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Analysing Cross-Currency Basis Spreads

This paper studies the drivers behind the EUR/USD basis swap spreads widening.

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Abstract

This paper investigates the drivers of cross-currency basis spreads, which were historically close to zero but have widened significantly since the start of the financial crisis. Credit and liquidity risk, as well as supply and demand have often been cited as general factors driving cross-currency basis spreads, however, these spreads may widen beyond what is normally explained by such variables. We suggest market proxies for EUR/USD basis swap spread drivers and build a multiple regression and cointegration model to explain their significance during three different historical periods of basis widening. The most important drivers of the cross-currency basis spreads appear to be short- and medium-term EU financial sector credit risk indicators, and to a slightly lesser extent, short- and medium-term US financial sector credit risk indicators. Another important driver is market volatility for the short-end basis spread, and the EUR/USD exchange rate for the medium term basis spread, and to a lesser extent, the Fed/ECB balance sheet ratio.

Keywords: Cross-currency swap, basis spread, overnight indexed swap, cointegration, arbitrage

JEL codes: D53, G01, C31

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Analysing Cross-Currency Basis Spreads

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1. Introduction

Cross-currency basis swaps (CCS) have been for some years showing an interesting phenomenon of significantly negative (or positive) cross-currency basis spread to a floating rate of one currency vs. the other (Figure 1). CCS basis spreads were historically close to zero (apart from bid-ask spreads), based on the assumption of banks' continuous access to interbank market financing at IBOR rates. This assumption was widely questioned when basis spreads significantly widened in 2007 and practically became an independent market risk factor. The existence of the basis has been since then often associated with a deviation from the covered interest rate parity (CIP). In particular, the assumptions of the CIP, such as no restrictions to investing in the domestic or foreign market, and that the domestic and foreign interest rates roughly reflect the same risk, thus needed to be questioned. Identifying the drivers behind the basis and their relative importance offers more clarity on the CIP, helps to assess the fair value of the basis, or helps to project its future direction. In this paper, we discuss these drivers; in particular, we take a closer look at how credit and liquidity risk of underlying money market rates in two currencies, and demand and supply imbalances influence cross-currency basis swap spreads, and we discuss arbitrage-free boundaries in cross-currency funding and investing. We focus on the most liquid currency pair, the EUR/USD, and review historical episodes of EUR/USD basis. The outcome of this discussion leads to identifying the drivers, the market variables, changes of which reasonably capture changes in the EUR/USD basis. We then use them as regressors in the multiple regression model and cointegration analysis to explain their importance during three relevant historical periods of basis widening on the short end (3 months), and medium part (5 years) of the EUR/USD basis curve.

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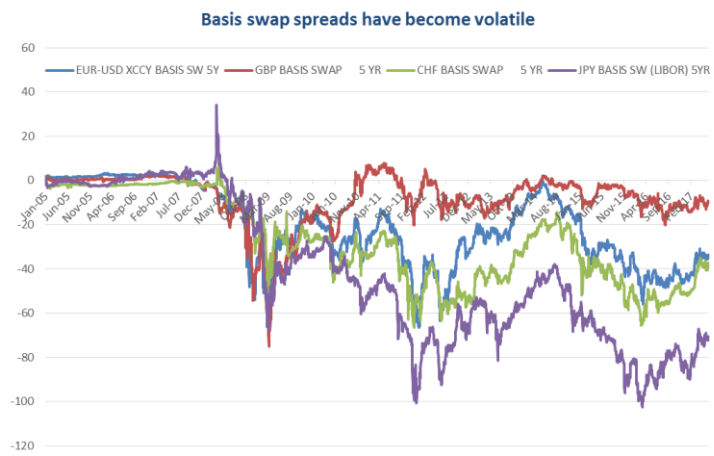

Figure 1. 5-year cross-currency basis swap spread vs. major currencies (3M USD LIBOR vs. 3M Euribor/AUD 3M Bank Bill/3M YEN LIBOR/GBP 3M Libor + spread) since 2005. *Source: Bloomberg*

2. Literature review

A float-to-float cross-currency basis swap is a swap that exchanges principal and periodic interest payments based on two money market reference rates in two different currencies. The exchange rate used to fix the initial and the final principal amount is determined at inception. These are the most commonly used cross-currency swaps and allow counterparties to temporarily transfer assets or liabilities in one currency into another currency. A cross-currency basis spread thus represents the costs associated with temporary swapping of two currencies. The mechanics of currency swaps are well explained e.g. in Baba et al. (2008b). Money market reference rates (i.e., IBOR rates) in different currencies reflect different credit and liquidity risk, which are partly translated into a spread over one leg of the cross-currency basis swap (see Figure 2). The shape of the basis spread term structure varies over time.

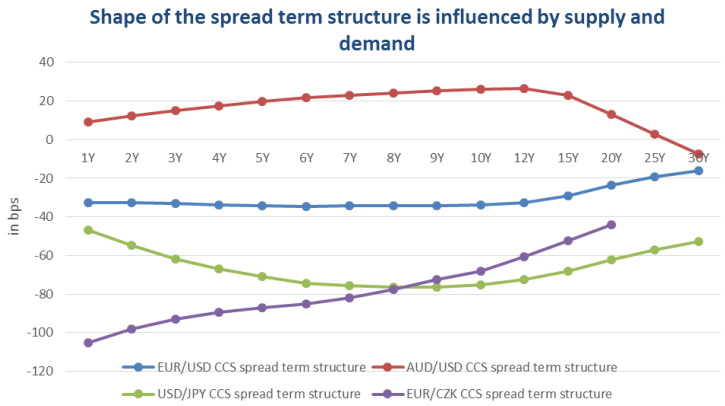

Figure 2. Term structure of CCS spreads of 3M Euribor vs 3M USD Libor, 3M Pribor vs 3M Euribor, and 3M AUD Bank Bill vs 3M USD Libor as at 2 June 2017. *Source: Bloomberg*

The existence of basis swap spreads itself leads to discrepancies with respect to this interpretation. According to Chang and Schlogl (2012), basis swap spreads are inconsistent with a classical arbitrage argument between the spot and forward markets. In Section 3 we discuss this arbitrage argument in a slightly stricter sense in a setting where entities borrow at a risky (unsecured) rate while invest at a risk-free rate. From the valuation point of view, Bianchetti and Carlicchi (2012) argue that basis spreads are consistent with an arbitrage-free market, with the consequence that the valuation of related derivatives needs multiple curve input for estimating forward rates and discounting future cash flows. In fact, when we change the discount curve, we change the market value of the derivative. This has led to a reassessment of the one curve concept (using one curve to both estimate the forward rates and to discount future cash flows) and to the introduction and adoption of multiple valuation curves.

Although the literature on cross-currency basis has been somewhat limited in the past, several papers have been recently published explaining the issue mostly in the context of a deviation from the CIP[3]. Since then, the topic has been attracting increasing attention with researchers studying the causes of CIP violations and discussing whether these violations create arbitrage opportunities or one should rather question the underlying CIP assumptions.

For example, Du et al. (2016) confirm that credit risk and transaction costs do not fully explain large and persistent deviations from the CIP, and they are rather caused by inefficient financial intermediation and imbalances between demand and supply across currencies. Borio et al. (2016) estimate that CIP violations across major currencies reflect demand for currency hedges while the arising arbitrage opportunities were limited due to risk limits and balance sheet constraints

[3] In fact, quoted basis spread *bs* largely captures "CIP violations" and modifies the original CIP equation to $(1 + r_f) = \frac{F}{S}(1 + (r_d + bs))$, where r_f is the foreign interbank rate, r_d is the domestic interbank rate, *F* is the forward exchange rate, and *S* is the spot exchange rate, for simplicity, omitting time to maturity.

of market participants. Arai et al. (2016) study the USD/JPY basis and argue that its recent widening has been caused by demand for USD, reduced market-making abilities, and lower USD supply from the foreign official sector.

Earlier works point out interbank market distress and demand for USD. Ando (2012) concludes that the volatility of basis swap spreads is caused by the stress in the unsecured interbank money market, although such stress does not explain the whole spread. Ivashina et al. (2012) present a model in which European banks cut their dollar lending more than euro lending in response to their credit quality deterioration. European banks are forced to turn to the secured FX swap market but limited demand on the other side also makes the synthetic secured dollar borrowing expensive, leading banks to cut their dollar lending. This model has been successfully tested in the context of the recent financial crisis. Baba et al. (2008) analysed spillover effects from money markets into FX swap markets, arguing that the shortage of dollar funding of non-US banks caused large deviations from covered interest parity (CIP). Authors also tested Granger causality between FX swap quotes and cross-currency basis swap (CCS) quotes and found that during the crisis period, deviations from CIP were spread from the FX swap market to the longer term CCS market.

We also note some of the earlier related works that study the determinants of interest rate swap (IRS) spreads (i.e. the difference between government bond yields and swap rates) since factors influencing CCS spreads could be similar to factors influencing IRS spreads in one currency, namely credit risk and bond supply. For example, Cortes (2006) uses principal component analysis to find that the term structure of swap spreads in different markets moves together and is upward sloping in the two to ten-year part of the curve, due to existence of a default term premium and global expectations of government bond issuance (the higher the net borrowing, the steeper the yield curve). Huang et al. (2002) confirm that liquidity has a significant negative effect on swap spreads (swap spreads fall with increased supply and a steeper Treasury curve).

We will presently analyse cross-currency basis swap spreads from different angles. In the next section, we discuss credit and liquidity risk, and supply and demand pressure of one currency versus another. We revive the work of Ando (2012) with more recent data to construct boundaries within which there should be no arbitrage opportunity. However, by testing these boundaries, we reconfirm that supply and demand imbalances may push basis spreads outside these boundaries, creating arbitrage opportunities for those market participants who are able to raise unsecured funding at interbank rates in one currency and swap it into another currency. Such episodes can take place across a number of currencies, however, we focus and illustrate it on the most actively traded pair, the EUR/USD basis swap.

We then build a multiple regression and a cointegration model to explain the drivers of EUR/USD basis swap spreads and their individual importance during three different relevant historical

periods. As regressors, we use variables that serve as a proxy for short- and medium-term credit risk, liquidity conditions, and demand and supply. We show that although an increase in interbank risk in both euro and US dollar caused a widening of EUR/USD basis swap spreads, the interbank risk only does not fully capture the level of these spreads. The residual term may be partially assigned to supply and demand imbalances, which may arise and persist over a longer period of time.

3. Cross-currency basis spread determinants

Credit, liquidity, and supply and demand forces all influence cross-currency basis spreads. These spreads are influenced by the ability and conditions of funding directly in a single currency, and thus by supply and demand for cross-currency financing.

CCS are used to hedge currency risk that arises if an entity decides to fund or invest in a foreign currency. A domestic entity uses CCS to either

a) fund domestic assets with foreign currency borrowings and use the demand side of the CCS swap market (a demand for domestic currency) or
b) fund foreign currency assets with domestic currency borrowings and use the supply side of the CCS swap market (a supply of domestic currency).

For example, a) can be used by corporates issuing bonds in foreign currency and swapping the proceeds into domestic currency while b) is often used by banks when they lack a deposit base in the foreign currency and need to swap deposits in their domestic currency.

Both sides are in balance if each of them is able to meet the other side of the trade. A *foreign entity* thus in case of a) issues debt in domestic currency and is a seller of the domestic currency to domestic banks in the CCS market or b) buys domestic assets and is a buyer of a domestic currency from domestic banks in the CCS swap market. If the sides of this equation are unequal then the imbalance causes volatility and puts pressure on the CCS basis spreads.

Short end of the curve

Some CCS spread drivers are more significant for short maturities of CCS swaps, while others for long maturities. Short end spreads (i.e. in FX swaps) appear to be more influenced by IBOR fixings and credit/liquidity premium in IBOR rates, while the long end (CCS swaps) seems to be more sensitive to supply and demand for assets in both currencies.

The credit element in the short end can be approximated by the IBOR-OIS spread[4], which directly influences the basis. It can be shown (Baran, Witzany, 2014) that the EUR/USD basis spread can be approximated by the difference in IBOR-OIS spreads in the two currencies plus a residual spread, i.e.

$$BS_{EUR/USD,3M} \approx BS_{EUR/USD\ OIS,3M} + \left(r_{USD\ LIBOR,3M} - r_{USD\ OIS,3M}\right) - \left(r_{EURIBOR,3M} - r_{EONIA,3M}\right),$$

where $BS_{EUR/USD\ OIS,3M}$ is the EUR/USD OIS basis swap (Fed funds vs. Eonia + spread on a quarterly basis). With such decomposition, we have removed the embedded credit and liquidity risk of the two IBOR rates and we are left with overnight rates in two currencies (risk-free rate proxies). This shows that the basis cannot be fully explained by the different credit and liquidity risk of Euribor and USD Libor and the remaining spread $BS_{EUR/USD\ OIS,3M}$, which is tradable in the market and reflects demand and supply for one currency vs the other (e.g. a negative EUR/USD CCS spread indicates that market participants prefer to hold USD liquidity). OIS is thus a cleaner measure of the balance between supply and demand.

Long end of the curve

In the near term, the long maturity currency swaps have been less volatile than short maturity currency swaps. Long maturities appear to be mainly driven by the capacity of the market to facilitate swapping of the cross-border bond issuance. This capacity is further affected by different regulation, market size, or liquidity from investors and issuers. For example, the issuance of US dollar bonds by European sovereigns, supranationals and agencies is often swapped back to EUR and narrows the EUR/USD basis. On the other hand, an increase in swapped euro issuance from US-based corporates widens the basis because demand for USD rises.

Bond credit spreads in different currencies

One important motivation for swapped bond issuance are cost savings that may arise from the levels of the basis and different credit spreads in different currencies of the same issuer. To compare bond credit spreads[5] of one issuer that have similar cash flows but are denominated in different currencies, we need to adjust spreads by the cross-currency basis and interest rate basis, if needed. For example, in case of EUR/USD, we can express the credit spread of a USD bond in EUR terms as

$$\overline{CS_T^{\$}} \approx CS_T^{€} - BS_T^{€3M-\$3M} + BS_T^{€3M-€6M} \qquad (1)$$

[4] i.e. the difference between the forward rate agreement (FRA) rate and forward OIS rate with the same maturity
[5] For this purpose, we use bond asset swap spreads (ASW) as a proxy for credit spreads.

where $\overline{CS_T^{\$}}$ is the synthetic dollar asset swap spread against 3-month USD Libor of the EUR denominated bond with maturity *T,* and asset swap spread of $CS_T^{€}$, $BS_T^{€3M-\$3M}$ is the EUR/USD cross—currency basis spread for the maturity *T,* which exchanges 3-month Euribor plus spread against 3-month USD Libor payments , and $BS_T^{€3M-€6M}$ is the EUR interest rate basis swap spread, which exchanges 3-month Euribor plus quoted spread against 6-month Euribor (adjusting for interest rate basis is in this case necessary, as the asset swap spread in USD is marked against 3-month USD Libor, while the asset swap spread in EUR is by convention expressed against 6-month Euribor).

The following graph (Figure 3) compares credit spreads of USD denominated investment grade corporate bonds with credit spreads of EUR denominated investment grade corporate bonds[6] swapped into USD and adjusted for 3 vs 6-month basis.

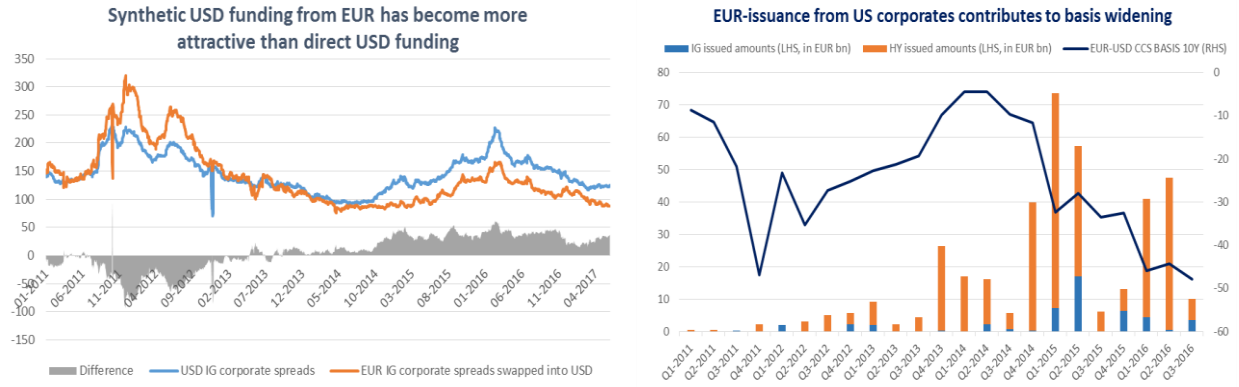

Figure 3. Left: Since the end of 2014, asset swap spreads of USD investment grade (IG) corporates have been higher than synthetic USD spreads implied from EUR IG corporate spreads and CCS basis. Right: Total EUR denominated issuance by US based corporates have picked up due to cost advantage. *Source: Bloomberg, Dealogic, Authors' calculations*

EUR and USD credit spreads tend to be, to some extent, correlated with the EUR/USD currency basis spread, however, their importance as a driver changes over time. Since the end of 2014, indirect USD funding in the EUR market has been cheaper for corporate issuers, as credit spread difference between EUR and USD denominated bonds more than offsets negative CCS basis. Tighter credit spreads of EUR denominated corporates compared to USD leads to higher funding in EUR and thus supports basis widening (Figure 4).

[6] Measured by Bloomberg EUR and USD Investment Grade European Corporate Bond Index ASW spreads.

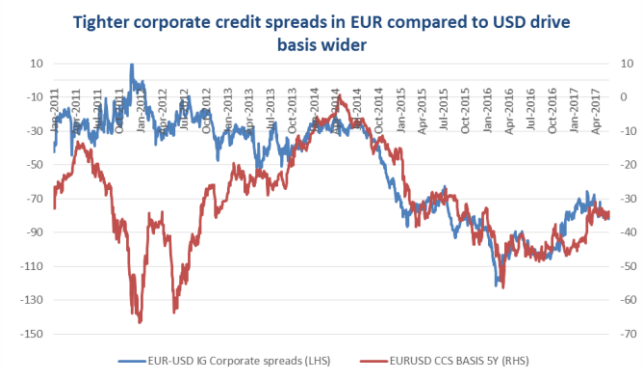

Figure 4. Recent tightening of EUR corporate credit spreads vs their USD counterparts has contributed to basis widening. *Source: Bloomberg, Authors' calculations*

3.1 EUR/USD basis swap spread story

The EUR/USD cross-currency swap is often used by European banks to fund US dollar assets if other dollar funding sources become inaccessible. The natural other side of this trade are European issuers (in particular, agencies, supranationals, and sovereigns) which swap US dollar debt issuance into euros[7]. European issuers look to issue US dollar bonds and swap the proceeds into euros in order to diversify into other funding sources and potentially to obtain cheaper funding. Several authors have pointed out (e.g. Ivashina et al. (2012)) that during the crisis period, uncollateralised dollar cash markets were less functional for European banks, which had to shift to secured transactions such as FX swaps as US money market funds had restrained from buying short-term dollar unsecured debt (i.e. CDs, CPs[8]) of European banks. This heavy dependence of European banks on the wholesale dollar market during the European sovereign debt crisis created a supply and demand imbalance (increased pressure on dollar funding) and EUR/USD cross-currency basis spreads widened.

This, however, goes hand-in-hand with the credit risk element as a period of increased volatility leads to the perception of increased credit risk in banks. This was the case in the EUR/USD basis swap market during financial crisis, when European banks started to be perceived by US banks as becoming increasingly riskier, as is empirically investigated in Baba and Packer (2008a). Figure 5 shows the co-movement of euro-interbank risk (expressed as Euribor-Eonia spread) and

[7] Usually the issuer sells a US dollar fixed rate bond which is immediately swapped against 3-month USD Libor plus a spread. Then USD Libor payments are swapped against 3-month Euribor payments using cross-currency basis swaps so the dollar funding is converted into euro funding. Finally, issuers who use 6-month Euribor as a benchmark enter into a basis swap to convert 3-month Euribor payments into 6-month Euribor or a fixed rate. All these steps can be done in a single transaction.

[8] CD – Certificate of Deposit, CP – Commercial Paper

EUR/USD basis spreads, suggesting that an increase in interbank risk causes widening in EUR/USD basis spreads.

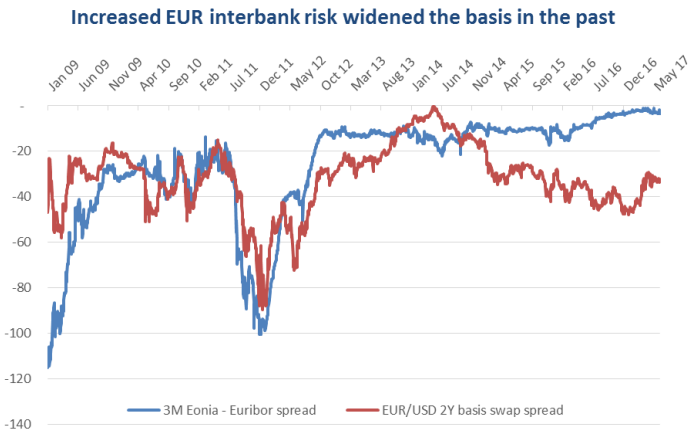

Figure 5. 3M Eonia-Euribor spread in basis points (LHS) and EUR/USD 2-year CCS spread since 2009. *Source: Bloomberg*

It is important to note that the explanatory power of any such variable varies over time. For example, the above fails to explain the basis spread widening since the second half of 2014, since credit spreads remained stable. In fact, in June 2014 the ECB announced a number of credit expansion steps, including cutting the deposit rate to -0.1%. This second wave of EUR/USD cross-currency basis widening grew stronger with the announcement of the ECB's expanded asset purchase programme (APP) on January 22, 2015[9]. The ECB has started buying bonds of euro area governments, agencies, and supranationals within its monthly €60 billion framework. Since then, the ECB's monetary policy has expanded further; the deposit rate has been gradually cut to –0.4%, and the additional corporate sector purchase program (CSPP) was introduced under the envelope of APP, which was further increased to €80 billion, prolonged until March 2017, and further prolonged until the end of 2017, at the original pace of €60 billion. The initial market impact has been large with yields compressing and curves flattening. Since then, the EUR/USD basis spreads have remained in deep negative territory.

In contrast to 2009, when basis widening was driven by the inability of European banks to access unsecured dollar funding, the 2015 widening appears to be driven by the inability to invest into highly-rated EUR denominated government bonds. The general low-yield environment in Europe and the negative rate on ECB's deposit facility is pushing investors out of EUR into other currencies like USD. As the ECB purchases have been absorbing large volumes of bonds from the secondary markets and driving yields into even more negative territory, investors started to look for currency-hedged investment opportunities abroad.

[9] ECB press release: http://www.ecb.europa.eu/press/pr/date/2015/html/pr150122_1.en.html

Central bank actions in terms of supply of currency affect interest rates and borrowing conditions and may cause moves in basis swap spreads. In fact, by simply calculating the ratio of the Fed balance sheet to ECB balance sheet, we may construct a simple and rough indicator of relative supply of EUR to USD and compare it to changes in basis swap spread levels (Figure 6).

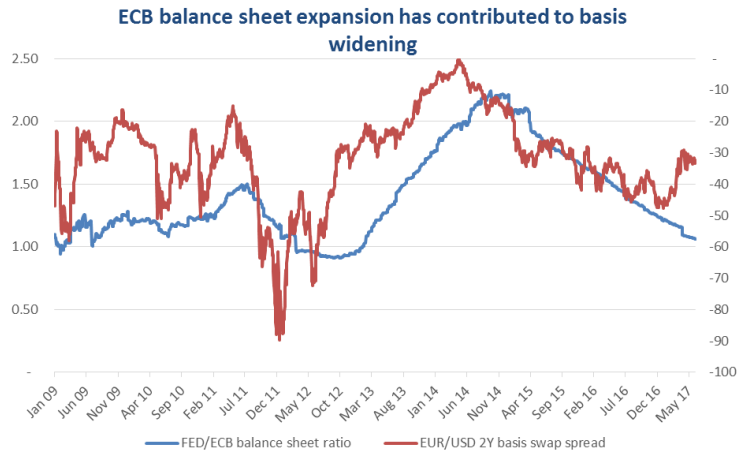

Figure 6. Ratio of Fed to ECB balance sheet (LHS) and EUR/USD 2-year basis swap spread since 2009. *Source: Bloomberg, Authors' calculations*

The expansion of the Fed balance sheet relative to the ECB balance sheet (the Fed balance sheet continued to expand on US Treasury bond-buying while the ECB balance sheet between 2012 and 2014 was shrinking due to repayments of long-term refinancing operations) led to basis spread tightening (increased supply of dollars). Since June 2014, it was the ECB's turn to expand while the Fed has been decreasing its pace of US Treasuries purchases and halted them in October 2014. This, together with the ECB asset purchase programmes, created an excess supply of EUR vs. USD and pushed basis spreads wider. Generally it appears that an increase in the supply of USD liquidity decreases USD funding costs (and tends to tighten the basis), while an increase in the supply of EUR liquidity decreases EUR funding costs (and tends to widen the basis).

The most recent period of EUR/USD basis widening can be observed in 2016, and it has been characterised by a divergence between US and European interbank spreads, namely, USD Libor-OIS spreads and Euribor-Eonia spreads. While Euribor-Eonia spreads have been continuously drifting lower, suggesting easy access to EUR liquidity, USD Libor-OIS spreads have been gradually widening and the USD Libor curve has been steepening (Figure 7). Market participants have named the 2014 US Money Market Fund Reform[10] as the main source of the recent Libor-OIS widening. This reform brings substantial changes to money market investing. Among other things, the reform introduces restrictions on the remaining maturity of securities purchased by

[10] Money Market Fund Reform adopted by SEC came into effect on October 14, 2016. https://www.sec.gov/rules/final/2014/33-9616.pdf

money market funds and limits the interest rate and credit risk exposure. Specifically, the maturity of any security must not be greater than 397 days, the limit on dollar-weighted average maturity of owned securities was reduced from 90 to 60 days, and average life to maturity may not exceed 120 days. Further rules apply to liquidity, and diversification limits, and moving from accrual based to market-based valuation for institutional prime (non-government) money market funds. In addition, funds will be able to suspend redemptions for up to 10 days and impose liquidity fees up to 2% if the fund's weekly liquid assets fall below 30% of its total assets.

The new regulation thus treats government money market funds more favourably at the expense of prime funds. In fact, there was a notable trend of flows from non-government money market funds into government funds on average of around $10 billion per week in 2016 (Figure 8).

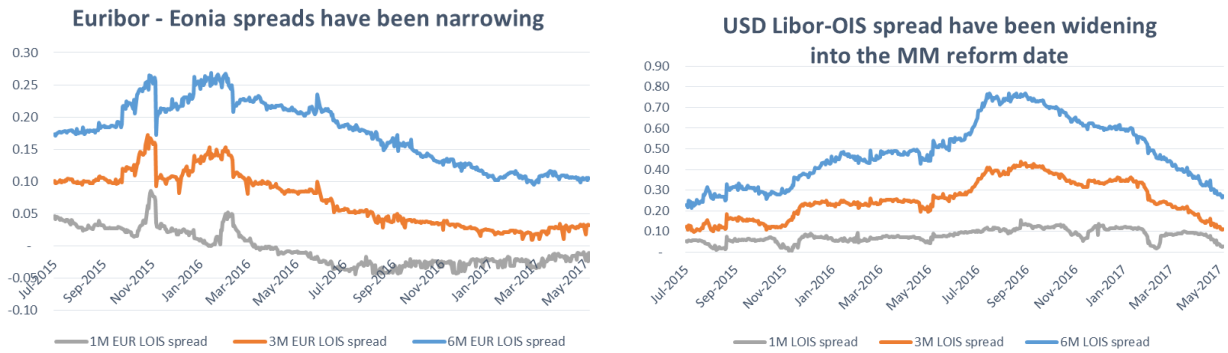

Figure 7: Left: 1-month, 3-month and 6-month Euribor – Eonia spreads show no signs of EUR interbank stress. Right: 1-month, 3-month and 6-month USD Libor-OIS spreads have been widening into the effective date of US money market reform. *Source: Bloomberg*

Despite the different driving factor in 2016, there has been again a pronounced shortage of USD, intensifying the pressure on cross-currency basis swap spreads. Higher Libor rates mean a higher cost of USD money market unsecured funding (e.g. via commercial paper). The current EUR/USD CCS spread widening shows that it is once again becoming more expensive for European banks to raise USD.

The USD funding pressure has been more apparent when we eliminate EUR and USD Libor-OIS spreads from the cross-currency basis and look only at the 3-month EUR/USD OIS cross-currency basis swap spread[11] (Figure 8).

[11] EUR/USD OIS CCS exchanges cash flows based on Fed Funds Effective rate vs. Eonia + spread on a quarterly basis.

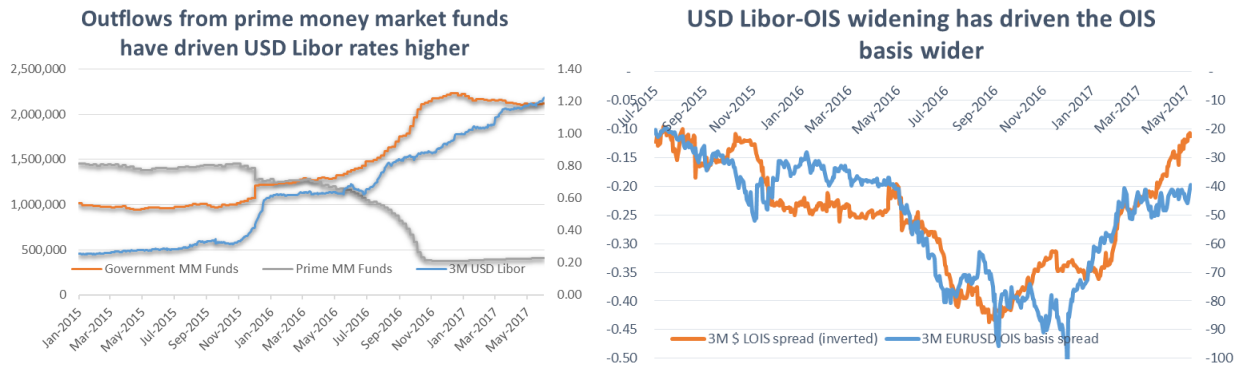

Figure 8: Left: Reallocation from prime funds into government funds driving USD Libor rates (RHS) higher. Right: Increasing 3M USD LOIS spread has contributed to 3-month EUR/USD basis spread widening. *Source: Bloomberg, Investment Company Institute*

Despite the currently low perceived credit risk of European banks, the USD funding pressure has been considerably intense, given the fact that the ECB provides USD liquidity to European banks at fixed rate USD OIS + 0.5% p.a. and all bids are satisfied at full allotment[12].

Changes in the supply of a currency affect changes in market conditions and motivate market participants to borrow or invest in one currency or another. Another supportive driver of basis widening has been the increased EUR issuance by US corporates. The ECB easing monetary policy pushed investors to look for a yield pick-up and has driven credit spreads of European corporates to significantly tighter levels while USD credit spreads were less impacted. This makes it attractive for US corporates to tap the EUR market.

As already mentioned, agencies, supranationals, and sovereigns are the beneficiaries of wide EUR/USD cross-currency basis spreads as they can potentially obtain cheaper funding in USD. It goes hand in hand that cheaper USD funding for European issuers also means that EUR bonds are more attractive for investors when swapped into USD. Foreign demand for EUR bonds may thus increase from those USD investors who are able to invest in EUR and swap back into USD. Therefore, both USD supply from European issuers and EUR investments from USD investors cause EUR/USD cross-currency basis to tighten. In fact, from time to time for the same issuer, similar bonds in terms of maturities and coupon payments but issued in different currencies are being traded at different credit spreads after adjusting for cross-currency basis spreads.

Changes in central banks' balance sheets seem to indicate a general trend of basis spread. However, there is no single explanatory variable and each of them varies over time. One can see

[12] Perhaps one explanation is that despite being a more attractive funding option, central bank swap lines are being perceived as last-resort facilities to borrow, and are subject to further collateral and haircut requirements and are thus to some extent avoided.

that cross-currency basis swaps do not trade flat and that cross-currency basis spreads are not close to zero. This holds only theoretically if the two currencies have same credit and liquidity risk, and there is perfect balance between supply and demand.

The exact decomposition of basis spreads remains challenging, as cross-currency basis swap spreads reflect both a combination of changes in risk of underlying money market instruments and supply and demand imbalances. However, in Section 5, we investigate cross-currency basis spread drivers and their individual importance in further detail, using multiple regression analysis.

4. Arbitrage-free boundaries for EUR/USD basis spread

In this section, we refresh the work of Ando (2012), who analysed arbitrage-free boundaries for funding and investing in foreign currencies, with recent data. The idea is to swap the funding rate in the local currency into the foreign currency (FX swap-implied funding rate) and compare it with a risk-free investment in the foreign currency. The final FX swap-implied funding rate will be expressed as a function of four variables: the risk-free rate in the foreign currency, the interbank market stress of each currency, and the residual term indicating supply and demand imbalance. The existence of a residual term would additionally indicate that the basis is not fully explained by the interbank risk.

We discuss the case of EUR/USD CCS basis and, in contrast to Ando (2012), we will work directly with EUR/USD CCS basis swap spreads rather than forward and spot FX rates[13]. A EUR/USD basis swap exchanges by convention periodic 3-month USD Libor payments against the 3-month Euribor + spread, which can be written by a simplified and approximate relation[14] as

$$r_{USD\ LIBOR,T} \sim r_{EURIBOR,T} + BS_T$$

where BS_T is the quoted basis spread for maturity *T* of the swap contract, and for illustration, we assume that IBOR funding rates reflect funding conditions for domestic banks, and that a bank can invest at OIS[15] risk-free rate in either euros or US dollars. In this setting, the natural boundaries for risk-free investing become

[13] FX swaps follow different mechanics than CCS, however, they both have the same economic function.

[14] Correctly, a CCS basis swap puts into equality the discounted future cash flow payments of the USD Libor leg and discounted future payments of the Euribor leg plus the basis spread and includes the exchange of principal at inception and maturity. However, the above can be used as an equivalence relation, and one can subtract/add a spread to one leg or the other: $r_{USD\ LIBOR,t} \sim r_{EURIBOR,t} + BS_t$; $r_{USD\ LIBOR,t} - BS_t \sim r_{EURIBOR,t}$.

[15] One way to invest into the OIS rate would be to roll over overnight deposits at the overnight rate and hedge it by paying in the OIS swap market.

$$r_{EONIA,T} - r_{EURIBOR,T} \leq BS_T \leq r_{USD\ LIBOR,T} - r_{USD\ OIS,T}, \quad (2)$$

If (2) does not hold, the following arbitrage opportunities arise:

- If $r_{USD\ LIBOR,T} - BS_T < r_{USD\ OIS,T}$, then a bank with access to the unsecured EUR market will borrow at Euribor, swap the proceeds into USD and invest at the risk-free USD OIS rate[16].
- If $r_{EURIBOR,T} + BS_T < r_{EONIA,T}$, then a bank which can access the unsecured USD market will borrow at USD LIBOR, swap the proceeds into EUR via FX or cross-currency swaps and invest at the risk-free EONIA rate.

The investment into OIS rates is considered as a proxy for risk-free investment in order to make the covered interest arbitrage free of credit and liquidity risks.

Further, setting $BS_T = r_{EONIA,T} - r_{EURIBOR,T} + X$, we can use X as an indicator of arbitrage opportunity (for $X < 0$ arbitrage theoretically exists). Following Ando (2012) and decomposing the FX swap-implied USD funding rate $r_{FX,T}$ from EUR funding rate (Euribor) into the variables X, IBOR and OIS rates leads to

$$r_{FX,T} = r_{USD\ LIBOR,T} - BS_T = r_{USD\ LIBOR,T} - \left(r_{EONIA,T} - r_{EURIBOR,T}\right) - X = \\ = r_{USD\ OIS,T} + \left(r_{USD\ LIBOR,T} - r_{USD\ OIS,T}\right) + \left(r_{EURIBOR,T} - r_{EONIA,T}\right) - X. \quad (3)$$

The FX swap-implied rate is expressed as a function of a forecast of the Federal funds rate, stress in the USD and EUR money markets (IBOR-OIS spreads) and a residual term X, which indicates supply and demand pressure of one currency vs. another. Ando (2012) further notes that $X < 0$ may arise from low liquidity in unsecured USD money markets, specific counterparty risk, transaction costs and measurement errors in the Libor fixing rate.

Ando (2012) uses forward and spot prices in a decomposition analogous to (3) and shows how each factor contributed to changes in the EUR/USD and USD/JPY basis. The author concludes that when USD supply and demand tightens, stress in the unsecured money markets increases, basis spreads widen, and the FX-implied rate sometimes reaches levels not explained by the stress in the unsecured markets ($X < 0$).

Rewriting (2) using $r_{FX,T} = r_{USD\ LIBOR,T} - BS_T$ leads to

$$r_{USD\ OIS,t} \leq r_{FX,t} \leq r_{USD\ LIBOR,t} + \left(r_{EURIBOR,t} - r_{EONIA,t}\right), \quad (4)$$

where $r_{FX,T}$ is bounded by the risk free USD rate from below and by the sum of the unsecured USD money market rate and EUR market stress indicator from above. If (4) holds, then the level

[16] Or any other proxy of a risk-free rate, i.e. a repo rate with high quality collateral.

of the FX-implied dollar rate $r_{FX,t}$ is determined by supply and demand forces which, however, do not yet create any arbitrage opportunity in this setting. Note that the difference between the right-hand-side of (4) and $r_{FX,T}$ equals *X,* so the right-hand-side inequality is equivalent to the condition $X \geq 0$ so that the time period where $X < 0$ (or $-X > 0$) is the period where arbitrage opportunities exist, given our assumptions.

Applying the decomposition (3) to a 3-month maturity EUR/USD basis swap, one can observe that arbitrage opportunities arose and persisted over long periods of time. Figure 9 shows the evolution of the 3-month FX-implied USD rate from Euribor decomposed into the USD risk-free rate and euro and US market stress indicators.

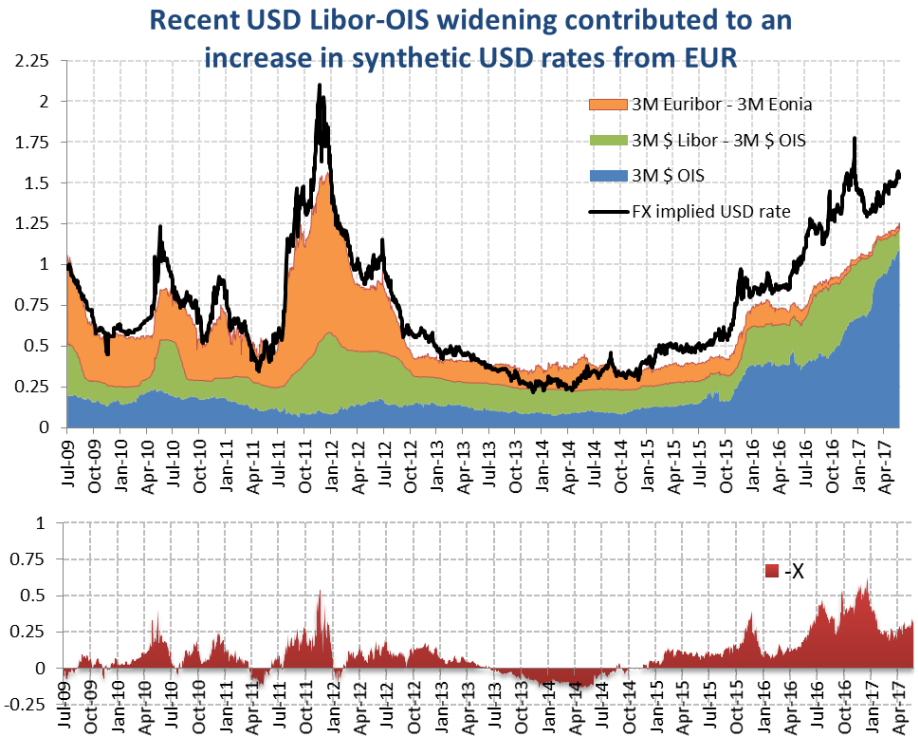

Figure 9**.** FX-implied USD rate from Euribor decomposed into EUR and USD interbank risk, USD risk-free rate and a residual term indicating supply and demand imbalances. *Source: Bloomberg, Authors' calculations*

The graph above indicates that an increase in interbank risk in both the euro area and the US (IBOR-OIS widening) causes widening of the EUR/USD basis spreads. The interbank risk, however, does not fully capture the movements in basis spread and the residual term indicates supply and demand imbalances. Short-term US dollar issuance had become more attractive for issuers having well-established US market access. An arbitrage opportunity for issuers who were able to raise US dollars at around the USD Libor rate arose and persisted over a long period of time. This

suggests that there exist additional restrictions to capital flows and there was only limited capital available to fully exploit this imbalance.

The arbitrage opportunity peaked at the end of 2011, right before coordinated actions by central banks that effectively capped the basis spreads. The central banks intervened with cross-currency swap lines, and European banks could borrow dollars directly from the ECB against euro collateral. Baba and Packer (2008a) present evidence that dollar term funding auctions by the ECB have stabilised the FX swap market. The EUR/USD basis has narrowed significantly during the first half of 2014 and the arbitrage opportunity vanished. Tighter basis spreads make funding in euros more attractive for US dollar issuers, and less appealing for euro issuers to issue in US dollars.

Another arbitrage opportunity arose in January 2015, when the ECB announced its public sector purchase programme, which has persisted since then, suggesting that the excessive supply of EUR has not yet been absorbed.

The same analysis can be performed with a different maturity (e.g. 6-months), risk-free rate (e.g. government bills or a repo rate) or a different currency. However, particular securities can trade special in the repo market and deviate from general money market rates. Therefore, for example, in case of repo rates, general collateral (GC) repo rates may be more suitable as they are driven by cash. One has to further incorporate bid-offer spreads and IBOR rates differ from actual funding rates of individual banks, however, there is no loss of generality to equations (2)-(4) and they can be easily applied to other currencies and tenors.

5. Regression analysis of EUR/USD cross-currency basis swap spreads

We have discussed several drivers behind cross-currency basis swap spreads, in particular, credit and liquidity risk, and supply and demand indicators. The objective of this section is to explain these drivers, and their individual importance with a statistical approach using ordinary least square multiple regression and cointegration analysis.

First, in order to analyse differenced time-series dependencies, we test two simple models, one with the 3-month EUR/USD basis swap spread as the dependent variable (to explain drivers of short-term basis spread changes), and the other with the 5-year EUR/USD basis swap spread as the dependent variable (to explain drivers of medium-term basis spread changes). Based on the discussion in the preceding sections, our goal is to explain the 3-month and 5-year spread changes with the independent variables presented below.

To capture short-term credit risk for euro and dollar rates, based on the analysis above, we use IBOR-OIS spreads. For example, if credit risk of European banks increases, we would expect basis swap spread to widen on increased concerns about their counterparty credit risk (Figure 5), as European banks would have to pay a premium in the swap market to borrow USD. On the contrary, we would expect that when credit risk of US banks increases, the 3-month basis spread tightens. The choice of LIBOR-OIS spreads is straightforward, as they directly influence the basis. It can be shown (Baran, Witzany, 2014) that the EUR/USD basis spread can be approximated as

$$BS_{EUR/USD,3M} \approx BS_{EUR/USD\ OIS,3M} + \left(r_{USD\ LIBOR,3M} - r_{USD\ OIS,3M}\right) - \left(r_{EURIBOR,3M} - r_{EONIA,3M}\right),$$

where $BS_{EUR/USD\ OIS,3M}$ is the EUR/USD OIS basis swap (Fed funds vs. Eonia on a quarterly basis).

To capture medium-term credit risk of European and US banks, we construct a blended CDS index for both groups of banks. For European banks, we construct the index as the average of CDS spreads of individual banks from the Euribor panel (each CDS is referencing to a single bank's EUR senior unsecured debt) for which CDS spreads are available, and after correcting for outliers. We do the same for the US banks, taking the average of CDS spreads (referencing to USD senior unsecured debt) of banks from the USD ICE Libor panel[17]. We work with CDS spreads rather than credit spreads of bond indices, as they tend to react faster than cash markets.

To capture changes in supply of each currency, we investigate Fed and ECB balance sheets. As hinted in Figure 6, when the Fed balance sheet expands relative to the ECB balance sheet, the basis spread tends to tighten (increased supply of dollars).

We also add the EUR/USD spot rate to see if the FX spot market affects CCS basis spreads. We could expect that if the depreciation of the euro against the dollar causes forward buying of euros by corporates, it may cause also a widening of the CCS basis spread due to a higher need to hedge these forwards by banks[18]. On the other hand, the appreciation of EUR may indicate higher confidence in the European economy and therefore cause a narrowing of the CCS basis spreads.

We also test dependence on the VIX volatility index. Increased volatility may indicate increasing market distress and preference of USD as the major global currency, thus widening the EUR/USD basis spread.

Independent variables in regression equation are displayed in the following table:

[17] Euribor panel composition: https://www.emmi-benchmarks.eu/euribor-org/panel-banks.html. USD ICE Libor panel composition: https://www.theice.com/iba/libor. We use an internal CDS index due to longer data history, for example, data from index providers, such as Markit iTraxx Europe Senior Financial CDS Index or S&P/ISDA CDS U.S. Financials Select 10 Index are not available before 2011.

[18] Banks would hedge the selling of EUR/USD forwards to corporates by buying EUR in the spot market and borrowing USD via FX swaps until the settlement of the EUR/USD forward.

Table 1. Independent variables in 3-month and 5-year EUR/USD basis spreads regression model.

Variable	Expected sign
$€\boldsymbol{ST\ spread} = \boldsymbol{Euribor_{3M}} - \boldsymbol{Eonia_{3M}}$ (in %)	(-) increase in European banks' credit risk widens the basis
$\$\boldsymbol{ST\ spread} = \boldsymbol{USD\ Libor_{3M}} - \boldsymbol{USD\ OIS_{3M}}$ (in %)	(+) increase in US banks' credit risk tightens the basis
$\boldsymbol{Fed/ECB\ ratio} = \boldsymbol{Fed\ balance\ sheet/ECB\ balance\ sheet}$	(+) increase in Fed balance sheet relative to the ECB balance sheet tightens the basis
$€\boldsymbol{MT\ spread} = \boldsymbol{Euribor\ banks\ average\ CDS\ spread}$ (in bps)	(-) increase in European banks' CDS spreads widens the basis
$\$\boldsymbol{MT\ spread} = \boldsymbol{USD\ Libor\ banks\ average\ CDS\ spread}$ (in bps)	(+) increase in US banks' CDS spreads tightens the basis
$\boldsymbol{EUR/USD} = \boldsymbol{EUR/USD\ spot\ rate}$	(+) EUR appreciation causes basis spread tightening
$\boldsymbol{VIX} = \boldsymbol{S\&P\ 500\ volatility\ index}$	(-) increase in VIX volatility widens the basis

To detrend the data, we calculate for each variable their weekly changes. The data sample consists of 492 observations between January 2008 and June 2017, and the data are taken from Bloomberg. We also split the sample into three subsamples, capturing different market periods, namely, from January 2008 to December 2009 to study the financial crisis period, from January 2010 to December 2013 to capture the European debt crisis, and from January 2014 until June 2017 to investigate the effect of diverging euro area and US monetary policies.

We regress weekly changes in 3-month and 5-year EUR/USD basis swap spreads (in basis points) against weekly changes in the above selected drivers. Our regression equation is

$$\Delta BS_{3M} = \beta_1 \times \Delta EUR/USD + \beta_2 \times \Delta€ST\ spread + \beta_3 \times \Delta€MT\ spread + \beta_4 \times \Delta\$ST\ spread + \beta_5 \times \Delta\$MT\ spread + \beta_6 \Delta \text{Fed/ECB ratio} + \beta_7 \Delta VIX + \varepsilon$$

$$\Delta BS_{5Y} = \beta_1 \times \Delta EUR/USD + \beta_2 \times \Delta€ST\ spread + \beta_3 \times \Delta€MT\ spread + \beta_4 \times \Delta\$ST\ spread + \beta_5 \times \Delta\$MT\ spread + \beta_6 \Delta \text{Fed/ECB ratio} + \beta_7 \Delta VIX + \varepsilon \quad (5)$$

5.1 Regression results

Regression results are summarised below.

Table 2. Regression output and summary statistics for 3M (LHS) and 5Y (RHS) changes in EUR/USD basis swap spreads. *Source: Authors' Calculations, EViews*

D(EUR CCS 3M)	**Full Sample**	**Jan 2008 - Dec 2009**	**Jan 2010 - Dec 2013**	**Jan 2014 - Jun 2017**
Independent variables	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)
D(EUR/USD)	-47.77	-95.81	4.06	**41.48****
	(26.71)*	(88.67)	(15.91)	**(20.64)**
D(Euribor 3M-EONIA 3M)	**-140.32*****	**-179.80*****	**-79.5*****	**-130.39*****
	(11.58)	**(30.67)**	**(7.58)**	**(23.02)**
D(EUR Financial CDS)	**-0.148*****	-0.365	**-0.108*****	-0.037
	(0.043)	(0.228)	**(0.021)**	(0.055)
D(USD Libor 3M-USD OIS 3M)	12.03*	16.33	**47.04*****	**50.48****
	(6.73)	(14.64)	**(17.59)**	**(19.47)**
D(US Financial CDS)	**-0.164*****	-0.147	-0.062*	-0.146
	(0.043)	(0.116)	(0.037)	(0.117)
D(FED/ECB ratio)	-12.51	-88.71*	**39.49*****	-1.36
	(8.59)	(48.84)	**(12.28)**	(3.38)
D(VIX)	**0.514*****	**1.414*****	**-0.214****	0.032
	(0.158)	**(0.532)**	**(0.099)**	(0.109)
Observations	**492**	**104**	**210**	**180**
R-squared	0.374	0.429	0.639	0.250
Adjusted R-squared	**0.366**	**0.394**	**0.628**	**0.224**
Durbin-Watson stat	2.248	2.158	2.065	2.393
Log likelihood	-1853.14	-460.46	-571.99	-487.44
Akaike info criterion	7.56	8.99	5.51	5.49
Schwarz criterion	7.62	9.16	5.63	5.61

*, **, *** shows significance at the 90%, 95%, and 99% level.

D(EUR CCS 5Y)	**Full Sample**	**Jan 2008 - Dec 2009**	**Jan 2010 - Dec 2013**	**Jan 2014 - Jun 2017**
Independent variables	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)
D(EUR/USD)	**27.32*****	**37.05****	7.94	**33.79*****
	(7.25)	**(18.1)**	(9.97)	**(11.64)**
D(Euribor 3M-EONIA 3M)	**-15.46*****	**-21.58*****	**-11.26****	-5.96
	(3.14)	**(6.26)**	**(4.75)**	(12.98)
D(EUR Financial CDS)	**-0.069*****	**-0.167*****	**-0.076*****	0.042
	(0.012)	**(0.046)**	**(0.013)**	(0.03)
D(USD Libor 3M-USD OIS 3M)	**3.905****	5.788*	-19.86*	-13.89
	(1.828)	(2.989)	(11.03)	(10.98)
D(US Financial CDS)	-0.023*	0.012	-0.01	**-0.196*****
	(0.012)	(0.024)	(0.02)	**(0.066)**
D(FED/ECB ratio)	-0.656	-5.67	**24.79*****	-1.01
	(2.332)	(9.96)	**(7.69)**	(1.91)
D(VIX)	-0.067	-0.065	-0.096	-0.001
	(0.043)	(0.108)	(0.062)	(0.061)
Observations	**492**	**104**	**210**	**180**
R-squared	0.303	0.366	0.453	0.1
Adjusted R-squared	**0.295**	**0.326**	**0.437**	**0.07**
Durbin-Watson stat	2.1	2.24	1.91	1.83
Log likelihood	-1211.75	-295.2	-473.9	-384.29
Akaike info criterion	4.95	5.81	4.58	4.35
Schwarz criterion	5.01	5.98	4.69	4.47

*, **, *** shows significance at the 90%, 95%, and 99% level.

In case of the full sample, the selected variables explain roughly 37% of the variance in the 3-month EUR/USD basis swap spread and around 30% in the 5-year EUR/USD basis swap spread (measured by adjusted R^2).

The following graphs display model results fitted to the actual data of weekly changes of both 3-month and 5-year EUR/USD basis spreads.

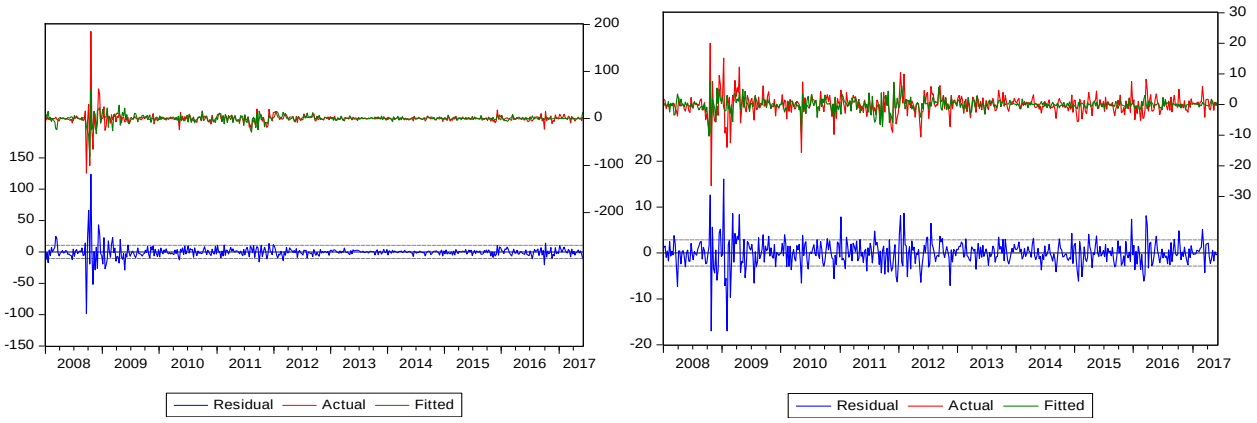

Figure 10. Residuals (left axis), fitted, and actual data (right axis) of 3-month basis spread (LHS) and 5-year basis spread (RHS) *Source: Authors' Calculations, EViews*

Looking at residuals, the model fits better to the part of the sample after the financial crisis. The fit of the 5-year basis swap seems to have smaller residuals in absolute terms and fewer outliers. Also, the smaller value of Akaike and Schwarz information criteria confirms a better model specification for the 5-year basis spread.

3-month EUR/USD basis swap spread

Full sample (January 2008 – June 2017)

Signs of the estimated coefficients confirm our expectations. The negative slope of Euribor 3m-Eonia 3m shows that when the credit risk of European banks increases, the 3-month EUR/USD basis spread widens (we can interpret the regression coefficient β_2 such that a 100 bps increase in Euribor-Eonia spread would cause a 140 bps widening in the 3-month basis spread, other variables being held fixed). The Euribor-Eonia spread has been the only variable significant at 99% for the whole sample, and every subsample.

Also, medium-term credit risk in the financial system in both Europe and the US impacts the basis swap spreads, although we expected the opposite sign for US CDS spreads. One possible explanation could be that an increase in counterparty credit risk of US banks suggests a general market distress and preference for USD as major global currency, similar to an increase in the VIX

volatility index, thus widening the basis. When either the US or European banks' CDS spreads increase, the basis tends to widen, with both regressors being significant at 99% level.

We record only a small dependence, at 90% level, of the EUR/USD spot exchange rate and 3m Libor-3m USD OIS (when 3m Libor-OIS spread widens, basis tends to tighten). We also note the importance of the VIX index (at 99% level) in the full sample, and contrary to our expectations, when VIX volatility rises, the basis tends to tighten. In the full sample, changes in the Fed/ECB ratio fail to capture any significant changes in the basis.

Financial crisis (January 2008 – December 2009)

This is the subsample with the highest volatility and the lowest number of observations (104). The 3m Euribor-Eonia spread and VIX volatility index appear to be the most important drivers of basis widening, solely explaining around 32% of the variation (when eliminating other regressors in the equation). When the 3M Euribor-Eonia spread widens, the basis tends to widen, while on the other hand, with increasing VIX volatility, the basis tends to tighten.

Adjusted R^2 of the subsample improves to 39%, although changes in other variables are too volatile to show any meaningful relationship.

European debt crisis (January 2010 – December 2013)

This subsample arguably provides the best fit to changes in the basis with over 60% of the variance explained. As expected, an increase in European short-term and medium-term bank credit risk widens the basis, while an increase in short-term US banks' credit risk acts in the opposite direction and tends to tighten the basis.

The VIX volatility index continues to be an important driver, however, to a lesser extent at 95% confidence level, and for the first time, with sign as expected (increase in the VIX leads to basis widening). We also note the positive slope of the Fed/ECB ratio, confirming the expected direction of the basis change; when the Fed balance sheet expands relative to the ECB balance sheet, the 3-month EUR/USD basis spread tightens.

Period of diverging US and EUR monetary policies (January 2014 – June 2017)

The last subsample, January 2014 to June 2017, puts into the spotlight short-term EU and US interbank risk and the EUR/USD exchange rate. However, this period of low volatility shows the lowest goodness of fit of the model at 22% adjusted R^2. Thus, the basis dynamics may have recently changed, there could be other factors influencing it and the model should be refit.

5-year EUR/USD basis swap spread

The model for the 5-year basis on the full sample period provides a slightly different picture. It appears that the EUR/USD FX rate, short-term and long-term EU bank credit risk, and to a lesser extent, short-term US interbank risk are the main drivers of the 5-year basis.

All signs confirm our expectations:

- when the euro appreciates against the dollar, the basis tends to tighten;
- when short-term or medium-term credit risk of European banks increases, the basis tends to widen;
- when short-term credit risk of US banks increases, the basis tends to tighten.

The model explains roughly 30% of the variation in changes in basis spreads. We also note a smaller dependence (at 90% level) of medium-term credit risk of US banks, with a negative slope, contrary to our expectations. The Fed/ECB ratio and VIX index coefficients are the only insignificant coefficients at 10% confidence level over the whole sample.

Financial crisis (January 2008 – December 2009)

The financial crisis period shows roughly the same picture with slightly higher adjusted R^2; with EUR appreciation tightening the basis, and European short-term and medium-term credit risk widening the basis.

European debt crisis (January 2010 – December 2013)

European banks' credit risk and the Fed/ECB ratio are more significant drivers during this period. Signs of coefficient are as expected, for example, when the Fed balance sheet expands relative to the ECB balance sheet, the 3-month EUR/USD basis spread tightens. The overall model fit improves to 44% (adjusted R^2).

Period of diverging US and EUR monetary policies (January 2014 – June 2017)

The EUR/USD exchange rate and US financial CDS appear to be the more significant drivers of the basis during the last subsample. However, it is difficult to draw any conclusions from the last subsample as the model explains only 7% of the variation of the basis and should be therefore recalibrated. Interestingly, the VIX index is not a significant driver of the 5-year basis during any of the studied periods.

5.2 A cointegration analysis

Figures 3, 4, 6, and 8 indicate that the relationship between the basis spreads and the credit or liquidity indicators is rather long-term and a cointegration analysis complementing the regression on differences (short-run model) should be used. We have applied the Granger-Engle and

Johansen test (see, e.g. Kočenda, Černý, 2014, or Arlt, Arltová, 2009) in order to inspect cointegration, i.e. long-term dependence of the 3-month and 5-year EUR/USD basis spread (restricting the coefficient to 1) and the other time series. In order to estimate the long-term dependence in a relatively simple way, we have applied the Fully-Modified OLS (FMOLS) regression on levels of the cointegrated time-series (see e.g. Phillips, 1995).

Based on the fundamental analysis above, univariate and multivariate testing, we have confirmed a cointegration relation between the 3-month EUR/USD basis spread, the EUR/USD exchange rate, EUR ST and MT spreads, the USD ST spread, and the Fed/ECB ratio (eliminating non-significant FMOLS regression variables) with signs as expected (Table 3). For example, there is a positive long-term dependence on the EUR/USD exchange rate as the basis tends to tighten with a stronger euro against the dollar. Over the full sample period, we could not confirm a long-term dependence of 3-month basis spread on the US financial CDS and VIX index.

Table 3. The FMOLS regression output based on the Granger-Engle test for 3M EUR/USD basis swap spread cointegration relations. *Source: Authors' Calculations, EViews*

EUR CCS 3M	**Full Sample**	**Jan 2008 - Dec 2009**	**Jan 2010 - Dec 2013**	**Jan 2014 - Jun 2017**
Independent variables	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)
EUR/USD	**99.27*** **	18.47	**30.57** **	**79.87*** **
	(11.79)	(63.02)	**(13.02)**	**(12.53)**
Euribor 3M-EONIA 3M	**-97.71*** **	**-48.42** **	**-122.14*** **	**-96.31** **
	(10.58)	**(20.61)**	**(6.03)**	**(40.62)**
EUR Financial CDS	**-0.095*** **	-0.152	**-0.052*** **	-0.025
	(0.025)	(0.204)	**(0.017)**	(0.095)
USD Libor 3M-USD OIS 3M	**38.79*** **	**-21.04** **	**41.81*** **	**-75.49*** **
	(6.59)	**(10.39)**	**(10.59)**	**(15.49)**
US Financial CDS	0.062	0.148*	0.078	0.284*
	(0.039)	(0.082)	(0.052)	(0.149)
FED/ECB ratio	**9.46** **	**-85.45*** **	**20.72*** **	**10.08** **
	(3.87)	**(16.83)**	**(3.68)**	**(4.40)**
VIX	-0.276	0.908	**-0.702*** **	0.035
	(0.266)	(0.628)	**(0.127)**	(0.268)
constant	**-143.26*** **	30.75	**-60.625*** **	-124.68***
	(18.99)	(109.27)	**(16.524)**	(15.024)
Observations	492	104	210	180
R-squared	0.621	0.512	0.963	0.763
Adjusted R-squared	0.615	0.477	0.962	0.753

*, **, *** shows significance at the 90%, 95%, and 99% level.

We have also confirmed the existence of a cointegration relation between the 5-year EUR/USD basis spread, EUR ST and MT spread, USD ST and MT spread, EUR/USD exchange rate, and the Fed/ECB ratio. Interestingly, the analysis did not confirm a long-term (cointegration) dependence of the 5Y basis spread on the VIX index over the full sample period (Table 4).

The signs of the estimated FMOLS regression coefficients correspond to our fundamental and differenced time-series analysis. FMOLS regression adjusted R^2 of around 85% indicates a strong long-term relationship between the cointegrated time series.

Table 4. The FMOLS regression output based on the Granger-Engle test for 5Y EUR/USD basis swap spread cointegration relations. *Source: Authors' Calculations, EViews*

EUR CCS 5Y	Full Sample	Jan 2008 - Dec 2009	Jan 2010 - Dec 2013	Jan 2014 - Jun 2017
Independent variables	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)	Coefficient (Std.Error)
EUR/USD	**97.97*** **	28.11	**64.713*** **	**98.19*** **
	(4.57)	(20.93)	**(10.75)**	**(5.30)**
Euribor 3M-EONIA 3M	**-18.99*** **	**-35.19*** **	**-15.40*** **	2.775
	(4.10)	**(6.84)**	**(4.98)**	(17.197)
EUR Financial CDS	**-0.039*** **	-0.112	**-0.041*** **	-0.009
	(0.009)	(0.068)	**(0.014)**	(0.04)
USD Libor 3M-USD OIS 3M	**9.71*** **	**14.75*** **	0.655	**-27.84*** **
	(2.56)	**(3.45)**	(8.749)	**(6.56)**
US Financial CDS	**-0.073*** **	-0.045*	**-0.100** **	**-0.372*** **
	(0.015)	(0.027)	**(0.042)**	**(0.063)**
FED/ECB ratio	**8.59*** **	**-20.39*** **	5.883*	2.382
	(1.50)	**(5.59)**	(3.043)	(1.864)
VIX	0.134	0.201	**0.277*** **	**0.315*** **
	(0.103)	(0.208)	**(0.105)**	**(0.114)**
constant	**-152.37*** **	-17.01	**-102.74*** **	-123.31
	(7.37)	(36.29)	**(13.65)**	(6.36)
Observations	492	104	210	180
R-squared	0.854	0.849	0.909	0.949
Adjusted R-squared	0.852	0.838	0.906	0.947

*, **, *** shows significance at the 90%, 95%, and 99% level.

With the above estimation, we wanted to illustrate to what extent individual predictor variables explain cross-currency basis swap spreads. This analysis has several caveats and limitations. The results may largely depend on the studied time period. Furthermore, the number of selected variables could further be minimised and there may be other potential drivers that we have not discussed and tested. Due to the presence of cointegration among variables, it would be useful to further test vector the error correction model to estimate both short-term and long-term effects of regressors on basis swap spreads. Also, explanatory variables and their explanatory power may change over time, thus some kind of a regime-switching or autoregressive model with lags could be further investigated. We aim to answer these questions in future research.

6. Conclusion

We have discussed factors that influence cross-currency basis swap spreads, in particular, credit and liquidity risks, and supply and demand pressures. We have argued that basis spreads in the short end of the curve are more influenced by IBOR fixing and the credit/liquidity premium, while the long end is more a function of supply and demand. We have tested arbitrage-free boundaries for cross-currency funding and investing and identified several long-lasting periods of arbitrage opportunities in case of the EUR/USD basis swap market, for market participants who were able to raise unsecured funding in one currency and swap it into another currency.

We have also discussed the historical development of EUR/USD basis spreads. The results of this discussion lead to identifying the potential drivers (market proxies) of the basis spread. We have then built regression models for changes in 3-month and 5-year EUR/USD basis swap spreads and tested them on three different historical periods of basis widening (financial crisis, European debt crisis, and a period of monetary policy divergence between the euro area and the US). We saw that different periods lead to different coefficients, and potentially, different model specifications. We have also confirmed the long-term dependence of regressors on basis swap spreads using cointegration analysis.

The most important drivers of the cross-currency basis spreads appear to be short and medium-term EU financial sector credit risk indicators, and to a slightly lesser extent, short and medium-term US financial sector credit risk indicators. Another important driver is market volatility for the short-end basis spread, and the EUR/USD exchange rate for the medium-term basis spread, and to a lesser extent, the Fed/ECB balance sheet ratio. The regression results largely confirmed our expectations; for example, an increase in short-term or medium-term credit risk of European banks widens both 3-month and 5-year EUR/USD basis spreads, an increase in US short-term credit risk tends to tighten the 3-month basis, or that the appreciation of the euro against dollar drives the 5-year basis tighter.

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