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The impact of the Term Auction Facility on the liquidity risk premium and unsecured interbank spreads

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The impact of the Term Auction Facility on the liquidity risk premium and unsecured interbank spreads*

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Abstract

This paper investigates the effectiveness of the Federal Reserve's Term Auction Facility (TAF) in alleviating the liquidity shortage in USD and reducing the spread between the 3-month Libor rate and the expected policy rate. I construct a proxy for the 3-month liquidity risk premium based on data from the FX forward market which enables me to (i) decompose the Libor spread into a liquidity premium and a credit premium, and (ii) test the effectiveness of the TAF in reducing the liquidity premium in money market spreads. I find that long-term (84-day) TAF auctions were effective in reducing the 3-month liquidity premium. Furthermore, a reduction in the liquidity premium led to a fall in the 3-month Libor spread in USD. Credit risk, however, seems to have been a rather modest factor in explaining the increase in the Libor spread during the financial crisis.

JEL Classification: E41, E43, E51

Keywords: Term Auction Facility, liquidity premium, credit premium, Libor-OIS spread

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1 Introduction

The recent financial crisis led to a sudden and persistent increase in US interbank lending rates, effectively contributing to an undesired tightening of monetary policy. On 9 August 9 2007, BNP Paribas triggered the first jump in interbank rates when it revealed difficulties in pricing a number of its investment funds; cf. Kacperczyk and Schnabl (2010). In an attempt to reduce interbank term spreads and relieve the strains in money markets, the Federal Reserve (Fed) introduced the Term Auction Facility (TAF) in December 2007. This facility provided term liquidity to eligible depository institutions against collateral. The following year, in the aftermath of the bankruptcy of Lehman Brothers, the spread between the 3-month US Libor and the overnight indexed swap (OIS) - a widely used measure of the interbank risk premium - peaked at extraordinary 360 basis points, see Figure 1.[1] In response to this development, the TAF was extended significantly in both the size and the term of the loans.[2]

Understanding the effectiveness of liquidity facilities in money markets is important to central banks.[3] Unsecured interbank rates serve as a benchmark for a vast number of financial contracts and play an important role in the transmission of monetary policy. Furthermore, money markets are fundamental in banks' management of liquidity in order to absorb liquidity shocks, raise short-term funding and ensure efficient use of collateral. In order to mitigate the disruptive effects on economic activity inflicted by unusually high money market spreads, the central bank can adjust its main policy rate; cf. Taylor (2008) and Woodford

[1] Libor is an abbreviation for London inter-bank offered rate.

[2] The Federal Reserve increased the maturity from 28 days to 84 days and expanded the maximum allotted volume from an initial USD 25 billion to USD 150 billion. The TAF was discontinued in March 2010. See www.federalreserve.gov/newsevwnts/reform_taf_htm for more details about the TAF.

[3] The term "money markets" may be interpreted as a general term for short-term funding (below 12 months). This includes unsecured and secured interbank markets, as well as non-bank funding sources (e.g. Commercial Paper (CP market) and Certificate of Deposit (CD market).

(2010). However, doing so may conflict with other monetary policy considerations or prove difficult if the zero lower bound limits further reductions in the policy rate; cf. Bernanke (2012). Therefore, it is important to consider whether central bank term-lending is an effective alternative to lowering the key policy rate.

This paper examines the effectiveness of the TAF in relieving the strains in US money markets and reducing the 3-month Libor-OIS spread. I create a proxy for the 3-month liquidity premium in USD using price data from the FX forward market and investigate the effect of the TAF on this liquidity premium and the Libor-OIS spread. This sheds light on the effectiveness of the TAF and the importance of liquidity premiums in determining interbank spreads.

While most of the existing literature comprises event studies (McAndrews et.al. (2008), Taylor and Williams (2009), Wu (2008), this paper employs econometric models with suitable measures for the relevant variables.[4] For both 1-month and 3-month auctions a continuous variable that captures both the outstanding maturity and the volume provided by the TAF is constructed to measure the effectiveness of the TAF. Hence the effectiveness of the TAF for different maturities can be distinguished. The liquidity premium are measured for three different currency pairs (EUR/USD, USD/CHF and GBP/USD).

My results show that the TAF successfully reduced the 3-month liquidity risk premium in USD. This effect, however, is not evident for the short term auctions (1-month maturity).[5] Moreover, while the proxy for the liquidity risk premium has significant explanatory power on the Libor-OIS spread, the credit risk premium (measured by CDS prices) seems to have had only a modest impact. This result

[4] Wu (2008) and McAndrews et.al. (2009) conclude that the TAF was effective in reducing the 3-month US Libor-OIS spread while Taylor and Williams (2009) draw the opposite conclusion. Additionally, Christensen et.al. (2009) find the TAF effective, while Szczerbowicz (2011) finds no such effect.

[5] However, the 28-day auctions had an individual effect on the Libor-OIS spread in the period before the Lehman Brothers bankruptcy.

stands in contrast with evidence presented in earlier studies including McAndrews et al. (2009), Wu (2008) and Taylor and Williams (2009), who all find a significant impact of CDS prices on money market spreads. This suggests that the impact of CDS prices is model-dependent. Finally, the results show that both the liquidity premium and the Libor-OIS spread decreased significantly following announcements related to the international swap lines established between the Fed and a number of central banks. This result is in line with the results of Baba and Packer (2009) and McAndrews et al. (2009).

The following policy implications can be drawn from these results. First, central banks can use market operations to reduce the liquidity term premium and the interest rate spread. Particularly, long-term loans can be useful in reducing banks' liquidity risk.[6] Second, the introduction of swap lines can be seen as a way of broadening the range of counterparties. This seems to have been a successful tool for the Federal Reserve to be able to reach a wider range of market participants and increase the effectiveness of liquidity-providing operations. This is a result in line with the Federal Reserve's intentions behind the introduction of the swap lines; cf. Goldberg et.al. (2010).

The paper is organised as follows: Section 2 discusses the distinction between different aspects of money market premiums and briefly explains the intuition behind using the FX forward market to measure the US liquidity risk premium. Section 3 describes the data while Section 4 specifies the econometric models. Section 5 presents the results while Section 6 concludes.

2 Liquidity and credit premiums in money market rates

In this section, the relationships between the key policy rate, the risk premium and the Libor rate are described. Furthermore, theoretical considerations

[6] The Federal Reserve increased the maximum allotment above the actual demand from the operation settled 9 October 2008.

connected to the difference between liquidity risk and credit risk are discussed, the TAF is examined in more detail and, finally, I take a closer look at the FX forward market and the connection to the US liquidity premium.

2.1 Key relationships

The relationship between the expected key policy rate (the OIS rate), the risk premium, the Libor rate and the current key policy rate can be expressed by the following four equations:

(1) $i_t^{ON} = r_t^{policy} + \tau_t^{ON}$

(2) $i_{t,t+s}^{OIS} = \left([\prod_t^{t+s} (1 + \frac{E(i_t^{ON}) * s_i}{360})] - 1 \right) * \frac{360}{s}$

(3) $i_{t,t+s}^{Lib} = i_{t,t+s}^{OIS} + \delta_{t,t+s}$

(4) $\delta_{t,t+s} = \varphi_{t,t+s} + \omega_{t,t+s}$,

where i_t^{ON} is the unsecured overnight interbank rate, r_t^{policy} is the key policy rate and τ_t^{ON} is the risk premium in the overnight rate, all at time t; $i_{t,t+s}^{OIS}$ is the OIS-rate, s is the maturity of the OIS in number of days and s_i is the number of days the overnight rate is valid, normally 1 day, but for instance 3 days when immediately before a weekend. $\delta_{t,t+s}$ is the total risk premium in the Libor rate, $\varphi_{t,t+s}$ and $\omega_{t,t+s}$ are the liquidity and the credit risk components of the total risk premium at time t to t+s, respectively.

In an OIS agreement, the investor receives (pays) the prevailing overnight interbank rate and pays (receives) a fixed rate over the maturity of the contract. The OIS-rate ($i_{t,t+s}^{OIS}$) is the fixed leg of the contract and is determined by investors' expectations as regards the overnight rate, c.f. Equation (2), which states that the OIS rate for a given maturity equals the geometric average of the expected overnight rates over the maturity of the contract. When the OIS contract matures, the net difference between the two alternatives is settled. If the average of the overnight rate during the contract equals the OIS rate, no cash needs to be transferred.

An OIS contract is associated with low counterparty and liquidity risk as the notional amount is not exchanged. In addition, the risk premium in the overnight interbank rate is normally negligible, meaning that τ_t^{ON} is close to zero; cf.

Equation (1).[7] The OIS rate can therefore be interpreted as the market's expectations with regard to the key policy rate since the unsecured overnight interbank rate, i_t^{ON}, is normally very close to the central bank policy rate.[8] If it were not, the central bank would take action to bring the overnight rate back in line with the policy rate. In short, Equations (3) and (4) show that Libor ($i_{t,t+s}^{Lib}$) is determined by the OIS rate and the liquidity and credit risk premiums.

2.2 Liquidity and credit risk

Several explanations have been proposed for the sudden rise in the spread between US unsecured interbank rates and the corresponding OIS rate during the financial crisis in 2008-2009. Commonly, the spread is split into a liquidity risk and a credit risk component.[9] *Liquidity risk* stems from the maturity mismatch on banks' balance sheets and is related to the availability of funding in a specific currency. When a creditor refuses to roll over a maturing liability, alternative funding sources have to be drawn upon or assets need to be liquidated. The interbank market serves as a backstop for banks during periods of large liquidity outflows, which cannot immediately be replaced by non-bank funding. The degree of liquidity risk varies across institutions depending on the maturity composition of assets and liabilities. However, when it becomes increasingly difficult to refinance assets - either by interbank or non-bank borrowing - the average maturity on the liabilities may decrease, leading to higher liquidity risk.

Prior to the recent financial crisis, term funding was readily available in both the interbank and in the wholesale market.[10] The crisis led to a sudden freeze in the availability of term funding, especially between banks. Cash providers in the interbank market refrained from lending or required a substantial premium as term funding became increasingly difficult to obtain in the non-bank funding market. The increase in the US liquidity risk premium during the financial crisis was widespread, affecting all market participants, and is frequently referred to as

[7] Strictly speaking, this does not imply a zero risk premium in the OIS price as there may be market risk (if the counterpart defaults and the value of the OIS agreement is positive). In addition, if the OIS contract is centrally cleared, margining is required and contracts that are "out of the money" create liquidity risk.

[8] This is basically a result of the commitment by central banks to keep the overnight rate close to the target.

[9] The term premium is included in the definition of the liquidity premium used in this paper. Liquidity risk increases with the term as cash has to be locked in for longer. Brunnermeier (2008) distinguishes between funding liquidity and market liquidity. Liquidity risk in the unsecured interbank market is mainly connected to funding liquidity. However, funding and market liquidity may be highly correlated.

[10] For a discussion of how market liquidity eroded in the wholesale market, see Coeuré (2012).

the global US dollar shortage.[11] To counteract the deterioration in term funding, central banks increased their intermediary role, effectively replacing interbank lending.

There are several possible explanations for the existence of a substantial liquidity premium in unsecured interbank rates during the financial crisis. However, the relationship between *collateralised* central bank funding and *unsecured* interbank rates is not obvious. It is well known among market participants that the supply of central bank reserves affects the overnight interbank rate for a given demand curve, often referred to as the liquidity effect.[12] Central banks can increase base money (central bank money) by lending money to banks directly or by outright asset purchases. A term lending facility increases the availability of term liquidity (base money) and may through this supply effect reduce term spreads, even in the unsecured market.

The effect of a term lending facility on unsecured interest rates, however, depends on the collateral scheme adopted by the central bank. For instance, envisage a central bank that accepts only highly liquid AAA-rated government bonds as collateral. A term lending facility will do no more than swapping highly liquid securities for highly liquid central bank reserves. As highly liquid assets can easily be liquidated in the market or used as collateral in the repo market, even during times of excessive financial stress, such a collateral scheme reduces the impact of central bank lending facilities on banks' funding conditions. In contrast, if central banks accept a wider range of collateral, less liquid assets can be substituted for highly liquid central bank reserves. In times of market stress and low willingness by market participants to accept lower-quality collateral, central bank liquidity facilities may play an important role in relieving banks' funding constraints. The effect on uncollateralised markets may come through the supply/demand channel as the central bank absorbs the demand for term funding that otherwise would have to be supplied by the market. The collateral eligible for the TAF was equal to the collateral eligible for the Discount Window, which is the Federal Reserve's overnight lending facility.

In contrast, the *credit risk premium* is the mark-up charged to account for the risk of losing the investment in the case of a counterparty default. Credit risk is therefore largely determined by asset values and the ability of banks to absorb losses on their assets.[13] In other words, credit risk is related to the asset side of the balance sheet, decreasing as asset quality and the amount of equity increase.

[11] For a discussion, see for example Baba et.al. (2009), McGuire and von Goetz (2009) and Fender and McGuire (2010)

[12] See Hamilton (1997), Thornton (2006), Whitesell (2006) and Syrstad (2012) for an elaboration on the liquidity effect. Furthermore, the increase in the supply of reserves by the ECB is a recent example of how the supply of reserves affects the overnight rate.

[13] See McAndrews et.al.(2008) for a discussion.

Overall, the total interbank risk premium (the Libor-OIS spread) is the premium banks charge each other to account for both their own liquidity risk and the counterparty`s default risk. Anecdotal evidence suggests that both factors contributed to the increase in interbank risk premiums during the crisis.[14]

2.3 The Term Auction Facility (TAF)

The Term Auction Facility was first established in December 2007. Figure 1 shows the outstanding amount provided by the TAF and the 3-month Libor-OIS spread.[15]

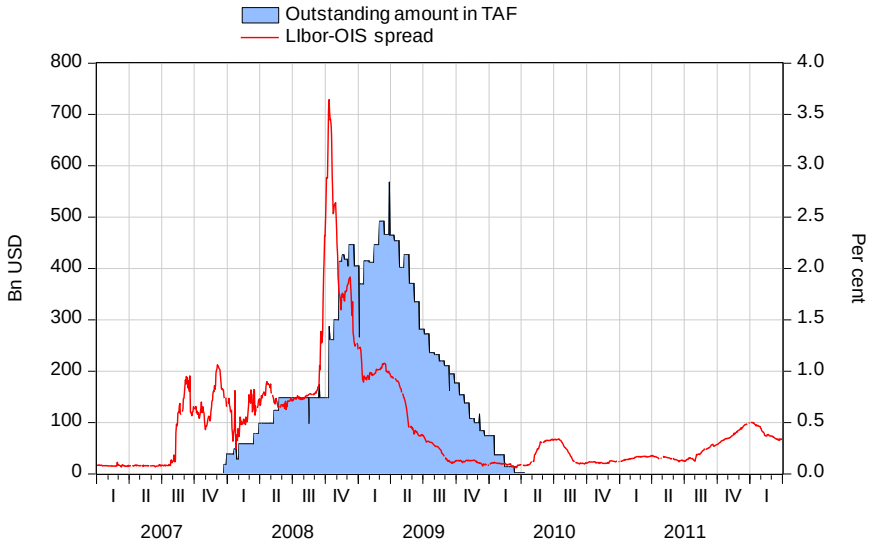

FIGURE 1. THE OUTSTANDING VOLUME IN TAF AUCTIONS

Notes: The figure shows the outstanding volume in all the TAF auctions. The TAF was established in December 2007 and was discontinued in March 2010. The series is compared to the 3-month Libor-OIS spread. *Source:* Bloomberg and Board of Governors of the Federal Reserve.

The allotment amount was limited at the beginning of the program, but increased significantly in the aftermath of the Lehman Brothers bankruptcy. During 2009, the outstanding amount successively decreased with the escalation of the asset purchase program.

[14] There may be a correlation between credit risk and liquidity risk as mentioned in both McAndrews et.al. (2008) and Wu (2008). However, Wu (2008) finds no significant impact of the TAF on the credit risk premium measured by CDS prices. As also emphasised in McAndrews et.al., if such a correlation exists, the impact of liquidity facilities on spreads is underestimated.

[15] "Outstanding volume" and "outstanding amount" are used interchangeably.

In order to account for the effect of maturity as well as volume, I create a measure for the volume-weighted maturity of outstanding TAF loans, see Figure 2. In contrast to simple outstanding volume, this variable recognises that the effect of an auction on the liquidity premium dissipates. Put differently, everything else equal, the strains in money markets build up again as funding successively matures on banks' balance sheets. This variable is measured in what will be referred to as *outstanding billion days* where one billion day is one billion USD with one day until maturity. Thus e.g. 25 outstanding billion days may be 25 billion outstanding with one day to maturity or 5 billion outstanding with 5 days to maturity. The volume-weighted maturity is split between the 28-day and the 84-day auctions and calculated in the following way:

$$\text{Vol.w.Mat.}(n,m) = \sum_{i=1}^{m}(V_i^n * M_i^n) \ , \ n\text{=28-day or 84-day auctions}$$

where V_i^n is the volume, M_i^n is the remaining days until maturity in auction *i*, and *m* is the number of auctions outstanding. The procedure can be summarised by the following three steps. First, all auctions conducted via the TAF are first split between 28-day and 84-day auctions. Second, within the two maturity buckets the outstanding volume in auction *i* is multiplied by its remaining days until maturity. Finally, this product is calculated for each outstanding auction before all auctions are summed. Volume-weighted maturity is calculated daily and takes the value of zero if no auctions are outstanding.

In their analysis of the effectiveness of the ECB's liquidity facilities, Abbassi and Linzert (2012) include the outstanding volume in the ECB's liquidity-providing operations, although without adjusting for outstanding maturity. Their results indicate that the 3–month Euribor-OIS spread decreased in line with the higher allotted volume in the ECB's facilities.

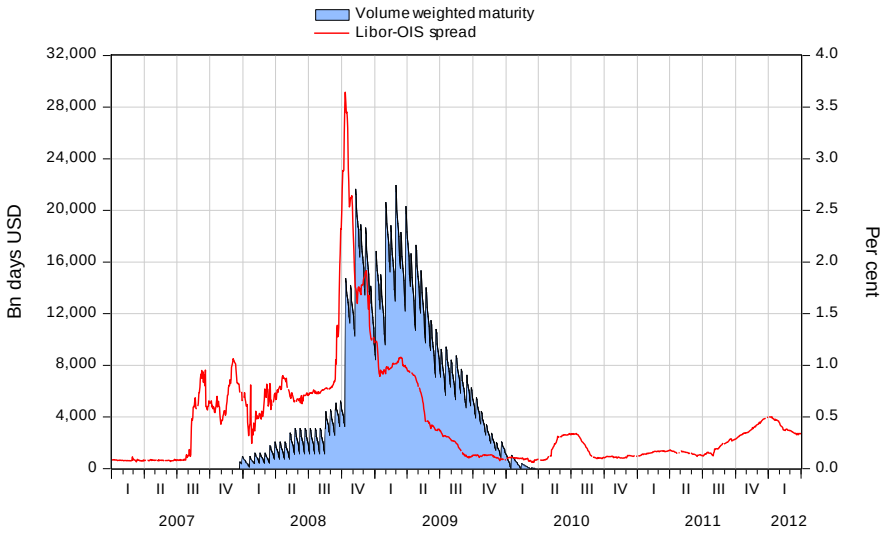

FIGURE 2. THE OUTSTANDING VOLUME IN TAF AUCTIONS

Notes: The figure shows volume-weighted maturity of outstanding TAF loans. The series is compared to the 3-month Libor-OIS spread. *Source:* Bloomberg and Board of Governors of the Federal Reserve.

The TAF can also be viewed in light of the relative price banks had to pay for liquidity in the auctions. Figure 3 shows the two components determining the relative auction price measured as the difference between the stop-out rate - the lowest accepted bid rate in the auction - and the corresponding OIS rate (1-month OIS for the 28-day auctions and 3-month OIS for the 84-day auctions).

The relative price may reveal additional information about the demand for liquidity and to what extent the Federal Reserve accommodated this demand. Between the startup of the facility and the Lehman bankruptcy (coinciding with the peak in the Libor-OIS spread in Figure 4), the TAF was less accommodative in satisfying liquidity demand, reflected by relatively high prices. During the first part of the TAF program, auctions were of short maturity (28 days) and the maximum allotment amount was relatively low, varying between USD 25 and 75 billion (see Table A.2 in the Appendix). This resulted in a wide spread between the stop-out rate and the OIS rate. After the Lehman episode, the price fell gradually, arguably because of a higher volume in the TAF auctions (with the highest allotted volume close to USD 140 billion). At the same time, the bid to cover ratio fell substantially.

When the Federal Reserve increased the maximum allotment amount and the bid to cover ratio decreased below 1, the stop-out rate in the TAF auctions fell significantly in the fourth quarter of 2008.[16]

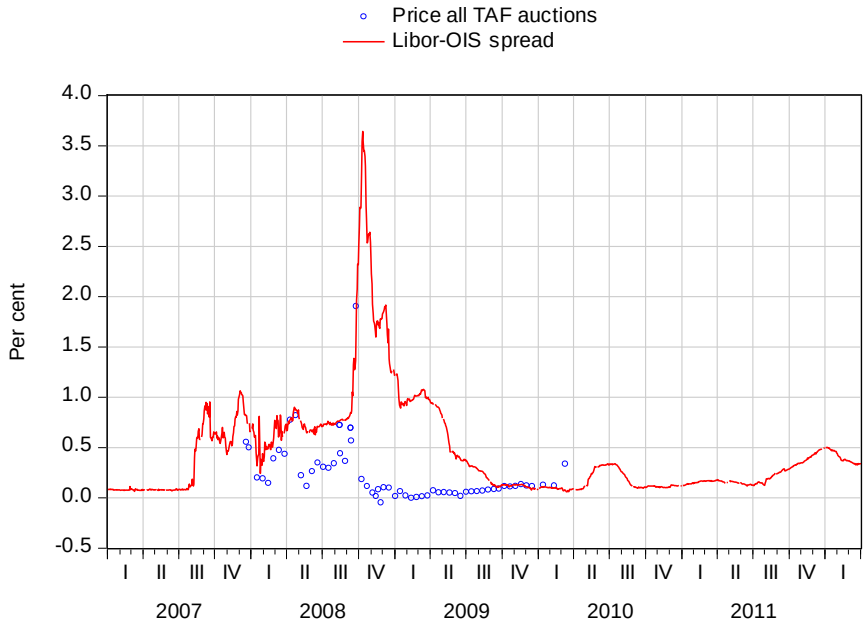

FIGURE 3.THE RELATIVE PRICE IN THE TAF AUCTIONS

Notes: The relative price is measured as the difference between the stop-out rate and the corresponding OIS rate in all TAF auctions. *Source:* Bloomberg and Board of Governors of the Federal Reserve.

2.4 The US liquidity premium and the FX forward market

Normally, FX forwards are priced in such a way that the domestic risk-free interest rate equals the implied risk-free interest rate. The implied interest rate in currency A is derived by combining the risk-free interest rate (e.g. the OIS rate) in currency B and an FX swap transaction.[17] If covered interest parity (CIP) holds, the difference between the FX forward and the FX spot price measured in basis

[16] See Table A.2 in the appendix for auction details.

[17] An FX swap transaction is a combination of an FX spot and an FX forward transaction. In this example it means to buy currency A spot, and sell currency A forward at a predefined exchange rate.

points should exactly represent the risk-free interest rate differential.[18] If not, arbitrage is possible.[19] However, the "risk-free" interest rate, here measured by the OIS rate, does not include the currency-specific liquidity premium, which may vary substantially between different currencies. If one currency is less available than another currency, the arbitrage argument needs to be modified to let differences in the liquidity risk premium be reflected in the FX forward market. Otherwise, a borrower could "circumvent" a high liquidity premium in currency A by borrowing currency B and enter into an FX swap contract. Put differently, the lender of the high liquidity premium currency requires equal compensation for the general liquidity risk premium in an FX swap transaction as for any other investment. If the liquidity premium is equally high in the two currencies, however, no compensation is necessary.

The liquidity premium may differ between currencies if the ability to attract funding differs.[20] For instance, if Bank A raises US dollars in a 3-month interbank transaction, the lender needs to price the interbank loan based on at least two considerations; (i) the credit quality of the borrower and, (ii) the disadvantage of being less liquid for 3 months. The same considerations should be made by the lender if Bank A carries out an identical transaction in another currency. However, the disadvantage of being less liquid in USD compared to an alternative currency may differ if the accessibility to liquidity varies between the currencies. This relative difference in the liquidity premium should be accounted for in the FX forward market. A dislocation in the FX forward market can, theoretically, only be attributed to a difference in the relative liquidity premium between the respective currencies as this is the only factor that is currency-specific.

The relative liquidity premium between two currencies is reflected in the so-called OIS basis, which can be written as:

$$(5)\ \textit{OIS-basis} = \frac{F_{t,t+s}}{S_t}\left(1 + OIS^{USD}_{t,t+s}\right) - \left(1 + OIS^{*}_{t,t+s}\right)$$

[18] Covered interest parity (CIP) means that it should be equally costly to (i) borrow money directly in currency A, and (ii) borrow money in currency B, exchange the proceeds to currency A and hedge the FX risk in the FX forward market.

[19] The arbitrage argument is simple: if the implied OIS rate based on currency A is lower than the actual OIS rate in currency B, borrow money in currency A combined with a swap transaction to lock in the interest rate and eliminate foreign exchange rate risk. The interest rate achieved by these transactions is then lower than the interest rate in currency B for a given credit risk and maturity.

[20] "Term premium" and "liquidity premium" are often used interchangeably. However, sometimes "term premium" refers to the expected interest rate path. The expected interest rate path is eliminated in the calculation of the OIS basis. To avoid any confusion, the term "liquidity premium" will be used in this paper.

where $F_{t,t+s}$ is the forward rate in the FX market from t to $t+s$, the S_t is the FX spot rate at time t, the $OIS^{*}_{t,t+s}$ is the OIS rate from t to $t+s$ in the foreign currency and $OIS^{USD}_{t,t+s}$ is the OIS rate in USD from t to $t+s$.

The OIS basis can be interpreted as the deviation from covered interest parity (CIP) and reflects the relative liquidity between two currencies. The reason for this is that while credit risk is counterparty-specific and should be equal in all currencies, liquidity risk, at least in the sense of availability of credit (funding), is currency-specific.

Figure 4 shows the OIS basis in euro, Swiss franc and sterling, which accordingly can be interpreted as the liquidity premium in the respective currencies relative to the US dollar. If the OIS basis is negative, the US dollar liquidity premium is higher than the liquidity premium in the corresponding currency, meaning that the US dollar is in high demand in the FX swap market.[21]

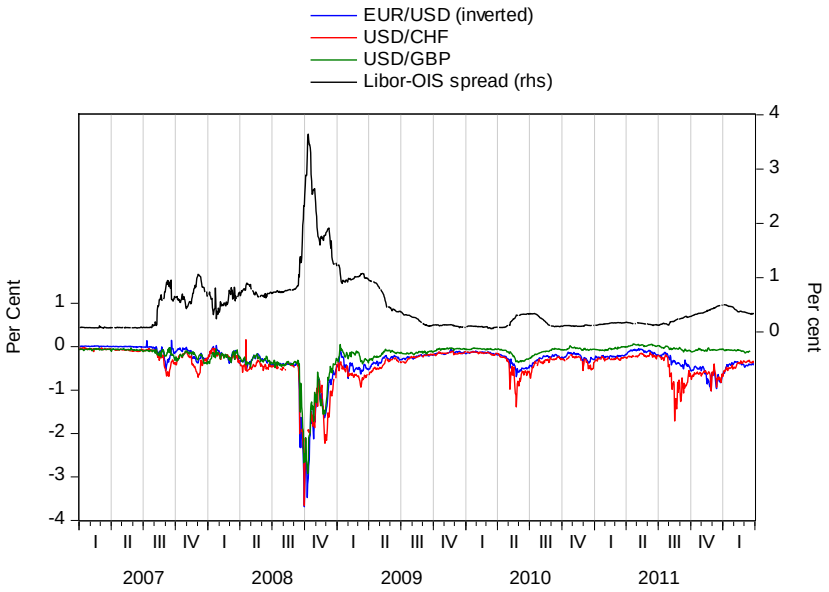

FIGURE 4. THE 3-MONTH OIS BASIS (DEVIATION FROM CIP)

Notes: The OIS basis for EUR/USD, USD/CHF, USD/GBP and the 3-month Libor-OIS spread from 1 January 2007 to 1 April 2011. The OIS basis is calculated as the implied 3-month OIS rate (based on the OIS in US dollar and the FX forward rate) minus the actual OIS rate in the respective currency. *Source:* Bloomberg and author's own calculations.

[21] An FX swap transaction is a secured transaction since one currency is collateral for another. This implies that the FX swap transaction itself does not contain much credit risk. Additionally, the FX forward market has normally good market liquidity (market depth) and a tight bid/ask spread.

If the OIS basis is zero, the currencies are in equal demand. As the liquidity premium can be high in both currencies, an OIS basis of zero does not necessarily mean that there is no liquidity premium, but rather that the liquidity premium is equal in both currencies.

To be able to extract the US liquidity premium we apply a principal component analysis on all the OIS bases. The first principal component is interpreted as a proxy for the general USD liquidity premium. A single deviation from zero for one currency pair is likely related to the individual currency, while a common deviation across all the currencies is likely related to the liquidity premium in USD. The first principal component represents the common factor where the OIS basis for all the three currency pairs moves in the same direction and may therefore be connected to a liquidity premium in USD.

In Figure 4, the CIP holds if the OIS basis is approximately zero. Up to 9 August 2007, the OIS basis was indeed close to zero.[22] The financial crisis led to major dislocations in the FX forward market, primarily driven by a substantial liquidity premium in USD. Worth noticing is the strong correlation between the 3-month *OIS basis* and the 3-month Libor-OIS spread during the financial crisis.

3 Data

My dataset covers the period from 1 January 2007 to 30 April 2010 and consists of 13 variables.[23] Most of the variables, 6 of 13, are connected to the TAF. The TAF was established in December 2007, the last TAF auction was conducted on 11 March 11 2010 and all the TAF loans were repaid on 7 April 2010. Additionally, 3 variables representing other Federal Reserve facilities are included as dummy variables. Finally, CDS prices as a proxy for bank credit risk, the MOVE index as a proxy for general uncertainty in financial markets, the Libor-OIS spread and a proxy for the liquidity risk premium based on FX forward prices are included in the dataset. Holidays and missing data are omitted. The Libor fixings are released by the British Bankers Association (BBA) at 11:00 GMT. The remaining variables are collected from Bloomberg (last value as of 17:00 New York time) or press releases on the Federal Reserve's webpage.[24] All variables except the 3-month Libor rate are lagged by one observation to account for the time-zone difference between the Libor fixing and the New York closing time.

[22] This is also confirmed by data from 2004 to 2007.
[23] Table A4 in the appendix presents descriptive statistics on all the variables.
[24] http://www.federalreserve.gov/

3.1 A proxy for the liquidity premium in USD

The liquidity premium in USD is derived from a standard principal component analysis on the 3-month OIS basis in USD/EUR, USD/CHF and USD/GBP (see Section 1.5 for details on the OIS basis). The first principal component is interpreted as a proxy for the 3-month liquidity premium in USD. This component captures the common movement in the relative liquidity premium of the three currency pairs. Since the OIS basis is interpreted as the relative liquidity premium between the respective currency pairs, the common movement in the OIS basis is a proxy for the liquidity premium in USD.

The methodology used to extract the US liquidity premium is similar to the one outlined in Baba and Packer (2009).[25] They apply a principal component analysis on the FX swap deviations (deviations from CIP) for EUR/USD, CHF/USD and GBP/USD. The main methodological difference related to the principal component analysis between Baba and Packer (2009) and this paper is that they use interbank rates as a basis for FX swap deviations rather than OIS rates. This is an important difference though, since the interpretation of the first principal component as the liquidity premium hinges on the fact that OIS rates do not contain credit risk.

Figure 5 shows developments in the first principal component during the financial crisis.[26] The lower the value, the higher is the liquidity premium in USD. The figure shows that the volatility of the liquidity premium first appeared in August 2007 when BNP Paribas revealed its inability to price some of its investment funds. In the aftermath of the Lehman bankruptcy, unusually high volatility and large dislocations characterised the FX forward market in USD, implying a substantial liquidity premium.

One limitation of the method above is that the liquidity risk proxy does not capture a simultaneous change in the liquidity premium for all the involved currencies (USD, EUR, GBP and CHF). Hence, the level of the liquidity risk premium may be underestimated.[27] I conclude, however, that this is a minor problem since the econometric models applied in this paper solely consider short-run dynamics (specified in first differences).

[25] See also Bernhardsen et.al (2010), Syrstad (2012), Bernhardsen et.al (2012) for a detailed discussion on the *OIS basis* and how this deviation can be interpreted as the liquidity premium in USD.

[26] Table A.3 in the Annex shows the statistical data from the principal component analysis.

[27] Remember that the OIS basis is an expression of the relative liquidity risk premium across the currencies.

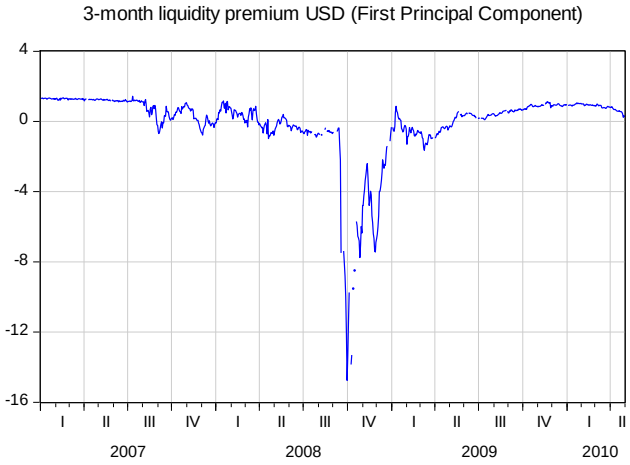

FIGURE 5. THE LIQUIDITY PREMIUM IN USD

Notes: The first principal component is based on the OIS basis (calculated as the implied 3-month OIS rate using the OIS in USD as a starting point and the FX forward rate) minus the actual OIS rate in the respective currency. *Source:* Bloomberg and author's own calculations.

3.2 A preliminary look at the spreads

Figure 6 shows the 3-month US Libor-OIS spread and the median of 5-year CDS prices for a range of panel banks contributing to the fixing of US Libor.[28] After several years of remarkably low and stable interbank spreads, BNP Paribas triggered the first outbreak of money market tensions on 9 August 2007, when it revealed difficulties in pricing some of its investment funds investing in subprime mortgages.

The next major wave of tensions in interbank markets, and financial markets in general, followed the Lehman bankruptcy. On September 14, 2008, Lehman Brothers, the fourth largest investment bank in the US, filed for bankruptcy. A tremendous spike in unsecured interbank spreads followed and the spread reached 360 basis points on 10 October.

Figure 6 suggests that the relationship between credit risk and the unsecured interbank spread may not be obvious. First, in early 2008 and early 2009 interbank spreads decreased substantially despite a continued upward trend in CDS prices. Second, the perceived credit risk observed from CDS prices is far

[28] Interbank credit risk is calculated by the median of the five-year CDS prices for 13 out of 14 Libor panel banks in USD. This is similar to the credit risk measure proposed by Taylor and Williams (2009). The Libor panel has been expanded during the sample period and 18 banks are currently contributing to the fixing. Including these banks in the credit risk measure does not change the results presented in Section 3.

higher in late 2011 than at the height of the crisis in autumn 2008. Overall, this casts some doubt on the importance of credit risk as a major driver of unsecured interbank spreads and strengthens the hypothesis of a substantial liquidity risk component.

FIGURE 6. UNSECURED INTERBANK SPREADS AND CREDIT RISK

Notes: The figure shows the median of the five year CDS prices for 13 out of 14 Libor banks and 31 out of 44 Euribor banks (basis points). LOIS is the spread between the 3-month Libor rate and the corresponding 3-month OIS rate in the US (percent) *Source:* Bloomberg

4 The econometric approach

In order to test the impact of the TAF on the 3-month liquidity premium and 3-month Libor in USD, I conduct a regression analysis in two stages. Both models (Equation (6) and Equation (7) below) are specified in first differences. Table A1 in the Appendix presents the results from standard unit root tests. The results show that the CDS price measure, the MOVE index and volume-weighted maturity all have a unit root. For the full sample, both the Dickey-Fueller and the Phillips-Perron test fail to robustly reject the hypothesis of a unit root in the Libor-OIS spread and in the liquidity premium (first principal component). The above-mentioned variables are therefore considered to be I(1) and the models are specified in first differences. This means that the models do not take into account possible long-run relations between the variables. Nevertheless, in this case we are interested in the short-run dynamics of temporary measures taken by the

Federal Reserve and short-lived dislocations in money markets.[29] The potential problems connected to non-stationarity in the variables have also been emphasised by McAndrews et.al (2008).

In stage one, the volume-weighted maturity variable and other variables that may have had an impact on the liquidity premium are regressed on the proxy for the liquidity premium. This stage aims to reveal the effect of the TAF, i.e. the supply of liquidity, on the liquidity premium.

The following econometric model is specified:

$$(6)\ \Delta y_t^{US.liq.prem} = \beta_0 + \beta_1 \Delta y_{t-1}^{US.liq.prem} + \beta_2 \Delta x_t^{CDS.LIB} + \beta_3 \Delta x_t^{MOVE} + \beta_4 \Delta x_t^{vol.w.mat.TAF28d} + \beta_5 \Delta x_t^{vol.w.mat.TAF84d} + \beta_6 x_t^{Rel.price} + d_1 x_t^{ANN.TAF} + d_2 x_t^{ANN.SWAP} + d_3 x_t^{OPE.TAF} + d_4 x_t^{LSAP} + d_5 x_t^{MMIFF} + d_6 x_t^{TALF} + \varepsilon_t$$

The dependent variable ($\Delta y_t^{US.liq.prem}$) is the first difference of the 3-month liquidity premium in USD, measured as the first principal component as described in Section 2.1. In this stage, the impact of the TAF can be measured directly on the liquidity premium.

In general, the right-hand side variables control for possible effects of different measures of the TAF and several financial market variables that may affect the liquidity premium. The median of the 5-year CDS prices for the Libor panel banks ($\Delta x_t^{CDS.LIB}$) controls for the credit risk premium. A priori, this variable is not expected to have any significant impact on the liquidity premium. The MOVE index (Δx_t^{MOVE}) is the implied volatility in the US Treasury Bills market and may capture elements of the liquidity risk premium not captured by the TAF variables. An increase in the MOVE index indicates higher appetite for highly liquid securities and the effect on the liquidity premium is expected to be negative.[30]

The variables $\Delta x_t^{vol.w.mat.TAF28d}$ and $\Delta x_t^{vol.w.mat.TAF84d}$ are the volume-weighted maturity in the 28-day and 84-day auctions, respectively. Since the auctions are split between 28-day and 84-day auctions, the effect of the two maturities can be tested separately. Furthermore, more weight is put on a USD outstanding the longer the time until maturity. Both variables are expected to have a negative impact on the liquidity premium. The relative price ($x_t^{Rel.price}$) takes

[29] There is no evidence of cointegration between the variables and an error correction model (ECM) is therefore ruled out.

[30] The MOVE index is the weighted average of the implied volatilities of two-year (20 percent), five-year (20 percent), ten-year (40 percent) and thirty-year (20 percent) Treasury securities. The variable is calculated by Merrill Lynch.

the value of the spread between the auction price and the corresponding OIS rate on the announcement day, and zero otherwise. A higher auction price indicates that demand is high relative to the allotted volume, possibly corresponding with an increase in the liquidity premium. The coefficient is therefore expected to be negative.

Finally, six dummies ($x_t^{ANN.TAF}$,$x_t^{ANN.SWAP}$,$x_t^{OPE.TAF}$,x_t^{LSAP},x_t^{MMIFF},x_t^{TALF}) are included in the regression. Any possible impact of announcements related to the TAF ($x_t^{ANN.TAF}$) is captured by the coefficient d_1, while the effect of announcements connected to the swap lines the Federal Reserve established with foreign central banks ($x_t^{ANN.SWAP}$) is captured by d_2. In addition, an operational dummy ($x_t^{OPE.TAF}$) is included to account for any effects connected to operational events.[31] The last three dummies (x_t^{LSAP}, x_t^{MMIFF},x_t^{TALF}) control for announcements connected to other important programs initiated by the Federal Reserve that might conceivably affect the liquidity premium. [32] All the dummy coefficients are expected to be positive, i.e. reducing the liquidity premium.

In stage two, the USD Libor-OIS spread is regressed on a set of variables. Hence, in the second step, all the TAF variables that were included in stage 1 are included in Equation (7) below. Additionally, the residuals from stage 1 are included in order to capture the full effect of the liquidity premium proxy on the Libor-OIS spread. This approach enables me to distinguish between different components of the Libor-OIS spread more carefully. Several papers, Taylor and Williams (2008), McAndrews et.al (2008) and Wu (2008) among others, have studied the effectiveness of the TAF on the Libor-OIS spread. The former study finds no effect of the TAF on the Libor-OIS spread, while the latter two conclude that the TAF significantly reduced interbank spreads. However, all these papers base their analysis on a short data sample covering only the period before September 2008. Furthermore, in my analysis I include the volume-weighted

[31] This dummy includes the operational day, the settlement day and the day when the result was announced. Notice that the dummy for the settlement day often corresponds with large changes in the volume-weighted maturity variable as new funds provided by an auction are first registered in the latter variable on the settlement day. The announcement dummies related to the TAF, the swap lines and the operational dummy are calculated in the same way as McAndrews et.al (2008). Data are available upon request.

[32] TALF, MMIFF and LSAP are abbreviations for Term Asset-Backed Securities Loan Facility, Money Market Investor Funding Facility and Large Scale Asset Purchase Program (also known as QE), respectively. In addition, CPPF (Commercial Paper Funding Facility), PDCF (Primary Dealer Credit Facility), AMLF (Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility) and TSLF (Term Securities Lending Facility) were introduced. These facilities are excluded from the regressions due to perfect correlation with some of the included facilities or they produced presumably spurious results. Nonetheless, the inclusion of the non-perfectly correlated dummies did not alter the main results.

maturity and the liquidity premium proxy in order to decompose the Libor-OIS spread more accurately and capture all possible effects of the TAF.

In this stage the following econometric model is specified:

$$(7)\ \Delta\gamma_t^{LIB} = \delta_0 + \delta_1\Delta\gamma_{t-1}^{LIB} + \delta_2\Delta x_t^{CDS.LIB} + \delta_3\Delta x_t^{MOVE} + \delta_4\Delta x_t^{vol.w.mat.TAF28d} + \delta_5\Delta x_t^{vol.w.mat.TAF84d} + \delta_6 x_t^{rel.price} + \delta_7 x_t^{resid} + \tau_1 x_t^{ANN.TAF} + \tau_2 x_t^{ANN.SWAP} + \tau_3 x_t^{OPE.TAF} + \tau_4 x_t^{LSAP} + \tau_5 x_t^{MMIFF} + \tau_6 x_t^{TALF} + \varepsilon_t$$

Where γ_t^{LIB} is the 3-month Libor-OIS spread and x_t^{resid} is the residuals from the regression in stage one (equation (6)).[33]

All TAF-related coefficients are expected to be negative (including the dummies for the additional programs initiated by the Fed (LSAP, MMIFF and TALF)). The coefficient δ_7 is also expected to take a negative sign, while the CDS and MOVE coefficients are expected to take a positive sign.

5 Results

This section presents the results from the regression analysis with the 3-month US liquidity premium and the 3-month Libor-OIS spread as left-hand side variables.[34] t-values based on standard errors calculated with a Newey-West correction) are reported in brackets next to the respective coefficients. The tables contain the results from regressions on two subsamples. Subsample I goes from 1 January 2007 until 14 September 2008, and covers the period before the Lehman bankruptcy, while subsample II covers the period after the Lehman bankruptcy and goes from 30 October 2008, until 30 April 2010. The period between 15 September 2008, and 30 October 2008, is excluded from the empirical analysis because of a number of outliers and missing data.

[33] The inclusion of the residuals from Equation (6) could possibly lead to generated regressor bias, see Pagan (1984). The bias may stem from the fact that $\Delta\gamma_{t-1}^{LIB}$ in Equation (7) is not included in Equation (6). However, when running Equation (6) including $\Delta\gamma_{t-1}^{LIB}$ the results are unchanged (not reported).

[34] The 3-month Libor is said to be the most representative term as most contracts and derivatives are issued with this maturity.

5.1 The liquidity risk premium in USD

Table 1 reports estimates from the regression for the 3-month liquidity premium presented in Equation (6). First, I find that the coefficient on the 84-day auctions is positive and statistically significant. On the other hand, liquidity provided on a considerably shorter maturity (28-days) did not contribute to a reduction of the 3-month liquidity premium. This result indicates that the liquidity premium in a specific maturity is affected by the maturity provided by the central bank in its liquidity providing facilities.[35]

Second, announcements related to the swap lines established by the Federal Reserver led to a significant reduction in the liquidity premium. This result is in line with earlier studies on the importance of the swap lines (e.g. Baba and Packer (2009), McAndrews et.al (2008)). The swap lines enabled the Federal Reserve to indirectly reach a much broader array of counterparties. In addition, since central banks adopt very different collateral frameworks, the swap lines were effectively an expansion of range of eligible collateral for the Federal Reserve without increasing the risk on the central bank's own balance sheet. This sheds light on the importance of access policy (in terms of both counterparties and collateral), especially in times of low confidence among market participants. If liquidity hoarding led Fed-eligible counterparties to stop redistributing USD liquidity during the financial crisis, the introduction of swap lines can be seen as a tool in providing USD liquidity to a broader range of market participants and against a wider array of eligible collateral.

Turning to the two other dummies concerning the TAF, in subsample II regular TAF announcements seem to be associated with a reduction in the liquidity premium. However, the variable is only significant at the 10 percent level.

Third, as expected, the credit risk component (measured by CDS prices) is not significant in either of the subsamples. As described in Section 1.5, the credit risk premium is counterparty-specific and should not influence the first principal component due to the use of the OIS rate as the basis for the calculations. On the other hand, a general increase in risk perception, expressed by the implied volatility in the US Treasury market (the MOVE index), had a significant impact on the liquidity premium in subsample II. US Treasuries are normally very liquid, meaning that it is easy to liquidate positions without moving the price. When the volatility of US Treasuries increases, it is a sign of excess demand for liquid assets, which in turn may coincide with a higher liquidity premium in USD.

[35] A regression on an alternative specification with outstanding volume instead of volume-weighted maturity shows that the outstanding volume in the 84-day auctions is not significant. This indicates that volume-weighted maturity is a more accurate measure of the TAF than outstanding volume.

TABLE 1
The effectiveness of the TAF on the US liquidity premium

Dependent variable: Δ3mUS.Liq.prem (FPC)	Subsample I (1.1.07-14.9.08)	Subsample II (30.10.08-30.4.10)
Constant	-0.007 (-0.88)	0.02 (1.16)
ΔUS.Liq.prem$_{-1}$	-0.19* *(-1.92)*	0.26** *(2.14)*
ΔMOVE	-0.003 *(-1.35)*	-0.005*** *(-2.61)*
ΔCDS	0.003 *(0.67)*	0.0005 *(0.23)*
ΔVol.Weight.TAF28d	-0.000 *(-0.02)*	-0.000 *(-0.78)*
ΔVol.Weight.TAF84d	0.07* *(1.88)*	0.014** *(2.14)*
Price TAF	0.01 *(0.10)*	-0.26 *(-1.25)*
ANN.TAF(dummy)	0.03 *(0.45)*	0.29* *(1.85)*
ANN.SWAP(dummy)	*0.24*** *(5.26)*	*0.33*** *(2.23)*
OPE.TAF(dummy)	-0.02 *(-0.80)*	-0.05* *(-1.83)*
LSAP(dummy)		0.15*** *(8.27)*
MMIFF(dummy)		0.23*** *(11.29)*
TALF(dummy)		0.06* *(1.75)*
Adj. R^2	0.05	0.11
No.obs	384	335

Notes: 3mUS.Liq.prem (PC) is the first principal component. Price TAF should be considered as a dummy variable taking the value of the spread between the auction price and corresponding OIS on the settlement day and zero otherwise. See Section 2 for more information on the variables. The coefficients associated with *Vol.Weight28d* and *Vol.Weight84d* are scaled by 10E^3.

*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Fourth, the introduction of the Large-Scale Asset Purchase program (LSAP) and the Money Market Investor Funding Facility (MMIFF) seem to have contributed to a reduction in the liquidity risk premium. Regarding the asset purchase program, buying assets without sterilising the reserves can make banks more liquid for at least three reasons: (i) non-bank investors receive money that has to end up as a form of bank liabilities, which could make it easier for banks to attract more funding, (ii) central bank reserves are considered to be slightly more

liquid than US Treasuries, and (iii) in the first round of LSAP the Federal Reserve also bought fewer less liquid assets such as mortgage-backed securities and replaced these assets with highly liquid central bank reserves. The Money Market Investor Funding Facility (MMIFF) facilitated the secondary market for money market instruments bringing confidence to these investors that longer-term investments were liquid. This provided helpful assistance for banks in reducing their own liquidity risk.

The results show that the parameters are not stable across the subsamples. Due to the impact of the Lehman bankruptcy on financial markets and the increased effort among central banks to limit the effects on market functioning, it is not surprising that the parameters are changing. However the results are largely consistent across the samples. The main difference between subsample I and II is related to the MOVE index, which is not significant in subsample I, but highly negative and significant in subsample II. Turning to the coefficients, the magnitude of volume-weighted maturity for the 84-day auctions is larger in subsample I, while the announcement effect is larger in subsample II. The large 84-day auction coefficient in subsample I is probably related to the difference in allotment volume between the two subsamples, which increased substantially after Lehman.

5.2 The impact of the TAF on the 3-month Libor-OIS spread

Equation (7) separates the effects of the TAF and the residual liquidity premium on the Libor-OIS spread. Basically, this approach explains the Libor-OIS spread by the credit risk premium (CDS prices), a general market risk indicator (the MOVE index) and the liquidity risk premium (the first principal component). However, the liquidity risk premium is split into (i) all the Fed-related variables, and (ii) the residual liquidity premium. The results are presented in Table 2.

The estimates indicate that the swap lines contributed to a significant reduction in the 3-month Libor-OIS spread. In total, it is estimated that the Libor-OIS spread fell by 46 basis points due to announcements connected to the swap lines.[36] As mentioned in Section 3.1, this may be related to the fact that the introduction of the swap lines enabled the Federal Reserve to indirectly increase the number of counterparties and widen the pool of eligible collateral.

In subsample I, volume-weighted maturity (84-day auctions) is significant and negative. This means that an increase in volume-weighted maturity for long-term TAF funds led to a reduction in the 3-month Libor-OIS spread. The total effect of the 84-day TAF funds on the 3-month Libor-OIS spread within subsample I is

[36] The number of announcements is 4 in subsample II and 9 in subsample II. Each announcement is associated with a reduction in the Libor-OIS spread of 7 basis points in subsample I and 2 basis points in subsample II.

estimated at 8 basis points. Moreover, announcements concerning the Large-Scale Asset Purchase program (LSAP) and the Money Market Investor Funding Facility (MMIFF) led to a significant reduction in the Libor-OIS spread, of 6 and 8 basis points respectively.

TABLE 2
The effectiveness of the TAF on the 3-month Libor-OIS spread

Dependent variable: ΔLibor-OIS spread	Subsample I (1.1.07-14.9.08)	Subsample II (30.10.08-30.4.10)
Constant	0.002 (1.41)	-0.002*** (-2.60)
ΔLibor-OIS spread$_{-1}$	-0.016 *(-0.23)*	0.65*** *(10.23)*
ΔMOVE	0.002*** *(4.02)*	0.00018 *(0.89)*
ΔCDS	0.0005 *(1.21)*	0.0002 *(1.02)*
ΔVol.Weight.TAF28d	-0.005 *(-1.27)*	0.005*** *(3.76)*
ΔVol.Weight.TAF84d	-0.02*** *(-3.19)*	0.0007 *(1.22)*
Price TAF	0.047** *(2.28)*	0.016 *(0.99)*
Resid (x_t^{resid})	*-0.10*** *(-4.01)*	*-0.035*** *(-2.71)*
ANN.TAF(dummy)	-0.008 *(-0.84)*	-0.0008 *(-0.17)*
ANN.SWAP(dummy)	*-0.08*** *(-3.34)*	*-0.02*** *(-2.97)*
OPE.TAF(dummy)	-0.0075 *(-1.35)*	-0.0008 *(-0.17)*
LSAP(dummy)		-0.04*** *(-35.77)*
MMIFF(dummy)		-0.048*** *(-21.18)*
TALF(dummy)		0.005 *(0.94)*
Adj. R^2	0.38	0.60
No.obs	364	321

Notes: The *Price TAF* variable should be considered as a dummy variable taking the value of the spread between the auction price and corresponding OIS on the settlement day and zero otherwise. The coefficients associated with Vol.Weight28d and Vol.Weight84d are scaled by 10E^3. See Section 2 for more information on the variables.

*** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

As expected, the liquidity premium residual is negative and significant in both samples. The coefficients indicate that a change in the liquidity residual of 0.5

leads to a 5 basis point change in the Libor-OIS spread in subsample I and a 2 basis point change in subsample II. To put these results in perspective, the variable took a maximum value of 0.72 in subsample 1 and 1.65 in subsample II, and generally varied between -0.5 and 0.5. In contrast to most other studies, the credit risk premium comes out as insignificant in subsample II and is only significant on the 10 percent level in subsample I.

Furthermore, the magnitude of the coefficients is relatively low and indicates that a 10 basis point increase in the CDS prices led to an increase in the Libor-OIS spread by 0.9 basis points in subsample I and 0.2 basis points in subsample II. This is striking because it implies that if the liquidity risk premium is properly controlled for, the credit risk premium was not an important driver of the Libor-OIS spread during the crisis. This conclusion may be connected to the construction of the Libor panel. Normally, a bank will be excluded from the Libor panel long before it faces solvency problems due to the credit rating requirements for panel banks.[37]

Finally, during subsample I, when the relative price in the TAF still fluctuated (see Figure 4), a higher auction price relative to the OIS rate led to a modest increase in the Libor-OIS spread. The price has to be seen in connection with the demand for liquidity relative to the maximum allotment volume in the TAF auctions. A high price indicates that demand for liquidity exceeded the volume allotted.

Since the Libor is based on a survey and not actual trades, one might argue that Libor reacts with some delay to changes in financial instruments that are actively traded. For example, it could take some time before an increase in the CDS price would be incorporated in the Libor-OIS spread, especially during times of high volatility. I have tested for this by including several lags of all the explanatory variables.[38] The results show that the liquidity premium in subsample II was significant on lags 2 and 3, while all the other variables were not significant. This means that I find no evidence of a delayed effect of changes in the credit risk component and such an effect can thus not explain why the CDS variable is not significant in table 2.

6 Conclusions

This paper investigates the effectiveness of the TAF on the 3-month liquidity premium and on the 3-month Libor-OIS spread in USD. The liquidity premium is based on data from the FX forward market. Furthermore, in addition to dummy

[37] According to the BBA, banks contributing to Libor are selected in line with three guiding principles: (i) scale of market activity, (ii) credit rating, and (iii) perceived expertise in the currency concerned.

[38] The results from these regressions are not reported here, but are available upon request.

variables a constructed variable considering the outstanding volume and maturity in the TAF is included in the regressions to test the effectiveness of the TAF. I find that the 84-day TAF auctions significantly contributed to a reduction in the 3-month US liquidity premium. This is not very surprising, as a shortfall in 3-month funding could be covered by central bank borrowing close to this maturity. For example, providing 1-month funding cannot cover banks' need for 3-month funding. Announcements connected to the swap lines established by the Federal Reserve with other central banks significantly contributed to a reduction in both the liquidity premium and the Libor-OIS spread. Furthermore, the liquidity premium seems to be the major driver of the Libor-OIS spread during the financial crisis. The results have important policy implications. Liquidity facilities can be effective in reducing the general liquidity premium and the availability of a currency. It is, however, important to satisfy the demand for liquidity at the term of interest for the central bank. If the 3-month term is the most relevant for the economy and the relationship between the overnight rate and longer terms is distorted, the central bank should provide liquidity on a term close to 3 months to effectively restore the transmission of monetary policy. The results can be summarised as (i) the TAF had a significant effect on the 3-month US liquidity premium, (ii) the main effect of the TAF was through 84-day loans and announcements connected to the swap lines the Fed established with a range of central banks, (iii) credit risk seems to have been a very modest driver of the Libor-OIS spread during the financial crisis.

Several important conclusions can be drawn from the results. First, the TAF had a significant impact on the liquidity premium in USD extracted from FX forward prices. This suggests that the TAF had a wide impact on the implied interest rate and hence the overall liquidity premium in USD. By providing term funding through the TAF, the Federal Reserve induced a substantial fall in implied interest rates in USD. This brought the actual monetary policy stance in the US more in line with the federal funds rate. However, the maturity of the funds is crucial. If the central bank wants to impact 3-month rates , liquidity operations should provide funds at approximately the same maturity.

Second, by establishing swap lines with foreign central banks, the Federal Reserve was able to provide USD to a much larger range of counterparties than they normally reach. This was effective in reducing the strains in money markets in general and in lowering the Libor-OIS spread. An alternative way to achieve the same result could be to supply US dollars directly through FX forward operations or broaden the range of counterparties and the pool of eligible collateral in regular liquidity providing operations. These alternatives will, however, change the risk profile of the central bank. First, by providing liquidity to an expanded list of counterparties and against a wider array of collateral, the central bank will be directly exposed towards certain counterparties and certain

collateral instead of central banks. In the case of FX swap operations, the central bank has to invest the foreign currency in assets, with potentially low returns and/or credit risk exposure as a result.

Finally, the results indicate that the liquidity premium was the major driver of the Libor-OIS spread during the financial crisis, while credit risk seems to be rather limited as an explanatory factor. This result can be used to further develop and design liquidity facilities that are effective in reducing the liquidity premium.

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Appendix

A.1 Unit root tests

TABLE A.1.1
UNIT ROOT: FULL SAMPLEI (1.1.07-30.4.10)

	Levels: ADF	Levels: P-P	First differences: ADF	First differences: P-P
Libor-OIS spread	-1.64*	-1.45	-8.25***	-19.70***
US.Liq.prem	-0.97	-1.75*	-13.87***	-13.89***
CDS Libor	-0.72	-0.54	-24.03***	-23.76***
MOVE	-0.07	-0.11	-23.45***	-23.35***
Vol.Weight28d	-0.53	-6.79***	-5.65***	-66.71***
Vol.Weight84d	-1.08	-1.40	-3.92***	-38.87***
PriceTAF	-4.63***	-26.28***	-10.60***	-355.86***

Notes: ADF is the standard Augmented Dickey-Fuller test. P-P stands for Phillips Perron test. Include intercept only if the intercept is significant on 5 per cent level.
*** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.

TABLE A.1.2
UNIT ROOT: SUBSAMPLE I (1.1.07-14.9.08)

	Levels: ADF	Levels: P-P	First differences: ADF	First differences: P-P
Libor-OIS spread	0.40	0.04	-19.25***	-19.54***
US.Liq.prem	-1.94**	-2.05**	-24.72***	-24.73***
CDS Libor	0.75	0.75	-17.93***	-18.01***
MOVE	-2.43	-1.74	-15.62***	-19.89***
Vol.Weight28d	-0.05	-3.49***	-6.42***	-44.13***
Vol.Weight84d	1.29	2.69	-21.47***	-21.49***
PriceTAF	-1.68*	-17.77***	-24.01***	-67.05***

Notes: ADF is the standard Augmented Dickey-Fuller test. P-P stands for Phillips Perron test. Include intercept only if the intercept is significant on 5 per cent level.
*** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.

TABLE A.1.3
UNIT ROOT: SUBSAMPLE II (30.10.08-30.4.10)

	Levels: ADF	Levels: P-P	First differences: ADF	First differences: P-P
Libor-OIS spread	-2.55**	-2.20**	-5.45***	-10.49***
US.Liq.prem	-1.48	-4.51***	-7.03***	-13.54***
CDS Libor	-0.95	-0.95	-18.09***	-18.09***
MOVE	-0.90	-0.90	-16.69***	-16.59***
Vol.Weight28d	-6.16***	-6.26***	-17.04***	-25.08***
Vol.Weight84d	-1.55	-1.22	-20.09**	-22.05***
PriceTAF	-12.85***	-22.44***	-17.18***	-248.36***

Notes: ADF is the standard Augmented Dickey-Fuller test. P-P stands for Phillips Perron test. Include intercept only if the intercept is significant on 5 per cent level.
*** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.

A.2 TAF- auctions

Settlement date	Allotted volume (bn USD)	Price (%)	Bid to Cover ratio	Maturity (days)
11.03.2010	3.41	0.5	0.14	28
11.02.2010	15.426	0.25	0.31	28
14.01.2010	38.531	0.25	0.51	28
17.12.2009	46.035	0.25	0.61	28
03.12.2009	16.73	0.25	0.67	42
19.11.2009	31.119	0.25	0.41	28
05.11.2009	13.152	0.25	0.53	70
22.10.2009	39.566	0.25	0.53	28
08.10.2009	24.83	0.25	0.5	70
24.09.2009	55.763	0.25	0.74	28
11.09.2009	31.908	0.25	0.43	84
27.08.2009	73.404	0.25	0.73	28
13.08.2009	42.941	0.25	0.43	84
30.07.2009	82.375	0.25	0.66	28
16.07.2009	47.768	0.25	0.38	84
02.07.2009	86.337	0.25	0.58	28
18.06.2009	48.023	0.25	0.32	84
04.06.2009	95.588	0.25	0.64	28
21.05.2009	55.57	0.25	0.37	84
07.05.2009	131.562	0.25	0.88	28
23.04.2009	83.83	0.25	0.56	84
09.04.2009	106.251	0.25	0.71	28
26.03.2009	101.642	0.25	0.68	84
12.03.2009	116.872	0.25	0.78	28
26.02.2009	111.683	0.25	0.74	84
12.02.2009	142.448	0.25	0.95	28
29.01.2009	136.051	0.25	0.91	84
15.01.2009	107.747	0.25	0.72	28
02.01.2009	102.979	0.2	0.69	84
18.12.2008	63.014	0.28	0.42	28
04.12.2008	66.471	0.42	0.44	84
27.11.2008	31.075	0.38	0.21	13
20.11.2008	104.478	0.51	0.7	28
14.11.2008	12.629	0.528	0.08	17
06.11.2008	138.939	0.6	0.93	84
23.10.2008	113.271	1.11	0.76	28
09.10.2008	138.092	1.39	0.92	84
25.09.2008	75	3.75	1.78	28
12.09.2008	25	2.53	1.85	28
11.09.2008	25	2.67	1.27	84
28.08.2008	75	2.38	1.12	28
15.08.2008	50	2.45	1.51	28
14.08.2008	25	2.754	2.19	84
31.07.2008	75	2.35	1.21	28
17.07.2008	75	2.3	1.24	28
03.07.2008	75	2.34	1.21	28
19.06.2008	75	2.36	1.19	28
05.06.2008	75	2.26	1.28	28
22.05.2008	75	2.1	1.13	28
08.05.2008	75	2.22	1.29	28
24.04.2008	50	2.87	1.77	28
10.04.2008	50	2.82	1.83	28
27.03.2008	50	2.615	1.78	28
13.03.2008	50	2.8	1.85	28
28.02.2008	30	3.08	2.27	28
14.02.2008	30	3.01	1.95	28
31.01.2008	30	3.123	1.25	28
17.01.2008	30	3.95	1.85	28
27.12.2007	20	4.67	2.88	28
20.12.2007	20	4.65	3.08	28

A.3 Principal component analysis

TABLE A.3
PRINCIPAL COMPONENT ANALYSIS

Sample period: 1.1.07 -30.4.10	Value	Difference	Proportion
Principal component 1 (US liq.prem)	2.87	2.77	0.9578
Principal component 2	0.09	0.064	0.0319
Principal component 3	0.03	--	0.0103

Eigenvectors (loadings)	Principal component 1	Principal component 2	Principal component 3
OIS-basis (USD/EUR)	0.58	-0.03	-0.81
OIS-basis (USD/CHF)	0.57	-0.68	0.44
OIS-basis (USD/GBP)	0.57	0.72	0.38

Notes: Normal loadings. Sample period is 1 January 2007 to 30 April 2010. The OIS-basis for the currency pairs USD/EUR, USD/CHF and USD/GBP is the difference between the 3-month OIS-rate in USD and the implied 3-month OIS-rate based on the 3-month OIS-rate in the respective currency and the 3-month Fx-forwards between this currency and USD.

A.4 Descriptive statistics

TABLE A.4
DESCRIPTIVE STATISTICS

	Full Sample			Subsample I			Subsample II		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
3m Libor-OIS spread	0.55	0.06	3.47	0.67	0.25	1.06	0.63	0.06	3.47
US.Liq.prem	-0.06	-14.7	1.43	0.03	-1.34	1.17	-0.51	-14.7	1.13
CDS Libor	82.4	5	225	69	79.3	178	119	67	225
MOVE	119	51	250	127	79	178	133	74	250
Vol.Weight28d	831	0	3988	964	0	3150	1058	0	3988
Vol.Weight84d	3396	0	20104	129	0	3500	7019	0	20104

Notes: The full sample period goes from 1 January 2007 to 30 April 2010. Subsample 1 covers the period from 1 January 2007 to 14 September 2008 and Subsample 2 covers the period from 30 October 2008 to 30 April 2010. The US liquidity premium is first principal component depicted in A.3. The CDS Libor is the median of the 5y CDS prices for the Libor panel banks. The MOVE index is the weighted average implied volatilities of the two-year, five-year, ten year and thirty-year Treasury securities.The Vol.Weight28d and the Vol.Weight84d are the outstanding volume in all TAF-auctions multiplied by the individual auctions time to maturity.