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The Effect of the Term Auction Facility
on the London Inter-Bank Offered Rate

James McAndrews
Asani Sarkar
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Staff Report no. 335
July 2008

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The Effect of the Term Auction Facility on the London Inter-Bank Offered Rate

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Abstract

This paper examines the effects of the Federal Reserve's Term Auction Facility (TAF) on the London Inter-Bank Offered Rate (LIBOR). The particular question investigated is whether the announcements and operations of the TAF are associated with downward shifts of the LIBOR; such an association would provide one indication of the efficacy of the TAF in mitigating liquidity problems in the interbank funding market. The empirical results suggest that the TAF has helped to ease strains in this market.

Key words: LIBOR, liquidity, money markets, Term Auction Facility

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1 Introduction

The international money markets ran into serious trouble in August 2007. The rates of inter-bank loans with maturity terms of one-month or longer rose to unusually high levels. The spread between the three-month London inter-bank offered rates (LIBOR)¹ and the federal funds rates rose from its typical level of a few basis points to about 50 basis points and ascended further to 90 basis points in September. The widened spread was largely due to a sharp increase in the liquidity risk as well as the credit risk perceived by the market players.² The volume of transactions in the inter-bank market declined, and borrowers reportedly often could not obtain funds at the posted rates. Since the LIBOR affects interest rates on a wide variety of loans and securities (e.g. home mortgages and corporate loans), unusually high term rates can have disruptive effects on the economy.

In the immediate response to the disruption in the money markets, the Federal Reserve (the Fed) used open market operations to maintain the effective federal funds rate (i.e., the interest rate on overnight loans of reserves between depository institutions) close to its target rate. Although the Fed succeeded in stabilizing the overnight rate, the rates on term loans among banks continued to move up, reflecting a sustained reluctance of banks to lend to each other at longer terms.

On December 12, 2007, The Federal Reserve responded to the continuing difficulty that banks faced in obtaining term funds by introducing the Term Auction Facility

¹Libor is an average interbank borrowing rate gathered and published daily by the British Bankers Association (BBA). For the U.S. dollar, the BBA assembles the interbank borrowing rates from 16 contributor panel banks at 11am, looks at the middle eight of these rates (discarding the top and bottom four) and uses these to calculate an average, which then becomes that day's BBA LIBOR rate.

²Liquidity risk arises from uncertainty regarding a bank's cash needs and from its potential inability to borrow funds. Credit risk arises from the uncertainty of counterparty's capability to pay back a loan. An increase in those risks either leads to a higher borrowing rate for a bank or causes a bank to lose access to willing lenders.

(TAF). The TAF provides term funding³ to eligible depository institutions in sound financial condition through periodic auctions. The total amount of the funds available at any TAF auction is announced in advance by the Federal Reserve, and the rate (known as the “stop-out rate”) is set in a competitive auction process among the participating depository institutions. Those depositories with the highest bid rates receive the funds at the stop-out rate.⁴ Through auctions, the Federal Reserve provides term funds to depositories who need it most, with the intention of alleviating the strains arising from the unwillingness of sound institutions to lend to each other.

From December 17, 2007 to April 21, 2008, the Federal Reserve completed ten auctions in the facility. The amount of term loans auctioned was \$20 billion in each of the first two auctions, \$30 billion in the next four auctions, and \$50 billion in the last four auctions. There was strong demand for funds at the auctions. The number of banks bidding for the term loans in the TAF varied between 52 and 93 and the bid/cover ratio (i.e., the total amount bid as a ratio of funds auctioned) ranged between 1.25 and 3.08. A summary of the first ten auctions can be found in Armantier et al. (2008). The Fed plans to continue the TAF auctions until market conditions clearly indicate that the auctions are no longer necessary.

Did the Term Auction Facility help in reducing the liquidity risk premium in the strained money markets? This paper investigates the effects of the TAF on the London inter-bank offered rate (LIBOR). The particular question investigated is whether the announcements and operations of the TAF program are associated with negatives shifts (or jumps) of the LIBOR. The existence of such association will provide one indication of the efficacy of the TAF in helping to relieve the strains in the money

³The term funding is secured by the same collateral that is accepted at the discount window. Complete information about the collateral is provided at <http://www.frbdiscountwindow.org/>.

⁴The minimum bid allowed in each auction is based on the one-month overnight index swap (OIS) rate. This rate represents the market expectation of the average federal funds rate over that month. For a more details of the TAF, see Armantier, Krieger, and McAndrews (2008).

markets. The empirical evidence presented here suggests that the TAF has helped in easing the strained conditions in money markets.

The study of the effectiveness of the TAF is part of a broader research program that contributes to a better understanding of liquidity risk premia. In theory, when all banks face uncertainty of funding risk at the same time, the liquidity risk premium is high. In this situation, term loan markets come under stress, and term interest rates may be disconnected from overnight interest rates. This disconnection between the term and overnight rates is a key challenge faced by financial markets and the economy in the recent financial turmoil. The Term Auction Facility is a new approach taken by central banks to address the problem of a high liquidity risk premium and the resulting misallocation of funds. Measuring the effects of the new facility is a crucial first step toward understanding whether the central bank has the ability to reduce the liquidity risk premium effectively as well as to gain insight into the nature of the liquidity risk premium and its cause.

The rest of the paper is organized as follows. Section 2 discusses the reasons for the TAF to impact on the LIBOR. Section 3 presents the main econometric test and the TAF effect. Section 4 examines the robustness of the TAF effect. Section 5 concludes the paper.

2 Some Theoretical Considerations

Why might the TAF be helpful in reducing the liquidity risk premium in the term interest rate? The main reason is that the TAF may alleviate banks' liquidity risk. In the recent strained circumstances for term funding, banks experience a high degree of uncertainty about their sources for short-term funding. At the same time, banks

have also experienced increased needs for short-term funding.⁵ The risk involving the rate or availability of funding is high when banks face unsettled money markets—banks rationally fear that if they need to borrow funds in the coming weeks, it might not be available to them in the market, or might be available only on unattractive conditions. When these liquidity concerns became manifest, institutions with funds to lend may be more reluctant to lend and either require higher loan rates, shorter loan terms, or might restrict lending.

Possible monetary policy responses include loosening the policy stance or lending to the particular institutions facing funding pressures. The former could, with a sufficient easing of the policy stance, reduce banks funding costs significantly, ultimately addressing their liquidity risk concerns. However, it would require changing the monetary policy stance more generally, which could conflict with the overall goals of monetary policy. The latter option has the advantage of targeting the stressed institutions directly. The Federal Reserve reduced the spread of the primary credit rate of the discount window to 50 basis points above the target federal funds rate on August 17, 2007 to encourage direct borrowing by banks from the Federal Reserve from the discount window to address the increase in their liquidity risk.⁶ However, banks' general unwillingness to borrow through the discount window apparently made it less than fully effective in addressing banks' needs.

The TAF provides term funds to banks whose need to borrow is revealed through aggressive bidding in an auction. It reduces the uncertainty of banks' access to future

⁵Many banks had committed to funding various off-balance sheet assets in the event that the entities that held those assets could not successfully fund them in short-term commercial paper markets. In many cases, banks were required to make good on their commitments to fund those assets, placing strains on their cash resources.

⁶The Board of Governors of the Federal Reserve also extended the term of borrowing through the primary credit program to thirty days. See the announcement of this policy action at <http://www.federalreserve.gov/newsevents/press/monetary/20070817a.htm>. In addition, on March 16, 2008, the Board further reduced the spread of the primary credit rate above the target federal funds rate to 25 basis points and further extended the possible term of borrowing to 90 days.

short-term funding. The TAF also provides a new future funding source to banks that currently have funds to lend, making them more willing to supply loans. The increased availability of lending by some banks may reduce the uncertainty of other banks' sources for short-term funds. It may also prevent inordinate reliance by some banks on overnight funding that may cause excess volatility in the overnight market. These two effects of TAF—meeting banks' immediate funding demands and reassuring potential lenders of their future access to funds—should both work in the direction of reducing liquidity risks of banks, increasing transaction volumes and values, and reducing market interest rates.

Theoretical and empirical studies also suggest that direct funding provided by the central bank may reduce liquidity risk premium in private markets, especially when the markets face aggregate uncertainty in liquidity. Tirole (2006, page 526–527) has theorized that government provision of funding lessens the premium of aggregate liquidity risk. Sundaresan and Wang (2008) have shown that the funds auctioned by the Fed right before the Millennium date change (Y2K) was associated with the ease of the liquidity risk premium in the Treasury bond markets when primary dealers feared that the Y2K might cause an aggregate liquidity shortage. The auctions that the Fed conducted preceding the Y2K were similar to the auctions in the TAF.

The TAF is a tool to reduce liquidity risk in the market by improving the allocation of funds to depository institutions. Given the structure of the TAF, banks with the greatest funding needs are likely to be the most aggressive participants in the auctions. In particular, the stop-out rate and the auction design are intended to overcome the stigma of the traditional discount window format and encourage banks to participate in the auctions.⁷ The Fed stressed that “By allowing the Federal Reserve to inject term funds through a broader range of counterparties and against a broader range of

⁷The auction design issues are further discussed in Armantier et al (2008).

collateral than open market operations, this facility could help ensure that liquidity provisions can be disseminated efficiently even when the unsecured inter-bank markets are under stress. (Press release of the Federal Reserve Board on December 12, 2007)”

Although the TAF delivers funds to banks, it does not change the aggregate bank reserves in the system. The Federal Reserve offsets the impact of the TAF on its balance sheet through open market operations. In this way, the TAF is not expected to impair the Fed’s ability to maintain the effective fed funds rate near the target rate. Although the TAF is not intended to affect the aggregate amount of reserves, it is expected to lead to an improved allocation of reserves because it directly delivers funds to the healthy banks that typically rely on the wholesale money markets and promises a future funding source to the banks that can lend in the market. The improved allocation may lead to changes in banks’ expectations regarding the availability of reserves in the future.

In contrast to its anticipated effects on liquidity risk, the TAF is not expected to exert large or immediate effects in reducing credit risks of bank. Credit risks are largely determined by banks’ earnings and asset value. In the current situation, it is likely that changes in asset values are the driving force for the credit risk of banks. Much of the change in banks’ asset values is determined by the valuation of mortgages and related financial products. Since the valuation of mortgages is determined by the homeowners’ long-term ability to pay for their debt, there is no reason to expect the TAF to affect the value of banks’ mortgage and other assets. The TAF may indirectly influence banks’ credit risk by providing immediate working capital, but the influence is excluded in the measurement of the TAF effect in this study. The exclusion of this influence makes the estimation of the TAF conservative.

The focus of this study is the effect of the TAF on the liquidity risk premium in the interest rates on term loans among banks. The most important short-term interest-

rate index is the three-month LIBOR. Many securities, such as interest rate swaps, floating rate notes, and adjustable mortgages are tied to the three-month LIBOR. Consequently, the interest rate investigated in this study is the three-month LIBOR. Analyses are also performed on one-month interest rates. Since the results are similar to those of three-month LIBOR, only the later are presented for brevity.

A problem of focusing on the LIBOR is that the banks in the LIBOR panel are suspected to under-report the borrowing costs during the period of recent credit crunch. The under-reporting should mainly affect the general level of the LIBOR and thus has little impact on the daily changes associated with the TAF announcements and operations in this study. There is indeed a sharp increase in the LIBOR on April 17 and 18, 2008, immediately after the BBA announced its intent to investigate. The sharp increase in LIBOR on those dates can cause underestimation, not overestimation, of the TAF effect in this study if those dates coincide with some TAF events. Fortunately, there were no TAF events on or around those dates.

3 A Simple Econometric Test

Conceptually, an interest rate on a term loan contains four major components—the expected average overnight risk-free interest rate, the term premium, the credit risk premium, and the liquidity risk premium. The term premium three-month LIBOR is believed to be small, while the credit and liquidity risks have become the most important driving forces of the inter-bank rates since August 2007 (Michaud and Upper, 2008).

To examine the effect of the TAF programs on the credit and liquidity risk premium on a term loan, the overnight indexed swap (OIS) rate over the same term can be subtracted from the interest rate of the term loan. An overnight indexed swap

is a fixed/floating interest rate swap with the floating leg tied to the daily effective federal funds rate. The OIS rate is mostly the expectation of the average overnight federal funds rate during the term of the OIS contracts. It is believed to contain little liquidity or credit risk premium because the OIS market is liquid and the loss in the event of a counterparty default in an OIS contract involves with only the accrued interest but not the principal. Consequently, the spread between the interest rate on an inter-bank term loan and the OIS rate consists of mainly the credit and liquidity risk premia. The exact definition of the spread between the term rate and the OIS rate are as follows. Let R_t^{LIB} denote the three-month LIBOR reported by the British Bankers Association around 6:00 a.m. Eastern Time on date $t + 1$, and R_t^{OIS} the three-month OIS rate as reported at the close (Eastern Time) of date t . The spread between the LIBOR and OIS rate is defined as $Y_t^{\text{LIB}} = R_t^{\text{LIB}} - R_t^{\text{OIS}}$. The daily observations of the LIBOR-OIS spread from January 1, 2007 to April 24, 2008 are displayed in Figure 1, which shows that this spread went up substantially in August, 2007 and has remained volatile since then.

Since the LIBOR-OIS spread contains the credit risk premium, a component that the TAF is not designed to affect, a statistical test that measures the TAF effect on the LIBOR must control for the variation of the credit risk premium. The typical approach is to include a proxy of the credit risk in the regressions.⁸ A natural proxy of the credit risk of the inter-bank loans is the credit default swap (CDS) prices of the banks. The daily time series of the JP Morgan banking sector CDS index is the choice of the proxy in this study and denoted by X_t^{CRD} .

The task of this study is to test whether the TAF announcements and operations affect the three-month LIBOR-OIS spread. In efficient markets, news releases can

⁸A potential issue is that the credit and liquidity premiums are positively correlated. This correlation may cause underestimation of the TAF effect on the liquidity premium. Therefore, the TAF effect reported in this study should be regarded as a conservative estimate.

cause prices to change. Three sources of TAF news can potentially change the market's anticipation of the aggregate liquidity risk: the initial announcement of the TAF program, changes in the amounts available in the TAF auctions, and announcements of the expected future frequency of TAF auctions. Some of the TAF announcements inform the markets of participation by international central banks (e.g., the European Central Bank and the Swiss National Bank), whereas others deal with only the operations inside the U.S.

In addition to announcements, the TAF operations may contribute to the resolution of uncertainty faced by the market participants. The operations of TAF auctions and the notification of the auction results can affect banks' expected demand for liquidity and resolve uncertainty regarding the distribution of funds allocated in the auction, and thereby affect liquidity risk. The TAF auction conditions are announced prior to the auction when the minimum bid rate is set by the Fed. On an auction day, banks execute their bidding strategy and some may feel well assured about the possibility of funding from the auction because they may bid high to virtually guarantee winning funds. Of course, all uncertainty regarding the outcome of the auction, including the public announcement of the stop-out rate, is resolved on the day banks are notified of the results of the auction by the Fed.

To capture the effects of TAF announcements and operations, two indicator functions are defined as follows. An indicator, denoted by x_t^{ANN} , equals 1 on a day with any TAF announcements and zero on other days. Similarly, the collection of the dates of TAF operations is indicated by x_t^{OPS} . As the indicator of the TAF program, a variable x_t^{TAF} is defined to be one on days with any of the TAF announcements and operations, and zero otherwise. An exception is February 1 for which $x^{\text{TAF}} = x^{\text{ANN}} = -1$ because the ECB announced that it would not participate the February TAF auctions. The ECB's withdraw from the February auctions reduced the anticipated supply of the

funds in the TAF. Table 1 lists the dates of the TAF announcements and operations.

When indicators of the event dates are used to detect the TAF effect, the dependent variable in the regression must be the *changes*, not the level, of the LIBOR-OIS spread. An econometric specification with the level as the dependent variable is valid only under the assumption that the liquidity risk premium falls on a day with a TAF event but reverts to the previous level immediately after the TAF event. If the liquidity risk premium stays at the lower level over many days after each TAF-related event, the coefficient of the indicator cannot be interpreted as the TAF effect, and it likely would be insignificant in the regression. In fact, a Monte Carlo simulation (not reported) confirms that the coefficient of the indicators in a regression with the level of the spread likely would be insignificant even if the spread had dropped on every day of a TAF-related event and stayed constant on all other days.

An alternative approach is to regress the level of the LIBOR-OIS spread on the step functions of the TAF events. A step function equals zero before a TAF event and one after the TAF event. This approach has two difficulties. First, this approach assumes that reduction in the LIBOR-OIS spread associated with each TAF event is permanent. A non-permanent effect will be underestimated or undetected by this regression. Second, the level of the LIBOR-OIS spread is persistent. A Dickey-Fuller test (not reported) indicates that the level of the LIBOR-OIS spread has unit root, which invalidates the statistics obtained from the regression. Therefore, the dependent variable in the regression cannot be the level of the LIBOR-OIS spread. Instead, it must be the change of the spread.

The change in the LIBOR-OIS spread, measured in basis points, is assumed linearly associated with the TAF indicators, as well as the lag of the spread and the proxy of the credit risk. The exact econometric specification is

$$y_t^{\text{LIB}} = \alpha_{\text{INT}} + \alpha_{\text{LAG}} Y_{t-1}^{\text{LIB}} + \alpha_{\text{CRD}} x_t^{\text{CRD}} + \alpha_{\text{TAF}} x_t^{\text{TAF}} + \varepsilon_t, \quad (1)$$

where $y_t^{\text{LIB}} = Y_t^{\text{LIB}} - Y_{t-1}^{\text{LIB}}$ and $x_t^{\text{CRD}} = X_t^{\text{CRD}} - X_{t-1}^{\text{CRD}}$. In the period from January 1, 2007 to April 24, 2008, there are 338 observations on the daily change of the LIBOR-OIS spread. The regression includes the lag of the LIBOR-OIS spread as a control variable in case the change of the spread depends on its level. If the TAF is helpful in reducing the term borrowing rates, the coefficient α_{TAF} should be negative. The results of regression model (1) are presented in panel A of Table 2. The coefficient of the TAF indicator is -2.10 and significant with 99 percent confidence, showing that the TAF announcements and operations are indeed associated with a noticeable reduction in the spread.

For purposes of illustration, the economic importance of the TAF effects can be measured by the cumulative drop of the LIBOR-OIS spread associated with the TAF events. The cumulative drop is $\alpha_{\text{TAF}} \sum_t x_t^{\text{TAF}}$, which can be interpreted as the cumulative effect of the TAF events.⁹ The cumulative effect of the TAF program as of April 24, 2008 is -56.7 basis points with a standard error of 19.4 basis points (panel B). That is, the LIBOR-OIS spread as of April 24, 2008 might have been considerably higher were the TAF program not in operation. If twice the standard error is subtracted, the cumulative effect is still at least -18 basis points.

In the regression of the LIBOR-OIS spread, the coefficients of the control variables turn out to be as expected. The change in the CDS spread has a positive and significant coefficient, consistent with the hypothesis that credit risk explains a substantial part of the elevated LIBOR-OIS spread. The lag of the LIBOR-OIS spread is insignificant coefficient, suggesting that the level of the LIBOR-OIS spread is likely to be non-stationary. Therefore, the level of the spread should not be used as a dependent

⁹It is important to point out that this interpretation relies on the assumption that the effect of each event is permanent. However, the econometric tests in this study do not rely on such assumption. Regression (1) can detect the TAF effects no matter whether they are transitory or permanent.

variable in the regression for detecting the TAF effect.

The TAF announcements and operations may have different effects on LIBOR. To distinguish the two effects, the indicator of the TAF announcements and the indicator of the TAF operations enter the regression as separate independent variables:

$$y_t^{\text{LIB}} = \alpha_{\text{INT}} + \alpha_{\text{LAG}} Y_{t-1}^{\text{LIB}} + \alpha_{\text{CRD}} x_t^{\text{CRD}} + \alpha_{\text{ANN}} x_t^{\text{ANN}} + \alpha_{\text{OPS}} x_t^{\text{OPS}} + \varepsilon_t. \quad (2)$$

If the TAF announcements or operations are helpful in reducing the term borrowing rates, at least one of the coefficients α_{ANN} and α_{OPS} should be negative. The result of regression (2) is reported in panel A of Table 2. The coefficient of the TAF announcement indicator is -6.21 and significant at 99 percent confidence. The coefficient of the TAF operation indicator is -1.20 and significant at 90 percent confidence. Although α_{OPS} is smaller and less significant than α_{ANN} in terms of absolute value, the contribution of the TAF operations is as large as the announcement because the cumulative effect of the operations is -29.9 basis points whereas the cumulative effect of the announcements is -24.8 basis points (panel B of Table 2).

The TAF announcements can be split into two types, those about international central bank participation and those about domestic supply of funds, as shown in Table 1. Consequently, the indicator of TAF announcement (x_t^{ANN}) consists of x_t^{ANI} and x_t^{AND} , which indicate the dates of the announcements related to international operations and those related to domestic operations, respectively. Replacing the term $\alpha_{\text{ANN}} x_t^{\text{ANN}}$ by a linear combination of the indicators for the two types of announcements, regression (2) becomes

$$\begin{aligned} y_t^{\text{LIB}} = & \alpha_{\text{INT}} + \alpha_{\text{LAG}} Y_{t-1}^{\text{LIB}} + \alpha_{\text{CRD}} x_t^{\text{CRD}} \\ & + \alpha_{\text{ANI}} x_t^{\text{ANI}} + \alpha_{\text{AND}} x_t^{\text{AND}} + \alpha_{\text{OPS}} x_t^{\text{OPS}} + \varepsilon_t. \end{aligned} \quad (3)$$

In regression (3), the estimates of α_t^{ANI} and α_t^{AND} are -8.56 and -3.83 basis points, respectively, and both are significant at the 99 percent confidence level (panel A of

Table 2). The cumulative effect of the international TAF announcements is -8.6 basis point, only slightly smaller than the cumulative effect (-11.5 basis points) of the domestic announcements (panel B of Table 2). This result suggests that both international central bank coordination and the domestic program are important to banks in the market. The importance of the international coordination might reflect the dependence on wholesale funding markets by the banks that do not have extensive branch operations in the U.S. to raise deposits but hold U.S. dollar-denominated assets.

The TAF operations consist of three parts: setting the auction conditions, conducting the auctions, and notifying the auction results, as shown in Table 1. The effect of each part is of interest. The indicator of TAF operations (x_t^{OPS}) can be split into x_t^{CON} , x_t^{AUC} , and x_t^{NOT} , which indicate the dates of setting auction conditions, conducting auctions, and notifying auction results, respectively. The separate effect of each part can be tested in the following regression:

$$\begin{aligned}
y_t^{\text{LIB}} = & \alpha_{\text{INT}} + \alpha_{\text{LAG}} Y_{t-1}^{\text{LIB}} + \alpha_{\text{CRD}} x_t^{\text{CRD}} + \alpha_{\text{ANN}} x_t^{\text{ANN}} \\
& + \alpha_{\text{CON}} x_t^{\text{CON}} + \alpha_{\text{AUC}} x_t^{\text{AUC}} + \alpha_{\text{NOT}} x_t^{\text{NOT}} + \varepsilon_t.
\end{aligned} \tag{4}$$

The estimated coefficients for the three types of operations are -0.96 , -0.51 , and -1.18 , respectively (panel A of Table 2). The negative coefficients support the view that each part of the TAF operation helps in reducing the liquidity risk premium in the LIBOR. Based on the estimated cumulative effects (panel B of Table 2), notification of an auction result seems to be the most important among the three types of operations. Although all the three coefficients are negative, they are not significant at a conventional confidence level. Since much of the operations are expected, identification of the operation effects is difficult in regression (4) as the simple econometric model does not precisely measure the evolution of expectations.

4 Robustness of the TAF Effect

A natural question is whether the TAF effect detected in the simple econometric tests is robust after controlling for additional factors that drive the changes of the three-month LIBOR. Three additional factors are considered. First, the term premium is ignored in the simple econometric tests, but it can be important. To control for the term premium, the change of the spread between 5-year and 2-year Treasury yields,¹⁰ denoted by x^{TRM} , is added as an independent variable in the regression. Second, the variation of the risk environment in the general financial markets may also drive the LIBOR to change. To control for the variation of risk and risk aversion in the general markets, the change of the VIX index, denoted by x^{RSK} , is added as an independent variable. Third, short-term interest rates are well known to spike on quarter ends, when institutions report balance sheets. An indicator, denoted by x^{QRT} , is constructed to capture the potential quarter-end effects. This indicator equals one on three days before a quarter-end to capture the positive changes and equals zero on three days after the quarter-end to capture the negative changes.¹¹ Incorporation of these additional control variables leads to the following expanded regression

$$\begin{aligned} y_t^{\text{LIB}} = & \alpha_{\text{INT}} + \alpha_{\text{LAG}} Y_{t-1}^{\text{LIB}} + \alpha_{\text{CRD}} x_t^{\text{CRD}} + \alpha_{\text{TRM}} x_t^{\text{TRM}} \\ & + \alpha_{\text{RSK}} x_t^{\text{RSK}} + \alpha_{\text{QRT}} x_t^{\text{QRT}} + \alpha_{\text{TAF}} x_t^{\text{TAF}} + \varepsilon_t, \end{aligned} \quad (5)$$

Table 3 presents the results of regression (5) and its variations. The change of the term premium has a positive, but insignificant, coefficient, consistent with the view

¹⁰The Treasury securities are well known to contain liquidity premium. Since the 5-year and 2-year notes are believed to contain similar liquidity premiums, the spread between the two yields should reflect mainly the term premium. In contrast, the 10-year note usually has larger liquidity premium than other Treasury securities. Consequently, its spreads over other Treasury securities should be correlated with the liquidity premium in the money markets.

¹¹However, the quarter-end indicator is adjusted for the fact that settlement of Eurodollar deposits is two days after the quote of the rate. The indicator is also adjusted for the fact that the date t LIBOR-OIS spread uses the LIBOR published at 6:00 AM on date $t + 1$.

that a term premium exists in the LIBOR-OIS spread but is small. The change of the risk environment has a positive, significant coefficient, which shows the influence of aggregate risk and risk aversion. The quarter-end indicator has an insignificant coefficient, possibly because the quarter-end effects appear in both the LIBOR and the OIS rate but cancel out in their spread. As an important benefit, the additional control variables boost the R-squared from 8% for regression (1) to 20% for regression (5). The large increase of the R-squared reflects the enhanced strength of the specification against potentially spurious attribution of some LIBOR fluctuations to the TAF effect. With the expanded specification, as shown in Table 3, all the TAF-related coefficients have magnitudes and significance levels similar to those obtained from the simple specification.

Instead of serving as a control variable in the regression, the CDS prices allow the separation of the non-credit risk component from the LIBOR-OIS spread. For this purpose, the credit risk premium can be estimated from the CDS prices on the debts of the banks and subtracted from the LIBOR-OIS spread.¹² The price of a CDS on a bank can be used to estimate the credit risk premium in the LIBOR. A valuation method similar to Hull and White (2003) can be used for calculating the implied default intensity. The calculated default probability implies the credit risk premium on a three-month loan.¹³ The daily time series of the average estimated credit premiums of banks is denoted by S_t^{CRD} . The credit premium in the LIBOR is

¹²A similar approach in separating the non-credit component out of the term rates was employed by the Bank of England (2008) to study the behavior of the LIBOR in 2007.

¹³The calculation of the credit risk premium from default probability requires an assumption about the recovery rate of the inter-bank loans. Although the recovery rate of the unsecured corporate debt under each CDS contract is provided by Markit (usually around 40%), there is no available data on the recovery rate of the inter-bank loans. Since the inter-bank loans are usually senior claims than unsecured corporate debts, the former should have higher recovery rate than the latter. Based on Table 3 in Kuritzkes, Schuermann and Weiner (2005), the U.S. banks with at least \$5 billion assets have a recovery rate of around 91.25% for unsecured deposit. Therefore, the recovery rate of the inter-bank loans is set to 91.25% for the calculation in this study. In fact, the level of the recovery rate does not affect the empirical results because the statistical tests in this study are based on the changes (not the level) of the premiums.

different from X_t^{CDS} , the CDS index of banks, for the following reasons. First, the term of the default risk in LIBOR is three-months, whereas the term of the default risk in the CDS index of banks is more than two years. Second, the recovery rate of dollar deposits is substantially higher than the recovery rate of corporate debts. Therefore, the changes of S_t^{CRD} and X_t^{CDS} should not be expected to have similar magnitudes, although they should be anticipated to be correlated.

The non-credit component of the LIBOR is $Y_t^{\text{LQD}} = Y_t^{\text{LIB}} - S_t^{\text{CRD}}$. The estimates of the credit risk premium and the non-credit component, along with the LIBOR-OIS spread, are displayed in Figure 1. The credit risk premium remained low and placid until August 2007. In 2008, it has been high and volatile, occasionally exceeding the LIBOR-OIS spread. The estimated credit risk premium may contain, besides estimation errors, a liquidity premium in the CDS themselves because the CDS market was sometimes illiquid during early 2008. If the CDS prices reflect a mix of both credit and liquidity risk premiums, the next regression may *underestimate* the TAF effect on the non-credit component. The regression is

$$y_t^{\text{LQD}} = \alpha_{\text{INT}} + \alpha_{\text{LAG}} Y_{t-1}^{\text{LQD}} + \alpha_{\text{CRD}} x_t^{\text{CRD}} + \alpha_{\text{TRM}} x_t^{\text{TRM}} + \alpha_{\text{RSK}} x_t^{\text{RSK}} + \alpha_{\text{QRT}} x_t^{\text{QRT}} + \alpha_{\text{TAF}} x_t^{\text{TAF}} + \varepsilon_t, \quad (6)$$

where $y_t^{\text{LQD}} = Y_t^{\text{LQD}} - Y_{t-1}^{\text{LQD}}$. The results of regression (6) and its variations are reported in Table 4. Again, all the TAF-related coefficients have magnitudes and significance similar to those obtained from the simple specifications, underscoring the robustness of the empirical results discussed in the previous section.

To further check for robustness, the regressions are repeated with a sub-sample of the data covering the period up to March 10, 2008, before the Fed introduced a series of new liquidity facilities (i.e., the Term Securities Lending Facility (TSLF) and the Primary Dealer Credit Facility (PDCF)) and lent to Bear Stearns. Distinguishing the

effects of the TAF from the other facilities and actions is difficult. The regressions using only the data (306 observations) up to the introduction of the other facilities at least excludes the effects of Fed's actions since March 11, 2008. The results with the shorter sample are presented in Table 5. The coefficients of the indicators of the TAF announcements and operations are negative and mostly significant. Therefore, the effect on the LIBOR-OIS spread remains after excluding the effect of later facilities.

5 Concluding Remarks

This study offers evidence consistent with the hypothesis that the TAF relieved strains in inter-bank money markets. In the LIBOR-OIS spread, a cumulative reduction of more than 50 basis points can be associated with the TAF announcements and its operations. The reduction is economically important because it is approximately 90 percent of the average level of the LIBOR-OIS spread in the recent period of credit crunch. Although the examination of the TAF effect is confined to the LIBOR-OIS spread, the TAF may have impacts on other interest rates, the volume of trade, or the conditions in various markets. The impact of TAF beyond the LIBOR is a subject for future research.

The results produced in this study are in sharp contrast to that reported by Taylor and William (2008), who conclude that the TAF has no effect at all in reducing the three-month LIBOR-OIS spread. Using an indicator of the TAF auction dates to detect the TAF effects, they find that the coefficient of the TAF auction indicator is positive and insignificant. The likely reason for their result is the use of the *level* (not the *changes*) of the LIBOR-OIS spread as the dependent variable in their regressions. As discussed in Section 3, the econometric specification with the level of the spread is valid only under the assumption that the effect of an auction disappears immediately after the auction. When the *change*, rather than the level, of the LIBOR-OIS spread

is used as the dependent variable in Taylor and William's regression, the coefficient of their auction indicator becomes negative.

The analysis in this study is very different from those reported by Wu (2008). He assumes that the level of the LIBOR-OIS spread is a linear function of a step function that equals zero before the TAF program and one after it. He estimates the level of the spread before the program and the level since the program. This specification relies on the assumption that the effect of each TAF event is permanent and the assumption that the level of the LIBOR-OIS is not persistent. As discussed in Section 3, none of the assumptions are satisfied.

Although the change of the LIBOR-OIS spread reflects the efficacy of the TAF, the problems encountered by banks in meeting their funding needs in the inter-bank money markets clearly was not fully solved by the TAF alone. Subsequently, additional actions have been undertaken by the Federal Reserve to improve market conditions. These actions include increasing the TAF auction sizes, lengthening the term of loans in the primary credit programs, lowering the interest rate premium in the discount window, and introducing several other lending facilities (such as the TSLF and PDCF).

The TAF is just one of many facilities designed to improve the liquidity conditions in the money markets. Identifying the impact of each individual liquidity facility, such as the TAF, is crucial for policy decisions. This investigation measures the separate benefit of the TAF. The result suggests that the TAF is useful as a complement to the other tools of the Federal Reserve in supporting liquid market conditions.

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B Tables and Figures

Table 1. Dates of the TAF Announcements and Operations

Date	Central bank actions	Announcements (ANN)		Operations (OPS)		
		International ANI	Domestic AND	Condition CON	Auction AUC	Notification NOT
12/12/07	Announcement of TAF initiation	1	0	0	0	0
12/14/07	Set conditions for the 1st auction	0	0	1	0	0
12/17/07	Conduct the 1st auction	0	0	0	1	0
12/19/07	Set conditions for 2nd auction	0	0	1	0	1
12/20/07	Notify the result of the 1st auction	0	0	0	1	0
	Conduct the 2nd auction					
12/21/07	Notify the result of the 2nd auction	0	1	0	0	1
	Announce continuation of TAF					
01/04/08	Announce increase of TAF quantity	0	1	0	0	0
01/11/08	Set conditions for 3rd auction	0	0	1	0	0
01/14/08	Conduct the 3rd auction	0	0	0	1	0
01/15/08	Notify the result of the 3rd auction	0	0	0	0	1
01/25/08	Set conditions for the 4th auction	0	0	1	0	0
01/28/08	Conduct the 4th auction	0	0	0	1	0
01/29/08	Notify the result of the 4th auction	0	0	0	0	1
02/01/08	ECB won't join February auctions	-1	0	0	0	0
02/08/08	Seconditions for the 5th auction	0	0	1	0	0
02/11/08	Conduct the 5th auction	0	0	0	1	0
02/12/08	Notify the result of the 5th auction	0	0	0	0	1
02/22/08	Set conditions for the 6th auction	0	0	1	0	0
02/25/08	Conduct the 6th auction	0	0	0	1	0
02/26/08	Notify the result of the 6th auction	0	0	0	0	1
03/07/08	Announce increase of TAF quantity	0	1	0	0	0
03/10/08	Set contitions for the 7th auction	0	0	1	1	0
	Conduct the 7th auction					
03/11/08	Notify the result of the 7th auction	1	0	0	0	1
	ECB & Swiss announce participation					
03/24/08	Set conditions for the 8th auction	0	0	1	1	0
	Conduct the 8th auction					
03/25/08	Notify the result of the 8th auction	0	0	0	0	1
04/07/08	Set conditions for the 9th auction	0	0	1	1	0
	Conduct the 9th auction					
04/08/08	Notify the result of the 9th auction	0	0	0	0	1
04/21/08	Set conditions for the 10th auction	0	0	1	1	0
	Conduct the 10th auction					
04/22/08	Notify the result of the 10th auction	0	0	0	0	1

The table lists the dates of the TAF announcements and operations. The column under ANI indicates the dates of the announcements regarding to international central bank participation. The column under AND indicates the date of the announcements with only domestic auctions. The column under CON indicates the dates when the conditions of the auctions are set. The column under AUC indicates the auction dates. The column under NOT indicates the dates when auction results are notified.

Table 2. The TAF Effect in a Simple Specification

A. Statistics of the Regressions									
Dependent variable:		Change of the LIBOR-OIS spread (LIB)							
Regression model:		(1)		(2)		(3)		(4)	
Independent variable	Notation	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.
Intercept	INT	0.39	1.60	0.33	1.42	0.32	1.39	0.32	1.38
Lag of LIBOR-OIS spread	LAG	0.00	-0.04	0.00	0.14	0.00	0.13	0.00	0.13
Changes in CDS spread	CRD	0.07	2.25 **	0.07	2.33 **	0.07	2.31 **	0.07	2.32 **
Term Auction Facility	TAF	-2.10	-2.92 ***						
Announcement	ANN			-6.21	-4.73 ***			-6.21	-4.55 ***
International	ANI					-8.56	-4.77 ***		
Domestic	AND					-3.83	-3.89 ***		
Operation	OPS			-1.20	-1.75 *	-1.19	-1.82 *		
Condition	CON							-0.96	-1.15
Auction	AUC							-0.51	-0.84
Notification	NOT							-1.18	-0.95
Adjusted R-squared		8%		11%		11%		10%	

B. Estimates of the Cumulative Effects									
Cumulative effects		Est.	St. err.	Est.	St. err.	Est.	St. err.	Est.	St. err.
Term Auction Facility	TAF	-56.7	19.4						
Announcement	ANN			-24.8	5.3			-24.8	5.5
International	ANI					-8.6	1.8		
Domestic	AND					-11.5	3.0		
Operation	OPS			-29.9	17.2	-29.7	16.3		
Condition	CON							-9.6	8.3
Auction	AUC							-5.1	6.2
Notification	NOT							-11.8	12.5

The table shows results from a regression of changes in the three-month LIBOR-OIS spread on the indicators of the TAF announcements and operations. ANN is the indicator of all announcement dates. ANI is the indicator of the announcements of international central bank participation. AND is the indicator of the announcements without international central bank participation. CON is the indicator of the dates setting the conditions of the auctions. AUC is the indicator of the auction dates. NOT is the indicator of the dates when auction results are notified. OPS is the union of CON, AUC and NOT. TAF is the union of ANN and OPS. CRD is the change of the average bank CDS index constructed by J.P. Morgan Chase. The cumulative effect of an indicator is the product of its coefficient and the sum of the indicator over time.

Table 3. The TAF Effect in an Extended Specification

Dependent variable:		Change of the LIBOR-OIS spread (LIB)							
Independent variable	Notation	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.
Intercept	INT	0.23	1.08	0.18	0.89	0.17	0.85	0.17	0.83
Lag of LIBOR-OIS spread	LAG	0.00	0.36	0.00	0.51	0.00	0.50	0.00	0.52
Changes in CDS spread	CRD	0.04	2.35 **	0.04	2.44 **	0.04	2.42 **	0.04	2.36 **
Changes in term premium	TRM	0.09	0.84	0.07	0.62	0.06	0.56	0.06	0.56
General market risk level	RSK	0.85	4.41 ***	0.84	4.36 ***	0.84	4.40 ***	0.85	4.38 ***
Quarter end	QRT	0.31	0.66	0.40	0.79	0.32	0.68	0.37	0.77
Term Auction Facility	TAF	-2.09	-3.09 ***						
Announcement	ANN			-5.83	-5.54 ***			-5.97	-5.55 ***
International	ANI					-8.08	-7.03 ***		
Domestic	AND					-3.57	-5.78 ***		
Operation	OPS			-1.19	-1.70 *	-1.17	-1.73 *		
Condition	CON							-1.55	-2.13 **
Auction	AUC							-0.30	-0.48
Notification	NOT							-0.77	-0.68
Adjusted R-squared			20%		22%		23%		22%

The table shows results from a regression of changes in the three-month LIBOR-OIS spread on the indicators of the TAF announcements and operations. ANN is the indicator of all announcement dates. ANI is the indicator of the announcements of international central bank participation. AND is the indicator of the announcements without international central bank participation. CON is the indicator of the dates setting the conditions of the auctions. AUC is the indicator of the auction dates. NOT is the indicator of the dates when auction results are notified. OPS is the union of CON, AUC and NOT. TAF is the union of ANN and OPS. CRD is the change of the average bank CDS index constructed by J.P. Morgan Chase. TRM is the change of the spread between five- and two-year Treasury yields. RSK is the change of the VIX index.

Table 4. The TAF Effect on the Non-Credit Component of the LIBOR

Dependent variable:	Change of the non-credit component (LQD)									
Independent variable	Notation	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	
Intercept	INT	0.47	1.81 *	0.46	1.82 *	0.43	1.74 *	0.45	1.77 *	
Lag of non-credit component	LAG	-0.01	-0.90	-0.01	-0.82	-0.01	-0.78	-0.01	-0.78	
Changes in term premium	TRM	-0.04	-0.39	-0.06	-0.49	-0.07	-0.58	-0.06	-0.53	
General market risk level	RSK	0.82	4.09 ***	0.81	4.10 ***	0.81	4.16 ***	0.82	4.08 ***	
Quarter end	QRT	0.61	1.05	0.70	1.11	0.60	0.99	0.69	1.13	
Term Auction Facility	TAF	-1.72	-2.47 ***							
Announcement	ANN			-4.01	-3.58 ***			-4.15	-3.16 ***	
International	ANI					-7.25	-3.25 ***			
Domestic	AND					-0.79	-0.28			
Operation	OPS			-1.38	-1.85 *	-1.34	-1.93 **			
Condition	CON							-1.57	-1.83 *	
Auction	AUC							-0.67	-0.88	
Notification	NOT							-1.00	-0.65	
Adjusted R-squared			12%		13%		14%		12%	

The table shows results from a regression of changes in the non-credit component of the three-month LIBOR-OIS spread on the indicators of the TAF announcements and operations. ANN is the indicator of all announcement dates. ANI is the indicator of announcements of international central bank participation. AND is the indicator of announcements without international central bank participation. CON is the indicator of the dates setting the conditions of the auctions. AUC is the auction dates. NOT is the indicator of the dates when auction results are notified. OPS is the union of CON, AUC and NOT. TAF is the union of ANN and OPS.

Table 5. The TAF Effect before March 11, 2008

Dependent variable:		Change of LIB				Change of LQD			
Independent variable	Notation	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.
Intercept	INT	0.26	1.21	0.22	1.05	0.32	1.32	0.31	1.29
Lag of LIB or LQD	LAG	0.00	-0.10	0.00	-0.02	-0.01	-0.79	-0.01	-0.75
Changes in CDS spread	CRD	0.03	2.44 **	0.04	2.51 ***				
Changes in term premium	TRM	0.10	0.88	0.09	0.78	0.00	-0.01	0.00	-0.01
General market risk level	RSK	0.78	3.91 ***	0.78	3.87 ***	0.70	3.88 ***	0.70	3.85 ***
Quarter end	QRT	0.09	0.18	0.21	0.38	0.35	0.60	0.43	0.66
Term Auction Facility	TAF	-1.98	-3.07 ***			-1.69	-2.20 **		
Announcement	ANN			-4.57	-4.77 ***			-2.20	-1.10
Operation	OPS			-1.13	-1.45			-1.55	-2.22 **
Adjusted R-squared		17%		18%		9%		9%	

The table shows results from a regression of changes in the three-month LIBOR-OIS spread and its non-credit component on the indicators of the TAF announcements and operations. The regression is estimated for the period from January 3, 2007 to March 10, 2008. ANN is the indicator of all announcement dates. OPS is the indicator of all TAF operations. TAF is the union of ANN and OPS. CRD is the change of the average bank CDS index constructed by J.P. Morgan Chase. TRM is the change of the spread between five- and two-year Treasury yields. RSK is the change of the VIX index.

Figure 1. The LIBOR-OIS Spread and Its Decomposition

