the prominent role of USD in the global financial system may be an important factor for these preferences.

7 CIP arbitrage with marginal funding

In this section I investigate the returns from an alternative cross currency trading strategy. This strategy implies rasing unsecured funding in one currency, investing in a risk-free asset in another currency and simultaneously hedge the foreign exchange rate risk and can be interpreted as incorporating the cost of Funding Value Adjustment (FVA), see Andersen et al. [2019].[41] To this end, I exploit the bond prices for high-quality financial institutions to calculate the return from such a cross currency arbitrage strategy. High-quality (AA) financial institutions have among the lowest funding costs in the market and should therefore overestimate the return for most market participants.

The cross currency arbitrage trade can be illustrated as follows:

$$arbprofit = \left(1 + g^b_{\$}\right) - \frac{F^b}{S^a}\left(1 + y^a_{\star}\right) \tag{15}$$

$$arbprofit = \left(1 + g^b_{\star}\right) - \frac{S^b}{F^a}\left(1 + y^a_{\$}\right) \tag{16}$$

where $g^b_{\$}$ is the US government bond rate, $y^a_{\star}$ is the foreign currency corporate bond rate, $g^b_{\star}$ is the foreign currency government bond rate and $y^a_{\$}$ is the US corporate bond rate. The superscripts a and b symbolize ask and bid rates, respectively.

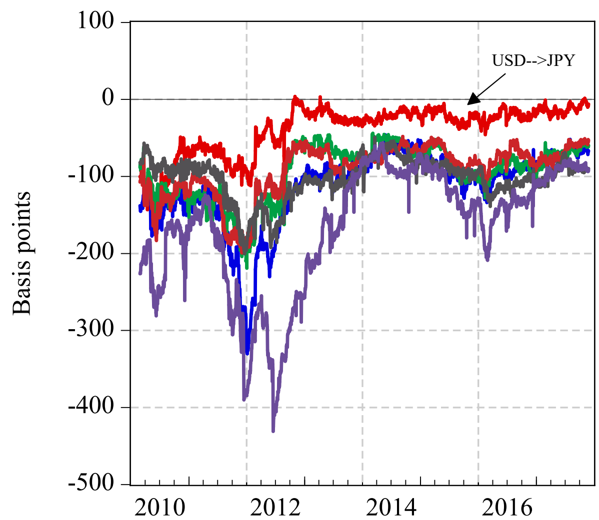
Figure 7 illustrates the arbitrage profit for Euro, GBP and JPY using USD as base currency. The maturity is 5 year. I include both directions in the graph meaning that each line in the graph may either represent borrowing in USD and investing in foreign currency or borrowing in foreign currency and investing in USD. The funding costs are based on corporate bond prices for AA financial institutions, while government bonds are used in the investment leg.[42] The line closest to zero in the graph is the return from borrowing in USD and investing in Japanese government bonds. This line has briefly crossed zero, but the maximum profit is not more than 4 basis points. Basically, this graph illustrates that bond and FX-swap prices have been consistent with the no-arbitrage CIP condition for this maturity.

Table 4 depicts the arbitrage profit across three main maturities, 2, 5 and 10 years. As before, senior corporate bond prices for bonds of high quality (AA) issued by financial institutions are used as a proxy for unsecured funding costs. As can be gleaned from the table, the average and median arbitrage profit is negative for all strategies independent of the funding currency. The most interesting figures, however, are the maximum value and the number of days with positive arbitrage

[41] FVA is basically an adjustment for the underlying funding cost. The FVA has become highly debated as banks started to report large FVA connected to the derivative book. FVA is typically related to uncollateralized derivatives with customers where the bank has hedged the risk in the interdealer market. If the customer is out-of-the money (and the bank is out-of-the money on the hedge), the bank has to pay margins without receiving margin payments from the customer. This has to be financed to a rate that is higher than what the bank receives on the margin account. In the case of the arbitrage strategy in this paper, the analogy is simply that the true funding cost has to be accounted for.

[42] Due to the use of zero coupon rates in the government bond market are based on mid-rates, the calculation does not account for bid/ask spreads in government bonds. This means, however, that the arbitrage profit reported in table 4 is biased upwards. The bid/ask spreads in government bonds are generally small.

Figure 7
Cross currency arbitrage 5-year bonds



Note: The graph shows the deviations between the synthetic funding cost and the government bond rates for EUR, GBP, USD and JPY. The maturity is 5-year. Positive numbers indicate arbitrage. Both directions are included, i.e. from USD to foreign currency and from foreign currency to USD.

profit. These figures reveal whether the mean/median hide periods of positive arbitrage profits. For the 10-year maturity arbitrage profit is not possible to reap. For the 5-year maturity, borrowing in USD and investing in JPY is the only trade that provides a small number of days in arbitrage (7 out of 2007) with a limited maximum arbitrage of 4 basis points. Turning to the 2-year maturity, USD borrowing invested in JPY shows a maximum of 22 basis points. The number of days in positive arbitrage return territory is now 195, close to 10 per cent of the observations. However, the average profit during days with arbitrage opportunities is only 5 basis points (not reported). For the rest of currencies no arbitrage profit is available. The main picture is that arbitrage profit is very difficult to reap across major bond markets.

8 Conclusion

This paper investigates the Covered Interest Parity condition for three long-dated fixed income securities across different tenors and currencies. All these securities - Libor swaps, corporate bonds and government bonds - are commonly used to test the validity of CIP.

I explain that the Libor basis, which is the difference between the synthetic and the direct Libor swap rate at a predefined tenor, cannot be arbitraged due to the roll-over and credit risk such a strategy embeds. My results indicate that the Libor basis can be explained by relative central bank balance sheets and benchmark rate discrepancies. Central bank balance sheet policies affect the price of locking in funding over longer periods - the term funding liquidity premium - in the respective

Table 4
Arbitrage profit in bonds

	(1) $–>EUR	(2) $–>JPY	(3) $–>GBP	(4) EUR–>$	(5) JPY–>$	(6) GBP–>$
			10-year maturity			
Mean (bps)	-125	-77	-113	-131	-100	-169
Median (bps)	-108	-60	-100	-1.18	-96	-170
Max (bps)	-66	-25	-51	-46	-53	-71
Obs	1932	1918	1896	1687	2009	1314
Arb days	0	0	0	0	0	0
			5-year maturity			
Mean (bps)	-92	-39	-94	-114	-103	-142
Median (bps)	-81	-25	-84	-99	-97	-113
Max (bps)	-48	*4*	-44	-46	-49	-52
Obs	2010	2007	2006	2012	2012	2011
Arb days	0	7	0	0	0	0
			2-year maturity			
Mean (bps)	-58	-24	-80	-98	-62	-119
Median (bps)	-52	-20	-71	-87	-59	-82
Max (bps)	-21	*22*	-37	-41	-5	-17
Obs	2006	1997	1974	2012	2012	2012
Arb days	0	195	0	0	0	0

Note: The table illustrates the arbitrage profit for three maturities based on actual funding cost in the funding currency and risk-free investment in government bond in investment currency. All figures are in basis points. USD–>EUR means that the funding currency is USD and investment currency is euro while EUR–>USD illustrates the case where euro is the funding currency and USD is the investment currency. Positive figures imply arbitrage opportunities. Bid/ask spreads are taken into account. The sample runs from january 2010 to December 2017.

currency and consequently the costs of obtaining funding for market participants. When the term funding liquidity premium varies across currencies, the Libor basis is basically an expression of this difference.

Corporate bonds do not face the issues of roll-over risk that colludes the Libor basis. This means that the corporate bond basis should be significantly closer to zero than the Libor basis after the global financial crisis when the term funding liquidity premium has varied across currencies. Indeed, I show that the corporate bond basis is smaller and much less persistent than the Libor basis in the post-crisis period. However, investments in corporate bonds are risky. Hence, trading the corporate bond basis is not riskless.

To avoid the default risk embedded in corporate bonds, I also examine cross currency deviations in government bonds. Based on a sample dating back to 2000 I show that the government bond basis is not particularly large compared to the pre-crisis period. I provide evidence suggesting that the government bond basis may be non-zero due to substantial costs (haircuts and lending fees) of taking advantage of this basis for round-trip arbitrageurs. Moreover, the observation that the government bond basis deviated substantially from zero prior to the financial crisis speaks against the common view that tighter banking regulation is the main driver of the current deviations.

Finally, I calculate the return based on an alternative arbitrage strategy and find no evidence of large and persistent arbitrage opportunities in bonds based on this measure. Overall, my results suggest that Covered Interest Rate Parity holds equally well in bond markets now as prior to the global financial crisis. Moreover, In contrast to the existing literature, I find little evidence of loss of market efficiency in the aftermath of the introduction of new banking regulation.

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Appendix A: Data and calculations

Table 5
Summary statistics

	A. Libor basis			B. Rel. CB balance sheets			C. Benchmark and CDS spreads			
	EUR	GBP	JPY	EUR	GBP	JPY	EUR	GBP	JPY	CDS USD-FRA
Mean	-29.95	-7.19	-63.45	0.81	1.13	1.29	15	5	20	23
Median	-30.96	-8.21	-63.62	0.85	1.09	1.06	10	3	13	15
Maximum	0.10	6.63	-25.86	1.10	1.58	2.19	46	24	81	106
Minimum	-65.40	-26.44	-101.63	0.54	0.66	0.85	1	-6	-18	3
Std. Dev.	12.90	6.21	16.66	0.16	0.22	0.42	11	6	20	21
Observations	413	413	413	413	413	413	377	377	377	391

Note: The maturity of the Libor basis is 5 years. The benchmark spread is the U.S. Libor minus the foreign currency equivalent benchmark rate with the foreign currency denoted in the column heading. The last column depicts the 5-year CDS spread between Germany and France. All numbers in basis points except the relative central bank balance sheets (Rel. CB balance sheets) which are indexed at 1 in January 2010. The sample runs from 2010 to 2017. Weekly data frequency.

Data sources and bond spreads

1. *Libor Basis/Cross Currency Basis Swap with 3m IBOR as underlying short rate*: Quoted on Bloomberg with tickers EUBSx, JYBSx, BPBSx, where x the number of years to maturity.

2. *Commercial paper rates*: Commercial paper rates from Tradeweb for A1/P1 rated financial institutions. Quoted on Thomson Reuters Eikon with tickers: YUSD3MCPF=TWEB, YGBP3MCPF=TWEB, Y3JPYMCPF=TWEB and YEUR3MCPF=TWEB.

3. *Interbank Offered Rates - IBOR*: Quoted on Bloomberg with tickers EUR003M, BP0003, JY0003 and US0003.

4. *Iterest Rate Swaps*: Interest rate swap rates with 3m IBOR as underlying short rate. Quoted on Bloomberg with tickers JYSWx (for Japanese Yen 6m LIBOR is the underlying short rate), EUSWxV3, USSWx, BPSWx, where x represents the number of years to maturity.

5. *Government bond yields*: Estimated (Nelson Siegel approach) zero coupon rates downloaded from Bank of England webpage and European Central Bank webpage. For US and JPY government bonds I use data sourced through Bloomberg with tickers GS x (generic strips) and ticker GJGBx, respectively. x represents the number of years to maturity.

6. *Bank balance sheet data*: Available at the respective central bank webpages.

7. *Central Bank balance sheet data*: Available at Bloomberg with tickers EBBSSECM, B111B56A, BJACTOTL and FARBAST.

8. *Credit Default Prices prices for France*: Quoted on Thomson Reuters Eikon with tickers FR5USD and FR5EUR.

9. *Corporate bond data*: The computation of corporate bond spreads follows the following steps:

   (a) Extract all individual bonds included in Barclays Global Aggregate Index (Bloomberg ticker for information about the index: LEGATRUU) issued by an institution classified as "banking" and issued by institutions domiciled in Germany, Netherlands, Australia, Canada, UK, and Japan and where the issuances are denominated in USD, EUR, GBP or JPY. Bonds included in the Global Aggregate index have an amount outstanding of at least 300mn USD or EUR, 200mn GBP, 35bn JPY.

   (b) Select Senior unsecured issues (bullet bonds) with rating AA or A1.

(c) Calculate the zero coupon spread over the respective currency interest rate swap curve. I follow the calculation of bond spreads in Du et al. [2019] closely. The bond pays a coupon ($coup$), q times a year. The investor receives the principal at $t+n$. Each coupon and principal payment are discounted with the term structure of the zero coupon Libor swap rates (interest rate swap rates), $c_{t,t+n}^{j,LibSwap}$. The bond spread is defined as $b_{t,t+n}^{j}$, i.e. the spread over the Libor swap rate necessary to achieve the observed price $P_{t,t+n}^{j}$ in currency j. The procedure can be expressed as follows:

$$P_{t,t+n}^{j} = \sum_{\tau=1/q}^{n} \frac{coup}{(1+c_{t,t+n}^{j,LibSwap}+b_{t,t+n}^{j})^{\tau}} + \frac{1}{(1+c_{t,t+n}^{j,LibSwap}+b_{t,t+n}^{j})^{n}} \tag{17}$$

(d) The average bond spread is calculated for each rating category, maturity bucket (1.5-2.5 years to maturity equals maturity bucket 2 year etc.), country of incorporation of the issuer and currency.

(e) The bond spread differentials are calculated for the same rating category, maturity bucket and country of incorporation separately. For instance, the n-year bond spread differential between Japanese issuers in JPY and USD with rating A1 is:

$$BondSprdDiff = b_{t,t+n}^{JPY,A1} - b_{t,t+n}^{USD,A1} \tag{18}$$

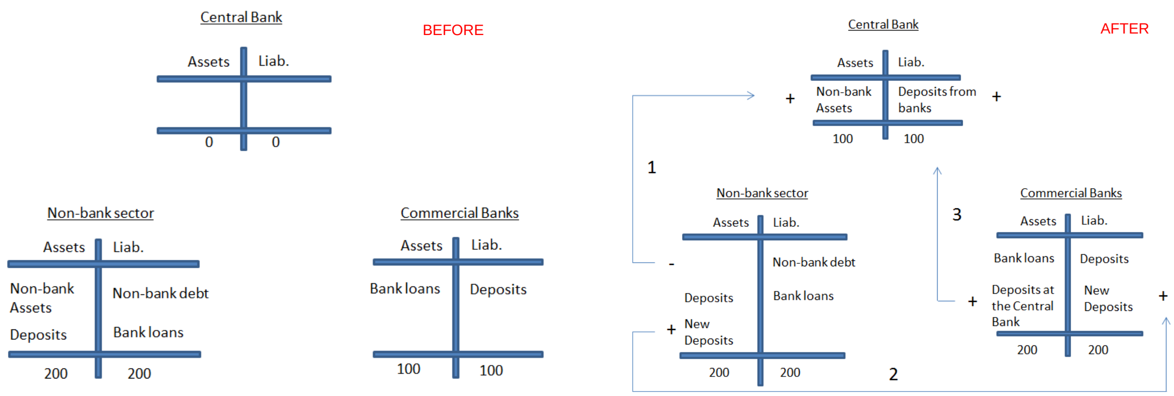
Appendix B: The relation between funding liquidity and central bank balance sheet policies

The central bank has the power to inject the most liquid asset in the monetary system - central bank reserves. Asset purchases, which effectively inject central bank reserves, may affect the funding liquidity through different channels. One of these is the bank balance sheet channel. This channel is a direct product of the central bank purchasing securities held by the non-bank sector.[43]

Figure 8 provides a stylized illustration of how this channel works. For simplicity the central bank has a clean balance sheet before embarking on asset purchases. For simplicity, the aggregate private bank balance sheet consists of bank loans and deposits. The non-bank sector holds non-bank assets and commercial bank deposits financed by bank debt and non-bank debt. As the central bank absorbs assets held by non-banks (1), it requires commercial banks to credit the non-bank client's deposit account as settlement for the assets the central bank has purchased (2). On the other side, the commercial bank simultaneously requires central bank reserves in return from the central bank. This leads to an increase in banks' deposits at the central bank (3). In figure 8, the central bank buys securities worth 100 from non-banks. For the non-bank sector, the transaction with the central bank is no more than an asset swap - securities in return for bank deposits. In contrast, the aggregate bank balance sheet increases by 100 - new deposit on the liability side and highly liquid central bank reserves on the asset side and the balance sheet size remain unaffected. The central bank has increased its balance sheet size by 100. The increase in banks' central bank reserves leads to an increase in liquid assets for banks, while the increase in non-bank deposit liabilities increase banks' deposit-to-illiquid asset ratio.

[43] See also Christensen and Krogstrup [2016] for an explanation of this mechanism.

Figure 8
Asset purchases and the bank balance sheet channel



(a) (b)

Note: Panel a) depicts a stylized illustration of the aggregate players' balance sheets before the central bank has initiated asset purchases. In panel b) the central bank is buying securities from the non-bank sector worth 100 (1). Simultaneously, the non-bank sector gets bank deposits on its asset side (2) and commercial banks get deposits at the central bank (3). Both the central bank and commercial banks have increased their balance sheet, while the non-bank sector's balance sheet is unchanged.

The illustration is highly simplified, but serve as an example of how central bank asset purchases may affect commercial banks balance sheets on the margin. The impact on banks' funding position depends on which type of deposits the banks receive, how large share of the new liabilities that ends up as deposits, what kind of alternative liabilities banks may receive and the maturity structure of these liabilities. However, on the margin at which the new liabilities created by the central bank will put downward pressure on the yields banks are willing to attract funding and increases the availability of term funding. This may be especially pronounced in situations with sluggish domestic growth in banks' illiquid assets.

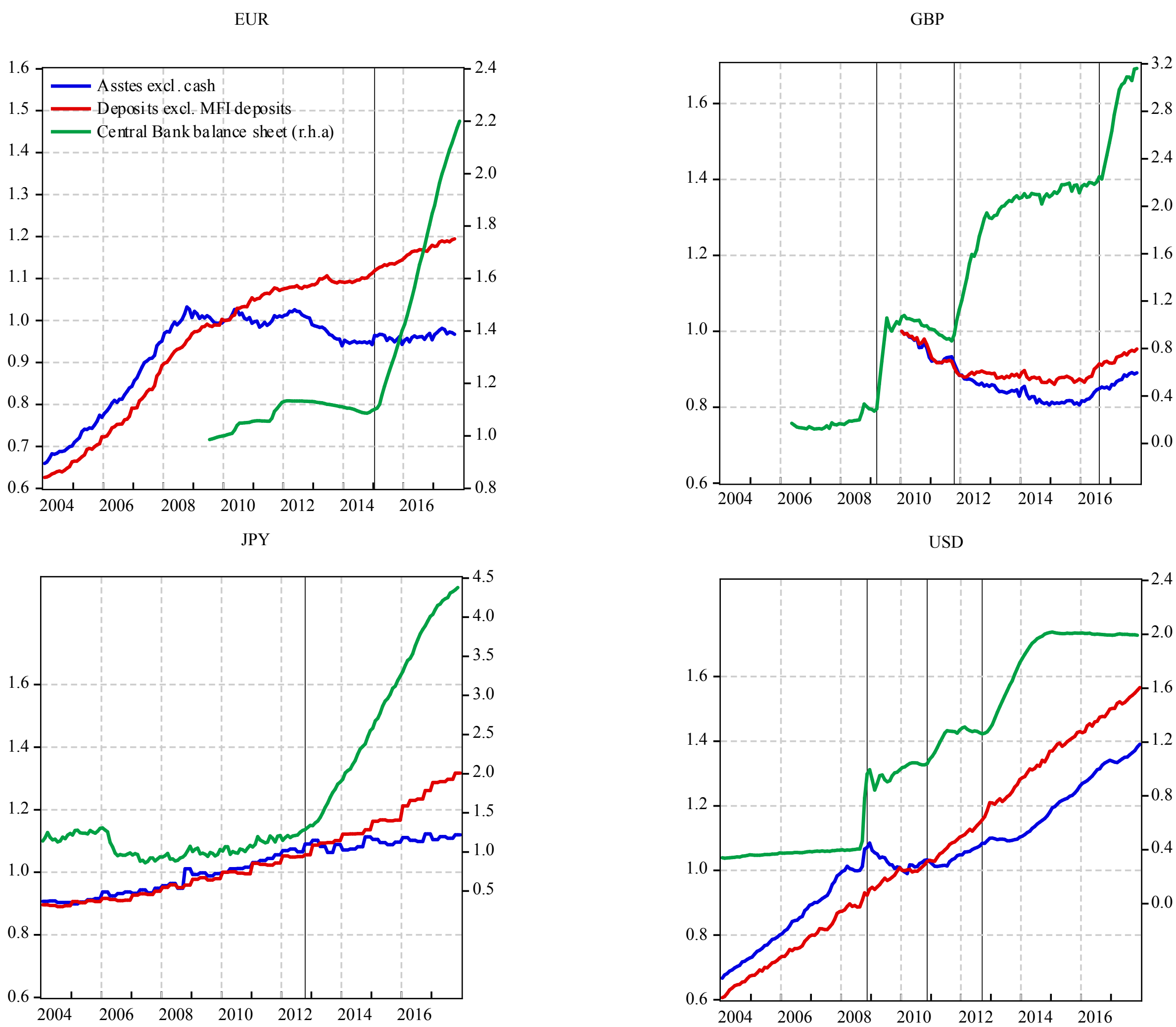
In short, if the additional deposits - or liabilities - are characterized as long term-funding (i.e retail deposits are regarded as long-term funding (Drechsler et al. [2017])) central bank asset purchases contribute both to a more liquid banking system *and* additional long-term funding for banks. When the central bank creates new long-term bank liabilities through asset purchases over and above the ex-ante demand by the banking sector for such liabilities, funding liquidity improves and the yield on long-term bank liabilities falls. Basically, this particular channel implies that banks can access long-term funding at favourable terms either by replacing bond issuances with deposits and/or attracting market based funding (by issuing bonds) at relatively low spreads. The increase in central bank induced liabilities is disconnected from the standard bank-driven increase in liabilities facilitated by non-cash asset growth. The new liabilities are instead matched by highly liquid central bank reserves. As shown in Figure 9, data indicate that this channel has indeed been at play.

The deposit-to-asset ratio may, however, increase independently of asset purchases. A change in the composition of liabilities can be driven by several factors. Negative interest rates may for instance induce a shift from market-based money market investments to deposits as it is difficult for banks to charge negative interest rates on household deposits. However, figure 9 depicts a remarkable correlation between the introduction of asset purchases and relative deposit growth, potentially reinforced by the introduction of negative interest rates.

The central bank may also purchase securities held by commercial banks. In such case, asset purchases can affect banks' asset composition and can potentially explain the correspondence between central bank asset purchases the relative increase in deposits. Although banks' total assets will not change, the share of cash relative to non-cash assets will increase. Figure 9 depicts assets excluding cash holdings. However, this can not explain the increase in deposits. When the central bank purchases assets held by banks, non-cash assets fall, but deposit liabilities are not affected.

There are also other ways asset purchases may affect funding liquidity. For instance the portfolio rebalancing channel may improve funding liquidity. The argument is that when the central bank buys a certain asset the seller seeks for alternative investments in other asset classes. This may be reinforced by extraordinary low yield on long-dated securities that often is the case when unconventional monetary policy is implemented.

Figure 9
Banks' assets and deposits



Note: The graph shows private banks' assets excluding cash in the central bank, deposits excluding deposits from Monetary Financial Institutions (interbank deposits) and the size of the central bank balance sheet in EUR, GBP, JPY and USD. All series are indexed to 1 at the beginning of 2010. The central bank balance sheet in EUR represents only the asset purchases due to the fact that the ECB has conducted a large range of open market operations. These operations have affected the size of the balance sheet, but are not relevant for the deposit channel. For the remaining currencies I use aggregate data on the central banks balance sheets. The vertical lines indicate the dates when the respective central banks embarked on large-scale asset programs.

Supplementary Internet Appendix to accompany

Has regulation ruined Covered Interest Parity in bond markets?

A Benchmark rate discrepancies

Unsecured term interbank reference rates all have one common problem: They are meant to represent rates on transactions that are virtually non-existent. Available data and surveys show that unsecured interbank lending is heavily concentrated in the shortest maturities, like overnight. Very little unsecured interbank lending goes on in maturities of 3 and 6-months.[44] This was the case even before the financial crisis, and the trend has been reinforced since then. This means that the banks submitting ibor-rate must rely on rates from other markets with similar characteristics, on their subjective judgement or a combination of the two. The current effort in many countries to produce nearly risk-free alternative reference rates must be seen in this context.

Since 1998, Libor has been defined by the panel banks' daily answer to the following question: "At what rate could you borrow funds, were you to do so by asking for and then accepting interbank offers in a reasonable market size just prior to 11 am?" This question is posed in a way that defines Libor as an interbank offered rate. However, recognizing the fact that interbank term transactions are rare, the administrator of Libor, ICE Benchmark Administration Limited (IBA), has laid out a roadmap for the transition of Libor to a new "waterfall methodology". This methodology entails a new output statement for Libor: "A wholesale funding rate anchored in LIBOR panel bank" unsecured transactions to the greatest extent possible, with a waterfall to enable a rate to be published in all market circumstances".

The term "waterfall" refers to the ordering of inputs for the submissions into three levels. To the extent available, panel banks should base their submissions on Level 1 input, which are "eligible wholesale, unsecured funding transactions". If no such eligible transactions were made, submissions should be transaction-derived (Level 2). That means utilizing time-weighted historical eligible transactions adjusted for market movements, and linear interpolation. If neither Level 1 nor Level 2 inputs are available, panel banks should base their submissions on expert judgement (Level 3).

One important feature of the new methodology is that the eligible transactions are no longer limited to interbank loans. The eligible transactions are rates paid by banks on unsecured term deposits, as well as fixed rates paid on primary issuances of commercial paper (CP) and certificates of deposits (CD). The major part of CP and CD funding comes from investors outside the banking system, like money market funds and non-financial corporations. Rates paid by banks on CP/CD funding are not interbank rates and cannot necessarily be seen as offered rates like in the current definition of Libor. Hence, the âIBOâ part of the abbreviation Libor will no longer apply. In general, funding rates from counterparties outside the banking system are likely to be somewhat lower than rates on interbank loans. The reason is that money market funds and corporations that supply funding to banks via CP/CD are not subject to the same regulatory requirements as a bank lending to another bank. Thus, all else equal, the price of funding from outside the banking system will be somewhat cheaper than interbank funding.

IBA expects the transition to the new waterfall methodology to be completed by no later than the first quarter of 2019. However, USD Libor already looks very similar to the rates paid for CP-funding by highly rated banks, as shown in figure OA.1. The waterfall methodology also means that even Libor, despite the same definition across currencies, can differ due differences in money market activity and judgment across currencies.

[44] See for instance Euro Money Market Survey (2015) by the European Central Bank.

Euribor was created in 1999 with the introduction of the euro. Currently 20 banks provide their daily submissions to EURIBOR according to the following definition: Euribor is defined as the rate at which euro interbank term deposits are offered by one prime bank to another prime bank within the EMU zone, and is calculated at 11:00 am (CET) at spot value (T+2).

Euribor is thus defined as an interbank rate. In contrast to US Libor it is not only an interbank rate in name, but also quoted as one. Chart 4 below shows the same as Chart 3, only for the euro area: The difference between 3-month Euribor and the rate on 3-month commercial paper in euros issued by highly rated European banks. As discussed above, differences in regulatory costs should imply that interbank rates are somewhat higher than comparable rates on banks' borrowing from non-banks. As can be seen from chart 4, this is the case for Euribor. The difference is not constant over time. Variation may be due to many factors, like shifts in the demand-supply balance in the CP market that are not transmitted one-for-one to Euribor. On average since 2011, the spread between 3-month Euribor and the corresponding CP rate has been 12 basis points. A simple back-of-the-envelope calculation substantiates such a spread. An interbank loan is subject to a 20 per cent risk weight in Basel III. Assuming 10 per cent capital requirement and 10 per cent required return on equity, the required spread on top of the borrowing cost is 20 basis points (0.2*0.1*0.1)

Since unsecured term lending transactions between banks are rare, the panel banks' Euribor submissions must to a large extent be based on expert judgement. Panel banks' submissions reflect what they believe the rates on eligible interbank lending transactions would have been, if they had taken place. This judgement is likely to be informed by rates on traded products in other markets like CP, CD and OIS, adjusted appropriately to reflect interbank term offered rates.

Acknowledging the decline in interbank activity, the administrator of Euribor, the European Money Market Institute (EMMI), has launched a program of Euribor reform. An important part of this has been to move from a quote-based methodology to a transaction-based methodology for Euribor (the latter sometimes referred to as Euribor+). To assess whether a seamless transition from a quote-based to a transaction-based methodology would be feasible, the EMMI ran a so-called pre-live verification program from September 2016 to February 2017. During this period, the EMMI calculated a transaction-based rate based on collected data. In order for a seamless transition to be feasible, the level and volatility of the transaction-based rate would have to be similar to the level and volatility of Euribor. In May 2017, the EMMI presented the outcome of the pre-live testing. It concluded that the level and volatility of the transaction-based rate differed too much from the quote-based Euribor to allow a seamless transition. This conclusion is mirrored by the different behavior of the 3-month Euribor and corresponding rate on banks' borrowing via commercial paper in figure OA.1.

As a way forward, EMMI now plans to introduce a hybrid methodology for Euribor. EMMI recognizes that the level of liquidity in the unsecured money market is currently not consistently sufficient to base the Euribor calculation solely on transactions. In a consultation paper published in March 2018, EMMI asked market participants for feedback on the proposed hybrid methodology. In short, the suggested hybrid methodology has many similarities to the waterfall structure for Libor described above. It is suggested to follow a hierarchical approach, where inputs to Euribor submissions are divided into three levels, ranging from real-time eligible transactions to panel banks' judgement. Eligible transactions include unsecured, fixed rate, cash deposits from banks and a range of non-bank financial institutions, as well as funds obtained from all counterparties via commercial paper and certificates of deposits.

B Additional tables and graphs

This section provides supplementary results complementing the evidence in the main text. Table OA.I shows an alternative regression specification to the panel specification in table 1 applying a Seemingly Unrelated Regression framework, table OA.II illustrates the cointegrating relationship between the Libor basis and the bond spread differential, while table OA.III and table OA.IV provide the results from a Vector Error Correction Model for maturity 2 and 10 years. Table OA.V and table OA.VI illustrate the haircut levels applied by EUREX Clearing and the bid/ask spreads in the forward exchange rate market, respectively. Furthermore, figure OA.1 shows the respective IBOR rates and the A1-P2 CP rates across currencies. Figure OA.2 depicts the 5-year bond spreads and relation to the Libor basis for GBP/USD while figure OA.3 and figure OA.4 show the bond spreads and Libor basis for 2 and 10 year maturities, respectively. Finally, figure OA.5 shows the repo haircut levels source from New York Federal Reserve.

Table OA.I
Seemingly Unrelated Regression

	2-year Libor Basis			5-year Libor Basis			10-year Libor Basis		
	EUR	JPY	GBP	EUR	JPY	GBP	EUR	JPY	GBP
ΔLB_{t-1}	0.05	0.1**	0.06	0.17***	0.18***	0.20***	0.18***	0.23***	0.21***
	(1.23)	*(2.32)*	*(1.33)*	*(4.07)*	*(4.07)*	*(4.59)*	*(4.06)*	*(4.70)*	*(4.63)*
$\Delta RelCBBalSheet(FC/US)$	4.91	-16.25**	-28.53***	-48.62**	-16.36**	-19.96***	-52.22**	-16.56**	-19.26**
	(0.17)	*(-2.23)*	*(-2.89)*	*(-2.35)*	*(-2.04)*	*(-2.62)*	*(-2.51)*	*(-2.11)*	*(-2.51)*
$\Delta CDSsprFR(USD - EUR)$	-0.3***	-0.2***	-0.09***	-0.19***	-0.19***	-0.09***	-0.10***	-0.11***	-0.11***
	(-5.50)	*(-4.46)*	*(-2.84)*	*(-5.13)*	*(-4.30)*	*(-3.33)*	*(-2.85)*	*(-2.71)*	*(-4.10)*
$\Delta CP - IBORsprdiff(FC - USD)$	-0.23***	-0.24***	-0.15***	-0.10***	-0.08***	-0.09***	-0.06	-0.06**	-0.07**
	(-4.24)	*(-9.36)*	*(-4.17)*	*(-2.63)*	*(-2.78)*	*(-2.95)*	*(-1.56)*	*(-2.16)*	*(-2.57)*
LB_{t-1}	-0.02**	-0.02***	-0.05***	(-0.03)***	-0.02***	-0.04***	-0.02***	-0.02**	-0.04***
	(-2.29)	*(-2.61)*	*(-3.76)*	*(-3.39)*	*(-2.85)*	*(-3.51)*	*(-3.15)*	*(-2.55)*	*(-3.25)*
Constant	-0.56	-0.62**	-0.37***	-0.80	-1.28***	-0.24**	-0.63***	-1.11**	-0.30**
	(-1.94)	*(-2.33)*	*(-2.73)*	*(-3.22)*	*(-2.82)*	*(-2.19)*	*(-2.98)*	*(-2.54)*	*(-2.25)*
Obs.	372	372	372	373	373	373	373	373	373
System obs.		1116			1119			1119	
Adjusted $\hat{R2}$	0.13	0.14	0.08	0.17	0.12	0.11	0.12	0.1	0.13

*Note: The table depicts the results from a Seemingly Unrelated Regression for EUR/USD, GBP/USD and USD/JPY. *** denote a statistical significance level of 1 per cent, ** 5 per cent and * 10 per cent, respectively. The model specification is specified in equation 7. The results depict a similar picture as the panel regression results. The currency specific coefficient estimates on the CDS-spread and the benchmark spread are slightly higher for EUR and JPY (and lower for GBP) than the common coefficients from the panel regression, especially for the 2-year basis swap. However, by translating the coefficients into the impact of one standard deviation change in the relative central bank balance sheets the effects are comparable across currencies and very similar to the panel regression results. The differences in the coefficients are related to the fact that the balance sheets are indexed and the base level varies across currencies. The sample runs from 2010 to 2017.*

Table OA.II
Johansen Cointegration test

	EUR/USD		USD/JPY		GBP/USD	
	Coint.rel.	P-value	Coint.rel.	P-value	Coint.rel.	P-value
Trace	None	0.00	None	0.00	None	0.00
	At most 1	0.85	At most 1	0.77	At most 1	0.10
Max E.V	None	0.00	None	0.00	None	0.00
	At most 1	0.85	At most 1	0.77	At most 1	0.10

Note: Cointegration test for the 5-year Libor basis and the 5-year bond spread differential for high quality issuers. I include two lags based on Schwarz Information Criterion.

Table OA.III
Vector Error Correction Model - 2 year maturity

	EUR/USD		USD/JPY		GBP/USD	
	(a)Unrestricted					
	bspr	LB	bspr	LB	bspr	LB
Coint. Coeff	1	-0.76	1	-0.97	1	-0.53
	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB
Adj. coeff $((\lambda_{bspr}),(\lambda_{LB}))$	-0.05	0.005	-0.004	0.005	-0.025	-0.00027
t-values	(-3.57)	(1.84)	(-0.99)	(2.52)	(-3.15)	(-0.13)
	(b)Restricted: Coint. relation (1,-1)					
	bspr	LB	bspr	LB	bspr	LB
Coint. Coeff	1	-1	1	-1	1	-1
LR test (prob.)	0.009		0.82		0.22	
	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB
Adj. coeff $((\lambda_{bspr}),(\lambda_{LB}))$	-0.03	0.002	-0.004	0.005	-0.02	0.0002
t-values	(-2.87)	(1.28)	(-0.95)	(2.52)	(-2.90)	(0.11)

Note: The table shows the results from a Vector Correction Model with two lags, no trend and intercept in the cointegrating relationship. The variables are the 2-year corporate bond spread differential (bspr) in EUR, JPY and GBP, against USD and the 2-year Libor basis (LB). The first model is an unrestricted model (a), while in (b) the cointegrating relationship is restricted to (1,-1). Bond spreads and the Libor basis are measured in basis points. The sample runs from January 2010 to December 2017.

Table OA.IV
Vector Error Correction Model - 10 year maturity

	EUR/USD		USD/JPY		GBP/USD	
	(a)Unrestricted					
	bspr	LB	bspr	LB	bspr	LB
Coint. Coeff	1	-1.59	1	-1.27	NA	NA
	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB
Adj. coeff $((\lambda_{bspr}),(\lambda_{LB}))$	-0.012	0.002	-0.004	0.0014	NA	NA
t-values	(-3.00)	(2.9)	(-1.70)	(2.21)	(NA)	(NA)
	(b)Restricted: Coint. relation (1,-1)					
	bspr	LB	bspr	LB	bspr	LB
Coint. Coeff	1	-1	1	-1	NA1	NA
LR test (prob.)	0.056		0.30		NA	
	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB	$\Delta bspr$	ΔLB
Adj. coeff $((\lambda_{bspr}),(\lambda_{LB}))$	-0.010	0.0013	-0.004	0.0010	NA	NA
t-values	(-2.91)	(2.37)	(-1.83)	(1.86)	(NA)	(NA)

Note: The table shows the results from a Vector Correction Model with two lags, no trend and intercept in the cointegrating relationship. The variables are the 10-year corporate bond spread differential (bspr) in EUR, JPY and GBP, against USD and the 10-year Libor basis (LB). The first model is an unrestricted model (a), while in (b) the cointegrating relationship is restricted to (1,-1). Bond spreads and the Libor basis are measured in basis points. The sample runs from January 2010 to December 2017. The estimates for GBP/USD is not available due missing data.

Table OA.V
EUREX Clearing cross currency haircut levels

Base currency	Cross currency	Cross currency haircut
USD	AUD	8.40 %
USD	CAD	5.00 %
USD	CHF	6.30 %
USD	EUR	4.30 %
USD	GBP	5.60 %
USD	JPY	4.20 %
USD	NZD	7.40 %

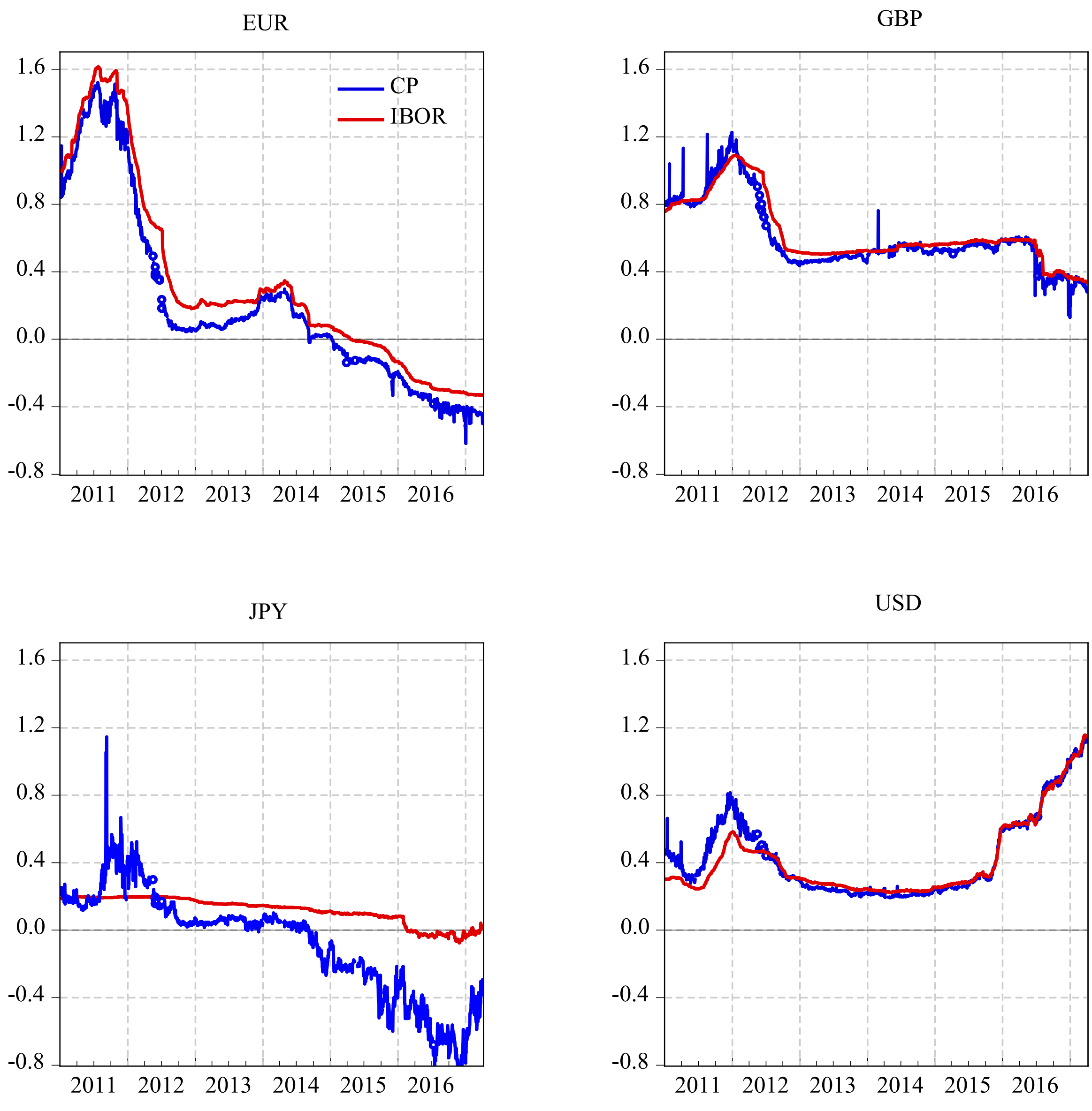
Note: The table shows the haircut applied by Eurex clearing - a large European clearinghouse - in the case of cross currency collateral. The numbers are updated by Eurex regularly. The numbers indicate a haircut level between 4 and 9 per cent depending on the currency pair. This indicates the additional risk connected to cross currency collateral. Source: EUREX Clearing.

Table OA.VI
Bid/ask spreads in the foreign exchange hedging market

	GBP/USD			EUR/USD			JPY/USD		
	2-year	5-year	10-year	2-year	5-year	10-year	2-year	5-year	10-year
Mean	3.83	3.19	2.91	3.75	2.88	3.03	4.28	4.19	3.76
Median	4.00	3.00	2.90	4.00	3.00	3.82	4.00	4.00	3.00
Max.	12.00	8.10	10.90	6.20	6.00	6.45	10.00	8.25	10.00
Obs.	2062	2062	2061	2062	2062	2061	2062	2062	2061

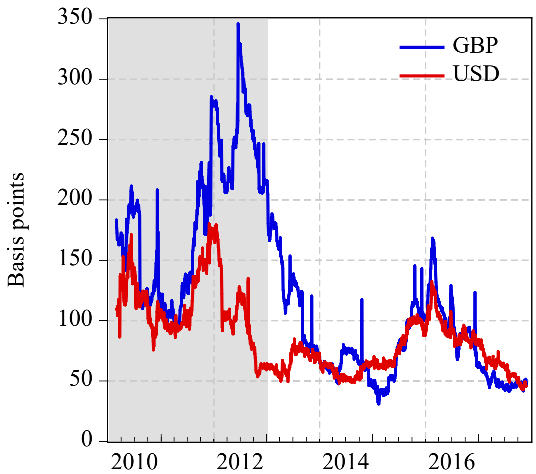
Note: The table shows the bid/ask spreads from 2010-2017 in the foreign exchange hedging market across different currency pairs and maturities. The data is extracted from cross currency basis swaps quoted on Bloomberg. All numbers are in basis points.

Figure OA.1
Libor and CP rates

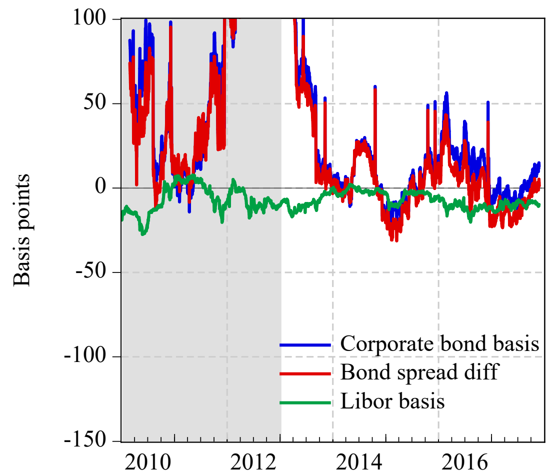


Note: The panels show 3-month A-1/P-1 commercial paper rates and the 3-month Libor rates in GBP, JPY and USD. In EUR I use Euribor as this is the most commonly used benchmark rate and the underlying benchmark rate in euro area Libor swaps. The Commercial Paper rates are quoted rates from Tradeweb and sourced through Thomson Reuters Eikon. The Libor and Euribor rates are downloaded from Bloomberg.

Figure OA.2
Bond spreads and the Libor basis, 5-year maturity



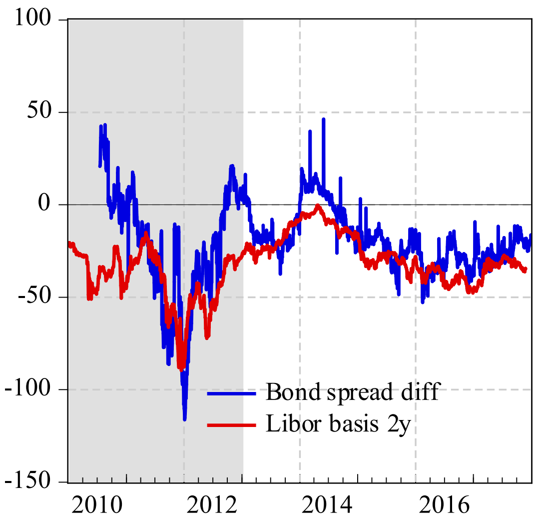
(a) Bond spreads in GBP and USD



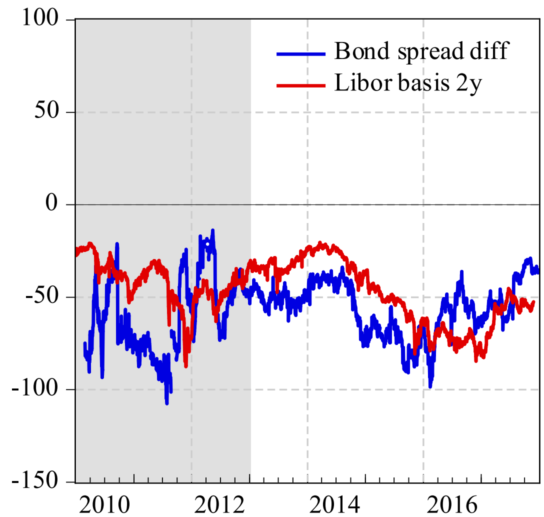
(b) Corporate bond basis GBP/USD

Note: The left-hand graph shows the corporate bond spread for a basket of corporate issuers with the same rating and domiciled in the same country in GBP and USD. The right hand graph shows i) the corporate bond spread differential (GBP minus USD) based on the corporate bond spreads depicted in graph a, ii) the Libor basis which is the difference between the synthetic and direct Libor swap rate, and iii) the corporate bond basis for similar issuers which is the difference between synthetic and direct corporate bond rate. Negative values of the basis mean that the direct corporate bond rate in USD is lower than the synthetic corporate bond rate implied from foreign currency denominated bonds. The corporate bond basis is zero if the Libor basis and the bond spread differential are equal. The shaded area illustrates the European sovereign debt crisis from 2010 to 2012.

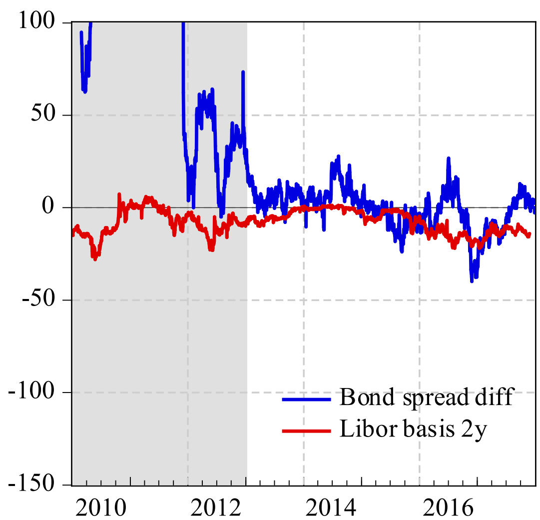
Figure OA.3
Bond spreads and the Libor basis - 2 year



(a) EUR



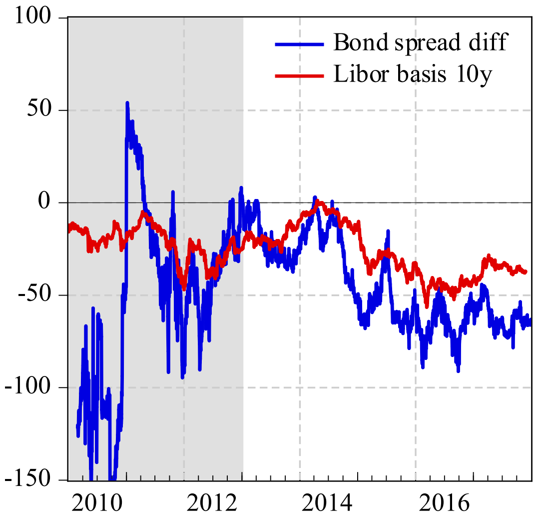
(b) JPY



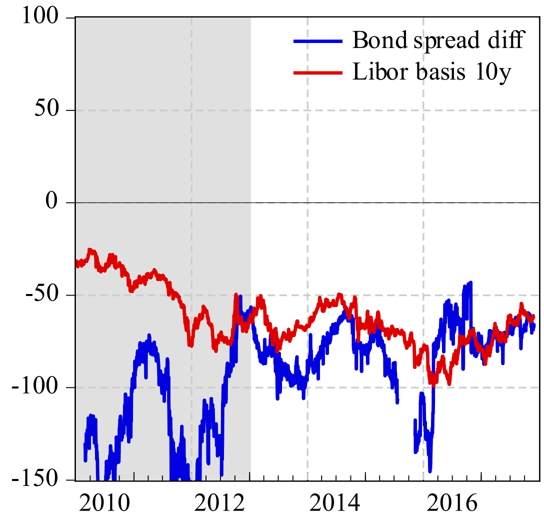
(c) GBP

Note: The graph shows the 2-year Libor basis and the corresponding corporate bond spread differential for high quality (AA) bonds denominated in EUR, JPY and GBP versus USD. The Corporate bond basis is zero if the Libor basis and the bond spread differential are equal.

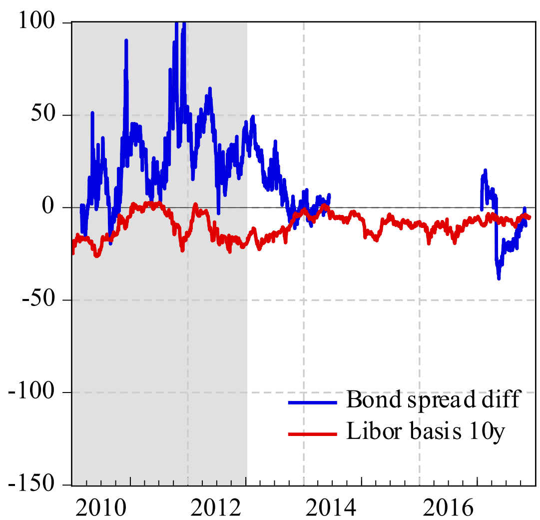
Figure OA.4
Bond spreads and the Libor basis - 10 year



(a) EUR



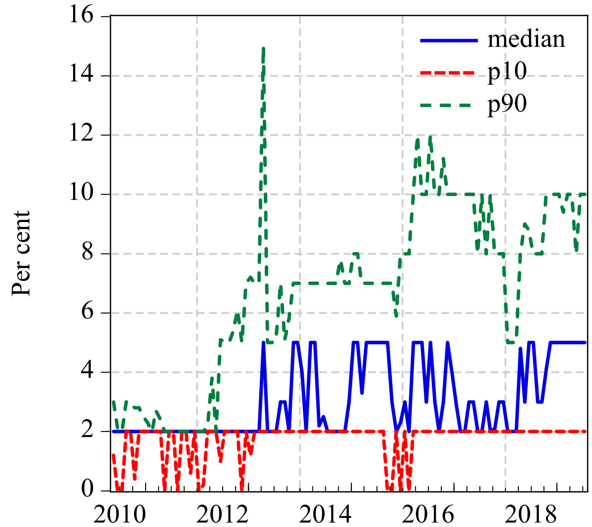
(b) JPY



(c) GBP

Note: The graph shows the 10-year Libor basis and the corresponding corporate bond spread differential for high quality (AA) bonds denominated in EUR, JPY and GBP versus USD. The Corporate bond basis is zero if the Libor basis and the bond spread differential are equal.

Figure OA.5
Haircut levels from NY Fed



Note: The figure depicts the evolution of the median, the 90th percentile and the 10th percentile of haircut levels for international securities in the U.S. tri-party repo market and Fixed Income Clearing Corporation (FICC).