A Black Swan in the Money Market

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ABSTRACT

The recent financial crisis saw a dramatic and persistent jump in interest rate spreads between overnight federal funds and longer-term interbank loans. The Fed took several actions to reduce these spreads, including the creation of the Term Auction Facility (TAF). The effectiveness of these policies depends on the cause of the increased spreads—whether counterparty risk, liquidity, or other factors. Using a no-arbitrage pricing framework and various measures of risk, we find robust evidence that increased counterparty risk contributed to the rise in spreads, but do not find robust evidence that the TAF had a significant effect on spreads.

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On Thursday, August 9, 2007 traders in New York, London, and other financial centers around the world suddenly faced a dramatic change in conditions in the money markets. The federal funds rate—the interest rate on overnight loans between banks—jumped to unusually high levels compared with the Fed's target. Rates on longer term inter-bank loans, measured for example by the 3-month London Inter-bank Offered Rate (Libor), surged as well. The turmoil did not disappear the next day. While the overnight interest rate whipsawed sharply down on Friday as the New York Fed pumped liquidity into the market, the term inter-bank rates did not come down at all and indeed moved up further on Friday despite the increase in liquidity provided by the central bank. Rates on such term lending seemed to disconnect from the overnight rate and thereby from the Fed's target for interest rates.

Traders, bankers, and central bankers found these developments surprising and puzzling after many years of comparative calm. Were banks suddenly demanding more liquidity? Had they grown reluctant to lend to each other for more than one day because of fears about newly disclosed losses on sub-prime mortgages? Or were they worried about problems on their own balance sheets? As we now know, that Thursday and Friday of August 2007 turned out to be just the start of a remarkably long period of tumult in the money markets with the spread between longer term bank loans and overnight loans remaining unusually high and volatile, reminiscent of the highly extraordinary "black swan" events described by Nassim Taleb (2007).

The episode raises important questions for monetary theory and policy. In many macro models now used for monetary policy evaluation, the federal funds rate set by the central bank is assumed to affect directly real output and inflation. In fact, the federal

funds rate typically appears in an equation determining output which in turn affects inflation through a price adjustment equation. Of course, this is a simplification because in reality the transmission mechanism involves interest rates on longer-term or higher-risk loans. For example, it is the Libor rate, not the overnight federal funds rate, which is linked to the interest rates on trillions of dollars of loans and securities, thus influencing spending decisions. As long as the spreads between interest rates are small or constant, as they have been in the interbank market for many years, ignoring movements in the spreads is a reasonable simplifying assumption. But the spreads have been anything but small or constant in the recent crisis. Even more complex models which incorporate relations between short-term and long-term interest rates must be able to predict movements in spreads if they are to be useful for policy. But for much of this crisis the spreads have been no more predictable than they have been constant, raising difficult problems for monetary policy.

To deal with these problems, the Federal Reserve made several attempts to reduce the spread between term inter-bank lending rates and the overnight rate. Early on, it lowered the penalty on borrowing at the discount window bringing the discount rate below Libor, and it strongly encouraged banks to borrow. But banks were reluctant to borrow from the discount window and there was little response. Then in December 2007—four months after the crisis began—the Fed introduced a major new lending facility, the Term Auction Facility (TAF), through which banks could borrow from the Fed without using the discount window. The Fed then increased the size of the TAF several times in the ensuing months.[1]

[1] The general stress in the financial markets also gave rise to other Federal Reserve actions that focused on investment banks and institutions other than depository institutions In March 2008 the Fed created a new

The purpose of this paper is to examine alternative explanations for these unusual developments in the money markets and to evaluate the impact of policy actions taken to address them. We use the framework of a no-arbitrage model of the term structure of interest rates which explicitly builds in both expectations of future short term rates and risk factors. Rather than estimate a structural model we test alternative hypotheses using a variety of market-based measures of expectations and risk, which we draw from derivative securities markets before and after the crisis. As explained below, we measure interest rate expectations using daily data on overnight index swaps (OIS) and we measure risk using credit default swaps (CDS), spreads between interbank interest rates on unsecured lending (Libor) and interest rates on secured lending through repurchase agreements (Repo), and spreads between rates on the Tokyo interbank market (Tibor) and Libor.[2] We begin by reviewing developments during the period beginning August 9, 2007.

I. The Break Point on August 9, 2007

Figure 1 focuses on three money market interest rates which nicely illustrate the abrupt change in the interbank market starting in August 2007: (1) the *target* for the overnight federal funds interest rate set by the Fed, (2) the daily *effective* overnight

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Term Securities Lending Facility (TSLF) and a Primary Dealers Credit Facility (PDCF) providing loans to primary dealers and thereby the major investment banks. In March 2008 the Fed also announced a package to assist in the acquisition of Bear Stearns by JP Morgan. In July the 2008 the Fed offered to open the discount window to Fannie Mae and Freddie Mac. Studying the causes of the stress in these markets and the impact of these other Fed actions is an important task for future research but conceptually separate from our focus in this paper on the interbank lending markets. See Stephen Cecchetti (2008) for a discussion of these other development and events leading up to the crisis. In September 2008, just after this paper was completed, the spread took another jump upwards and the Fed and other central banks responded in many other ways as summarized in the postscript to this paper.

[2] Interest rate, OIS, and CDS data were downloaded from Bloomberg and are updated through August 8, 2008. TAF data were compiled by the authors. Data are available upon request from the authors.

federal funds rate in the market, and (3) Libor for 3-month maturity loans. Libor is very close to the interest rate on term fed funds for comparable maturities, so we focus solely on the former in the charts in this paper. However, questions have been raised about the accuracy of the Libor survey during this period (see Carrick Mollenkamp, 2008). We therefore use the interest rate on term federal funds and on certificates of deposit as well as Libor in our formal statistical tests reported later in the paper. The 16 major banks that participate in the Libor survey for dollar-denominated loans are reported in the Appendix (Table 1, Column 1).

Observe in Figure 1 that the volatility of the effective federal funds rate relative to the target increased after August 9, 2007. The steadiness of the federal funds rate at 5.25 percent before August could have been the reason for the smaller volatility, but if you include the years back to 2002 the volatility is still much less than after August 2007. As discussed in Taylor (2001) the volatility was higher in the early 1990s, but that was before the Fed started announcing targets for the federal funds rate.

The main focus of our paper, however, is on how the 3-month Libor diverged from the Fed's overnight federal funds rate starting in August and this spread remained high and volatile after that. During the year before August 9, 2007, the 3-month Libor spread above the target federal funds rate averaged only 11 basis points with a standard deviation of a mere 1 basis point—a period of very low volatility. Similar changes in spreads between term rates and overnight rates are apparent for other Libor maturities and for several other countries, as we document below.

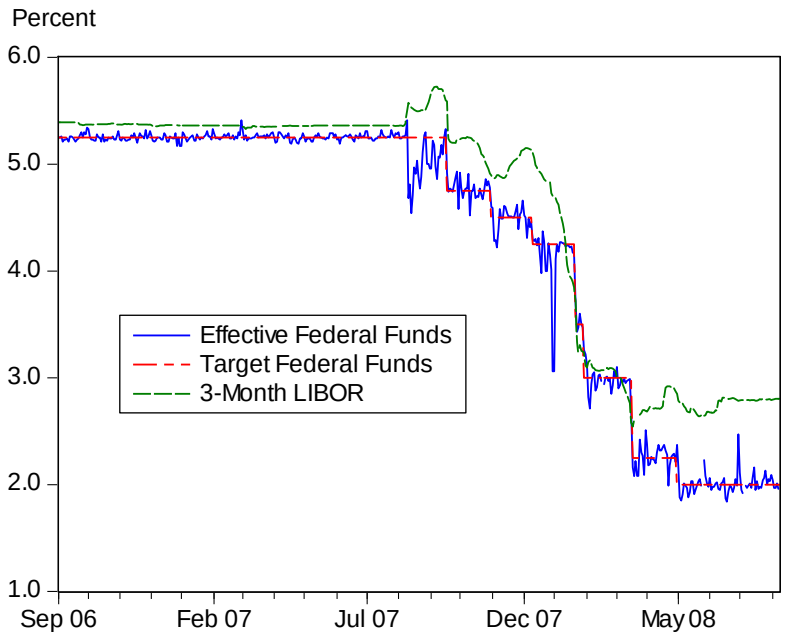

Figure 1. Key money market rates from September 2006 to August 2008

II. Potential Explanations

Ever since the financial turmoil began, traders, bankers, economists, and others have offered explanations for the dramatic increase in the Libor spread. One explanation is that there was an increase in "counterparty risk," which simply means banks became more reluctant to lend to other banks because of the perception that the risk of default on the loans had increased and/or the market price of taking on such risk had risen. Lending between banks in the Libor, CD, and term fed funds markets is unsecured. This explanation reflects the fact that many banks were writing down their loans and securities because they had either been downgraded or because they were backed by mortgages with delinquent payments or foreclosed properties. Clearly, the continuing decline in housing prices and the slowing economy raised the chances of a further deterioration of

banks' balance sheets. Moreover, the realization of the risks in derivative securities based on sub-prime mortgages triggered doubts about other aspects of the derivative market, including the ability of credit default insurers to meet their obligations and the size and nature of the likely restructuring of the off-balance sheet operations known as structured investment vehicles.

Another competing explanation is that there was an increased demand for, or shortage of, "liquidity." Indeed, liquidity was one of the most common explanations given to us by market participants in interviews we conducted early in the crisis, and many at that time thought that liquidity was a more serious problem than counterparty risk. Liquidity is not always defined the same way by different market participants, and indeed the concept is illusive. The way the liquidity story usually is told is that traders at one bank were reluctant to expose the traders' bank's funds during a period of time when those funds might be needed to cover the bank's own shortfalls. Effectively, the trader may not be given as much "balance sheet" to invest, which is perceived as a shortage of liquidity to the trader.

One simple way to understand this liquidity problem and perhaps even discriminate between liquidity and counterparty risk is to look at rates paid when parties other than banks lend to banks, as in the market for certificates of deposit (CD). As shown in Figure 2, the interest rate on CDs, which are also held by individuals and non-banks, follows Libor closely during the period of the crisis. As long as lenders exist who are not constrained by liquidity concerns, banks who seek to hoard liquidity can borrow from these lenders in the CD market. Indeed, large time deposits like CDs with a term of one year or less are a major source of bank deposits. Competition will lead to the

equalization of borrowing rates across instruments for borrowers of the same credit quality. That CD rates have tracked Libor closely during the crisis, as shown in Figure 2, suggests that liquidity concerns at banks are not a significant factor separate from counterparty risk driving term lending rates, but we will test this hypothesis more explicitly below.

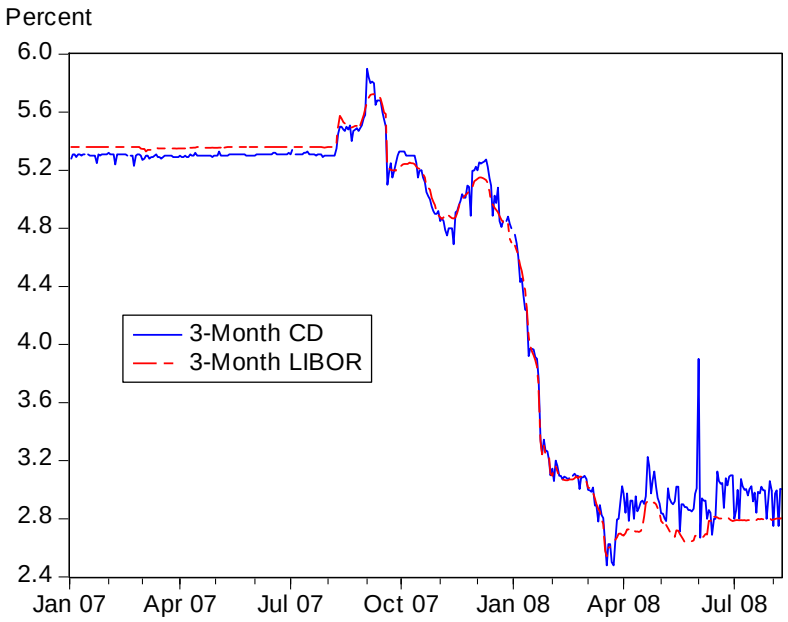

Figure 2. Libor and interest rates on CDs

Another explanation was often heard during the period of November 2007 through January 2008. It was that banks needed liquidity to make sure that their own balance sheets looked respectable in end-of-year financial reports, especially given the stress and scrutiny that many banks had been under. However, as the year-end 2007 drifted into the past and the spread remained high during the spring and summer of 2008,

this explanation was given less credence, though it clearly could explain some movements in spreads during part of the crisis period.

III. A Theoretical Framework and the Libor-OIS Spread

In order to distinguish between these explanations we need a theoretical framework through which we can study the different money market interest rates. Early models of the money market used for monetary policy developed in the1970s and 1980s (see Richard Anderson and Robert Rasche, 1982) are not sufficient for this purpose because they do not account for either expectations or risk. Moreover these models used estimated demand functions for securities, an approach that is not practical now because we do not have transactions data for the term interbank markets. However, due to the emergence of many new derivative products, there are now much more data on prices and yields which can be used to measure expectations and risk. And recent models of arbitrage-free pricing (see Andrew Ang and Monika Piazzesi, 2003) are more useful than the earlier models because they explicitly take expectations and risk into account. Following this literature, we can describe the term structure between Libor and overnight Fed funds.

Let $i_t^{(n)}$ = Libor with maturity n (with $n = 1$ the overnight federal funds rate) and let $P_t^{(n)}$ denote the price of a zero-coupon loan with n periods until maturity corresponding to this interest rate $i_t^{(n)}$ as defined in equation 1. The prices of zero-coupon loans follow the recursion given in equation 2, where m_{t+1} denotes the pricing kernel or stochastic discount factor. As in Ang and Piazzesi (2003), this pricing kernel takes the functional form shown in equation 3, where ε_t is a zero mean random variable and λ_t is the "market

price of risk" which we assume takes the linear form shown in equation 4, where x_t is a vector of variables that might influence risk. Equation 3 and 4 together are a convenient way to incorporate risk into the term structure relations. To see this, first note that if λ_t is zero then these equations boil down to the pure expectations hypothesis of the term structure in which only expectations of future short term interest rates matter for the current yield on longer term securities. If λ_t is not zero, then the risk factors enter into the determination of longer term yields.

(1) $i_t^{(n)} = -n^{-1} \log(P_t^{(n)})$

(2) $P_t^{(n+1)} = E_t[m_{t+1} P_{t+1}^{(n)}]$

(3) $m_{t+1} = \exp(-i_t^{(1)} - 0.5\lambda_t^2 - \lambda_t \varepsilon_{t+1})$

(4) $\lambda_t = -\gamma_0 - \gamma_1 x_t$

These relations imply that Libor at maturity *n* is a function of expectations of the average of future overnight rates and the risk factors over the next *n* days. We use the overnight index swap (OIS) to measure this average of expected overnight interest rates. An OIS is structured as follows: at maturity, the parties exchange the difference between the interest that would be accrued from repeatedly rolling over an investment in the overnight market and the interest that would be accrued at the agreed OIS fixed rate. In contrast to Libor loans, OIS transactions involve little counterparty risk as no money changes hands until the maturity date. The only potential loss in the case of default by the counterparty is the difference between the two interest rates on which the OIS is based. There does exist

interest rate risk reflecting uncertainty regarding the future path of interest rates. However, given the relatively short maturities of loans that we study, the market price of interest rate risk is likely to be very small. Thus, if we let

$s_t^{(n)}$ = OIS with maturuity n (with $n = 1$ also the overnight federal funds rate; that is $s_t^{(1)} = i_t^{(1)}$)

then equations similar to (1) through (4) can be written down for the OIS except that the market price of risk is negligible. In other words, the OIS rate equals the average of the overnight interest rates expected until maturity. Hence, by subtracting the OIS rate from Libor, we are able to remove expectations effects.

Taking out these expectations is essential if we are to understand whether risk or liquidity changes the spreads. Expectations of declining overnight rates, for example, will cause term Libor to decline as well, all else equal. Hence for the first part of the crisis period, expectations effects would tend to reduce the spread between Libor and the target fed funds rate because of expectations of future interest rate declines due to policy easing. For example, if you look closely at Figure 1 you see that the spread between Libor and the fed funds target comes down before cuts in the federal funds target. Indeed, in mid February, the spread narrowed significantly, and this was probably due to expectations of larger future interest rate cuts.

Under the null hypothesis that this model holds there is no additional liquidity effect, and the resulting difference in rates, $i_t^{(n)} - s_t^{(n)}$, reflects only the pricing of risk associated with Libor lending relative to the constant price of risk associated with OIS transactions. Similarly, under this null hypothesis, lending facilities which require backing by collateral, such as the Fed's term auction facility (TAF), would not be expected to influence the λ_i for the inter-bank rates.

For the remainder of this paper we focus on this difference in yields, $i_t^{(n)} - s_t^{(n)}$, and test, using reduced-form regressions, whether it is influenced by risk factors, as the theoretical framework suggests it should, and by liquidity factors, which the theoretical framework suggests it should not.

Figure 3 plots this spread $i_t^{(n)} - s_t^{(n)}$ using daily data on three month Libor and three month OIS from December 2001 to August 2008, Figure 3 paints quite a different picture of the spread than does Figure 1, and it clearly shows the value of removing expectations of future interest rates in analyzing term spreads. For example, looking at Figure 1 you might think the spread returned to normal by mid February 2008. However, examination of Figure 3 shows that the spread was still quite large.[3]

Figure 3 shows how the spread between Libor and OIS jumped on August 9th. From December 4, 2001—the day when our OIS 3-month data begin—through August 8, 2007, the spread averaged 11 basis points with a standard deviation of about 4 basis points. It then rose sharply on August 9th and on subsequent days, eventually peaking at over 100 basis points by early December 2007. This was followed by big downward movements in mid-December 2007 and in mid-January 2008, but the spread rose again in March 2008 and has remained elevated through August 2008. Looking at spreads going back to December 2001 illustrates just how unusual this episode has been. The spread averaged about 67 basis points from August 9, 2007 to August 8, 2008, about 17 times the 4 basis points standard deviation before the crisis—a 17-sigma event.

[3] In this chart and in the rest of our analysis we focus on 3-month Libor; similar results are found by looking at other maturities such as one-month Libor.

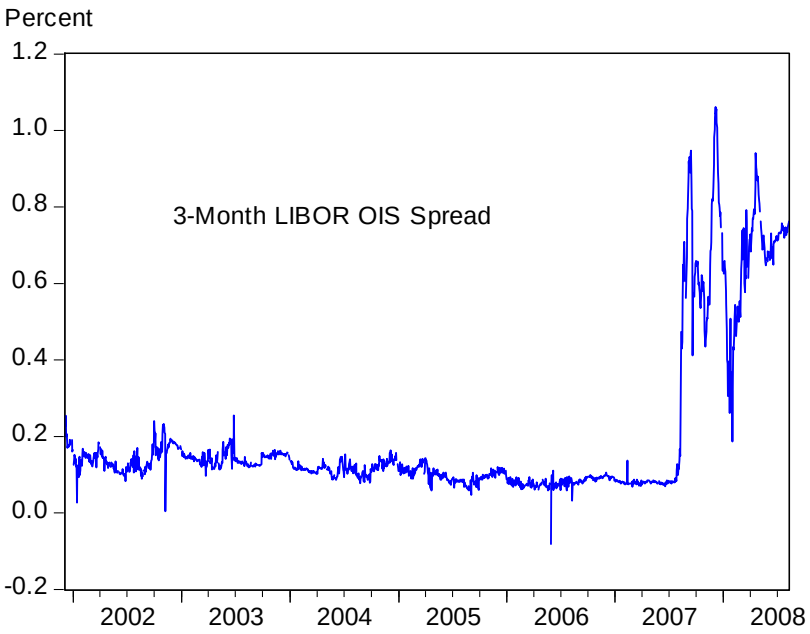

Figure 3. A Black Swan in the Money Market?

The turmoil affecting money markets was not limited to the United States. Spreads between term and overnight inter-bank lending also rose in the Euro area and in the U.K. at the same time as in the United States. Figure 4 shows the Libor-OIS spreads in Euros and Sterling along with dollar Libor-OIS spread since 2004. All three spreads move closely together, indicating that whatever the source of these spreads, it is affecting money markets for all three currencies in the same way. This close correspondence in spreads is not as surprising as it first may appear, because there is considerable overlap in the lists of banks (see Appendix Table 1) that are included in the Libor survey in these three countries.[4]

[4] Libor denominated in Swiss francs follows a different pattern because the Swiss National Bank targets the three-month Libor rate and adjusts the amount of liquidity in the overnight market to hit its target as discussed in Jordan and Kugler (2004). For a theoretical analysis of such a policy framework, see

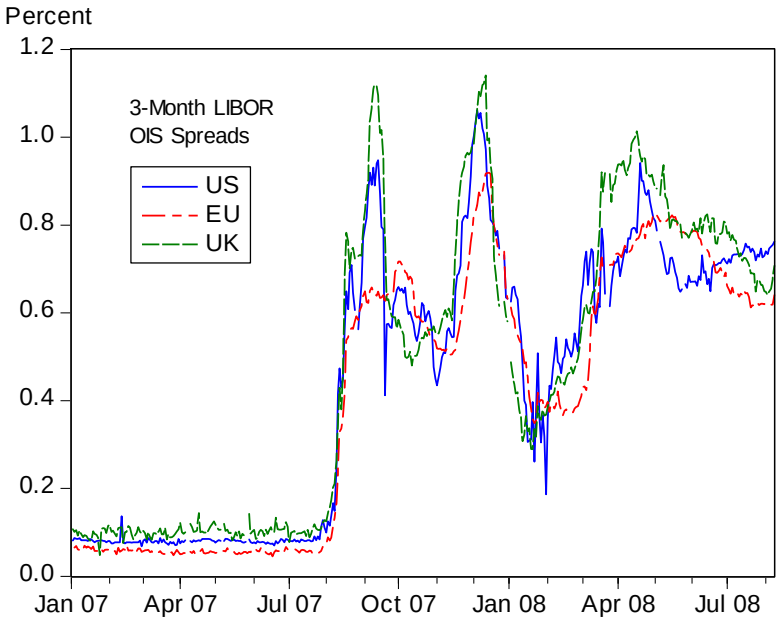

Figure 4. The Libor-OIS spread increased in three major currencies in August 2007

IV. Market-Based Measures of Counterparty Risk

In this section, we consider three market-based measures of counterparty risk in the U.S. banking sector. By including these measures in a regression with the Libor-OIS spread on the left hand side we hope to test whether such risks, rather than more general liquidity concerns, were the main reason for the increased spread in the interbank markets.

Credit Default Swaps. One potential measure of counterparty risk is the probability that banks might default on their debt. These probabilities can be assessed

McGough, Rudebusch, and Williams (2005). However, the same evidence of risk emerges if one looks at the spread between the term rates and the overnight rates.

using the premiums on credit default swaps (CDS) which are like insurance policies for corporate bonds. The buyer of a credit default swap pays a periodic fee to a seller in exchange for the promise of a payment, in the event of bankruptcy or default, of the difference between the par value and the market value of the corporate bond.

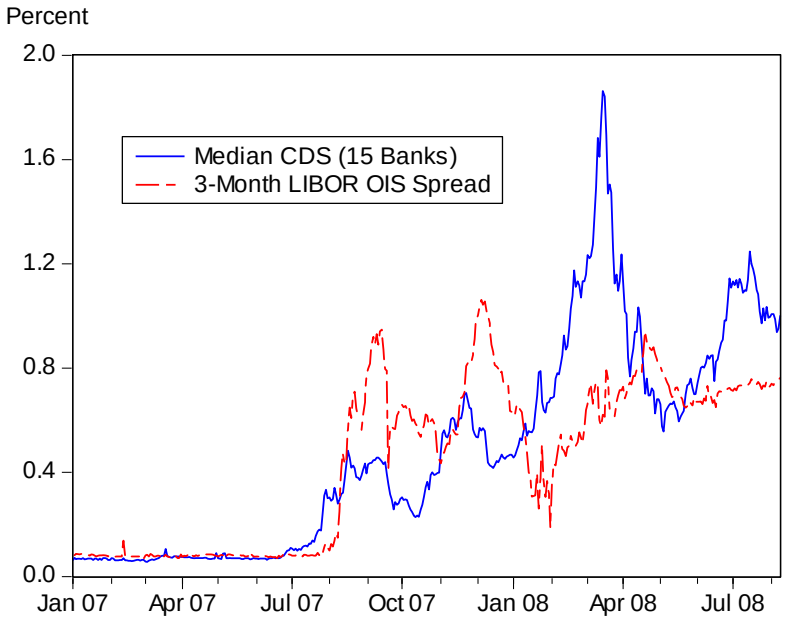

Figure 5. The Median Rate on Credit Default Swaps for 15 Banks in Libor.

Figure 5 shows the median five-year CDS annual rate for 15 of the 16 banks in the U.S. dollar Libor survey starting in January 2007.[5] Observe that by this measure, counterparty risk rose starting in the summer of 2007 and looks like a good candidate for explaining the increase spreads at that time. The large spike in the CDS market occurred during the period of the Bear Stearns crisis in March 2008. Following JP Morgan's

[5] We were not able to obtain CDS data for the 16th bank in the Libor survey, the Royal Bank of Canada. For several of the banks there are days when the CDS rates are missing. On dates with missing data we take the medina of the CDS rates of the banks for which we have data. We also examined using the medina CDS rates for the seven banks in the Libor survey for which there are no missing data. The results are qualitatively similar to those reported here.

purchase of Bear Stearns CDS rates fell, but then rose again and remained high through the summer of 2008, reflecting investor concerns regarding the conditions of the major banks in the Libor survey.

The Libor-Tibor Spread. A second market-based measure of risk in the U.S. banking sector can be constructed by comparing Libor with interest rates on inter-bank loans for a different group of banks that are potentially less directly affected by the problems related to U.S. mortgage-related securities afflicting the banks in the Libor survey. A natural candidate for such a measure is the inter-bank loan market in Japan in which many non-U.S. and non-European banks participate. The Tokyo Inter-Bank Offered Rate (Tibor) pertains to the interest rate on yen-denominated loans in the Japanese interbank market. It is computed from the same kind of survey used to compute Libor except that the banks in the survey are mainly Japanese banks. There is also a yen-denominated Libor survey in which most of the participants are the same banks as in the dollar-denominated Libor survey. The banks participating in the two surveys are listed in the Appendix Table 2.

The spread between Libor denominated in yen and Tibor denominated in yen thus provides an independent measure of counterparty risk for the banks in the U.S. dollar Libor survey, relative to that of the banks in the Tibor survey. Figure 6 shows these two rates since the mid 1990s. Note that the chart shows the yields themselves, not spreads. Japanese interest rates have been much lower than interest rates in the United States, Europe or the UK over this period. Nonetheless, spreads can and do develop between different types of inter-bank lending and indicate risk factors in the banking sector. Figure 7 shows the spread between yen-denominated Libor and Tibor. Observe that in

the late 1990s, Japanese banks experienced sizable spreads on inter-bank lending comparable to what has been experienced in New York and London during the recent crisis. As explained by Joe Peek and Eric Rosengren (2001) and Vincentiu Corvig, Buen Sin Low, and Michael Melvin (2004), risks in the banking sector in Tokyo caused interest rates on inter-bank loans to rise in Tokyo compared with London. In other words, Tibor rates rose relative to Libor rates, as seen in Figure 7..

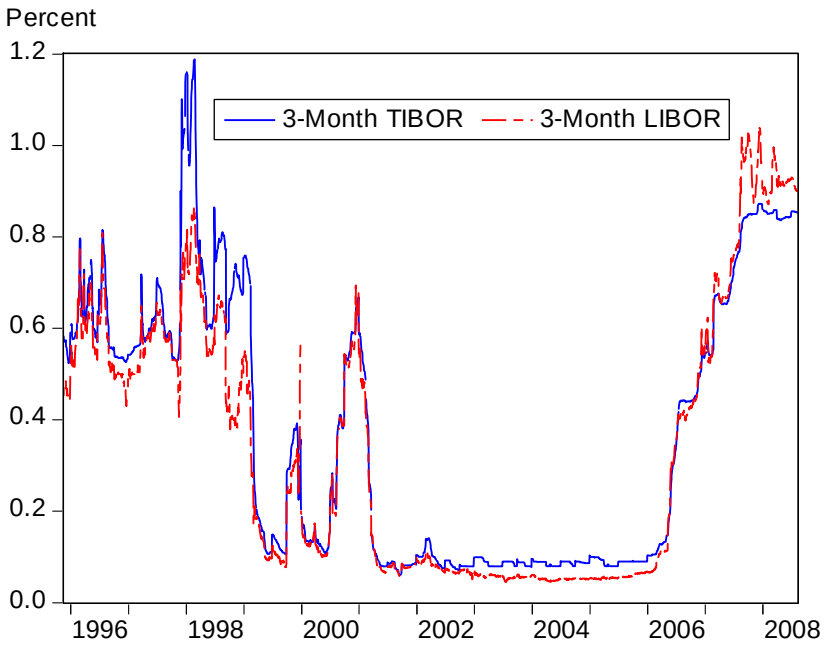

Figure 6. Tibor and Libor for yen-denominated loans since the mid 1990s

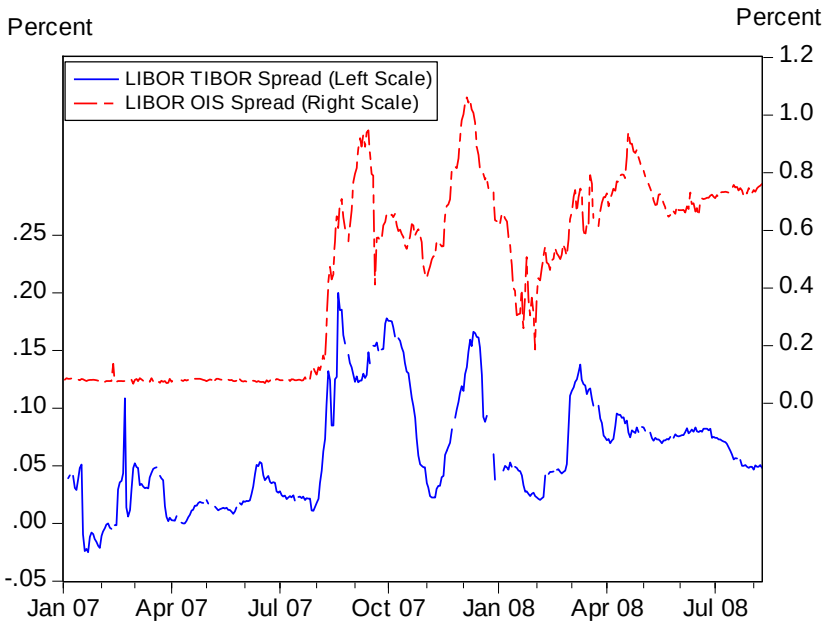

Figure 7. The Spread between Libor and Tibor for yen-denominated loans

This pattern of Libor-Tibor spreads has reversed during the recent crisis, with Tibor rates now lower than corresponding Libor rates. In our view, the most likely explanation is that the risks associated with inter-bank loans from American and European banks have increased relative to those for loans among Japanese banks. Accordingly, the "negative Japan premium," or "Japan discount," provides another measure of counterparty risk among banks in New York, London, and Frankfurt. To be sure, one could argue that the demand for liquidity has not risen as much for Japanese banks as for the major banks in these other markets, but given anecdotal and other information that the balance sheets deteriorated more in the other countries than in Japan we feel that differences in risk factors are more plausible.

Libor-Repo Spreads. A third market-based measure of risk is the spread between interest rates on unsecured and secured lending in the interbank market. The greater the risk of nonpayment of the loan, the higher the spread should be, all else equal. Repurchase agreements (Repos) between banks backed by Treasury securities are a form of secured lending. In contrast, Libor (as well as term fed funds and CDs rates) measures the interest rate on unsecured loans. Hence the spread between Libor and Repo rates of the same maturity is effectively the spread between unsecured and secured loans, a natural measure of counterparty risk. Figure 8 shows this spread starting in January 2007. Though there is more noise in this spread than in the Libor-OIS spread, it clearly turns up about the same time as the Libor-OIS spread. Traders we have consulted attribute the noise to technical factors such as tax considerations and collateral delivery glitches.

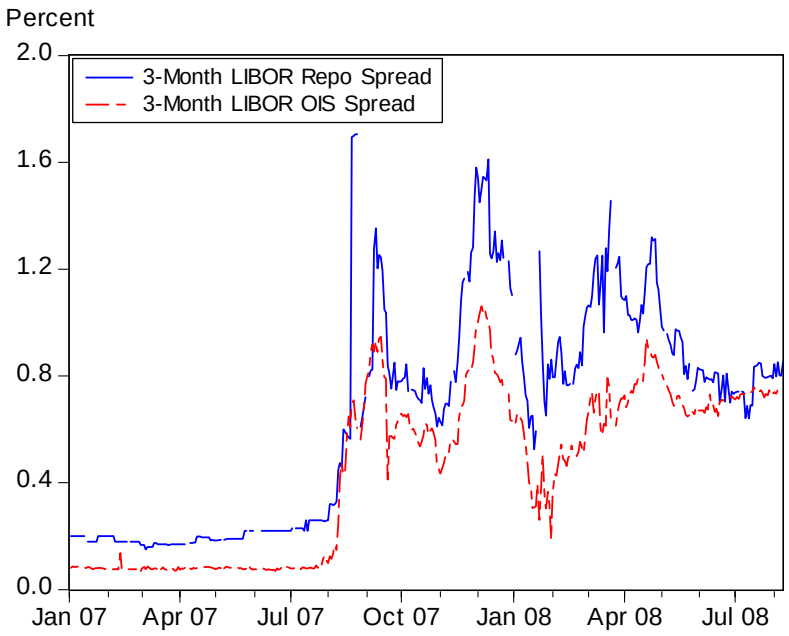

Figure 8. The Libor-Repo spread

V. Liquidity Effects and the Term Auction Facility

The term auction facility (TAF) created by the Federal Reserve in December 2007 was aimed specifically at providing liquidity directly to financial institutions in order to improve the functioning of the money markets and drive down the spread on term lending relative to overnight loans. According to the Federal Reserve Board, by injecting "term funds through a broader range of counterparties and against a broader range of collateral than open market operations, this facility could help ensure that liquidity provisions can be disseminated efficiently even when the unsecured interbank markets are under stress" (Board of Governors of the Federal Reserve, 2007). Hence, the TAF is a natural candidate to test for liquidity effects in the term structure.

The TAF allows financial institutions to make bids for term borrowing from the Fed, with maturities of typically 28 days.[6] Beginning in late December of 2007, two TAF auctions have been held each month. Table 1 provides key information about each of the auctions. TAF loans are collateralized following the procedures used for discount window borrowing from the Fed. The Board of Governors sets the auction amount and the minimum bid allowed for the interest rate, which is set equal to the OIS rate corresponding to the term of the loan. The interest rate on the loans is determined in a single-price auction and is reported as the stop-out rate in Table 1.

[6] TAF loans with an 84 day maturity were instituted in August 2008, outside the sample of our analysis.

Table 1
Term Auctions Facility (TAF)

Day of Bid	Day of Settlement	Term (days)	Amt ($B)	Min. Rate	Stop-out Rate	1-Month Libor	Bid/Cover Ratio
12/17/07	12/20/07	28	20	4.17	4.650	4.949	3.08
12/20/07	12/27/07	35	20	4.15	4.670	4.865	2.88
01/14/08	01/17/08	28	30	3.88	3.950	4.023	1.85
01/28/08	01/31/08	28	30	3.10	3.123	3.271	1.25
02/11/08	02/14/08	28	30	2.86	3.010	3.128	1.95
02/25/08	02/28/08	28	30	2.81	3.080	3.125	2.27
03/10/08	03/13/08	28	50	2.39	2.800	2.890	1.85
03/24/08	03/27/08	28	50	2.19	2.615	2.654	1.78
04/07/08	04/10/08	28	50	2.11	2.820	2.722	1.83
04/21/08	04/24/08	28	50	2.05	2.870	2.895	1.77
05/05/08	05/08/08	28	75	2.00	2.220	2.674	1.29
05/19/08	05/22/08	28	75	1.99	2.100	2.430	1.13
06/02/08	06/05/08	28	75	2.00	2.260	2.451	1.28
06/16/08	06/19/08	28	75	2.05	2.360	2.483	1.19
06/30/08	07/03/08	28	75	2.01	2.340	2.461	1.21
07/14/08	07/17/08	28	75	2.01	2.300	2.458	1.24
07/28/08	07/31/08	28	75	2.01	2.350	2.463	1.21

Notes: The 1-month labor rate refers to the rates on the day after the TAF bids were submitted. The bid/cover ratio is the ratio of the total dollar amount of bids at or above the minimum bid rate divided by the dollar amount being auctioned.

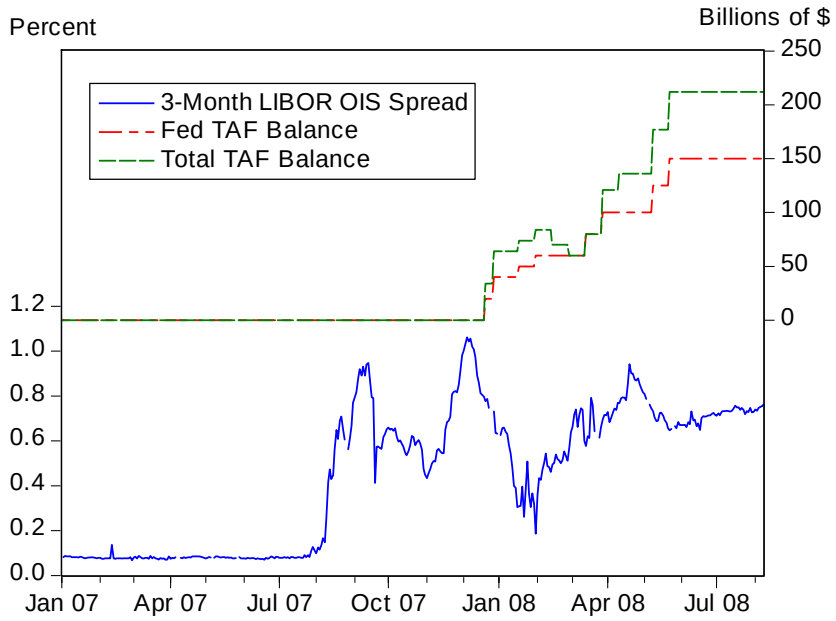

Figure 9. Outstanding amounts of TAF loans and the Libor-OIS spread

At the same time that the TAF was introduced, other central banks, including the Bank of Canada, the Bank of England, the European Central Bank (ECB), and the Swiss National Bank (SNB), also took measures to increase term lending. The ECB and SNB launched their own term auction facilities starting in December of 2007. These auctions are summarized in the Appendix. The total volume of outstanding TAF loans, including those from the Federal Reserve, ECB, and SNB is shown in Figure 9 along with the amount from the Federal Reserve TAF auctions alone. The ECB and SNB TAF auctions were halted for a while early in 2008 before starting up again with larger auction amounts in March 2008.

In assessing the effects of the TAF, it is important to note that it does not increase the amount of liquidity in the sense of total bank reserves or total "high powered money." Any increase in this kind of liquidity that comes from banks borrowing from the Fed

using the TAF will be offset by open market sales of securities by the Fed to keep the total supply of reserves from rising rapidly. The actions are essentially automatic in the sense that the Fed must sell securities to keep the overnight federal funds rate on target. Figure 10 shows that this is indeed what has happened under the TAF. The System Open Market Account reduced its outright holdings of securities (light blue area) as the amount of TAF lending (dark blue area) increased. Nevertheless, the view of many in the financial community has been that the TAF could ease some of the liquidity problems in the interbank market by providing banks with access to term lending secured with illiquid collateral absent the stigma traditionally associated with discount window borrowing, and thereby lower the spreads in that market.

Early reports on the effectiveness of the TAF were generally favorable. As seen in Table 1, all TAF auctions have been oversubscribed to date and the TAF stop-out rate has generally been well above the prevailing one-month OIS rate, indicating substantial demand for TAF borrowing.[7] Moreover, as noted above, Libor-OIS spreads fell sharply between late December and February. As a result, central bank officials and others judged that the TAF was working. For example, Frederic Mishkin (2008), speaking as a Governor of the Federal Reserve Board in mid February of 2008 and noting the decline in the term spread, stated that "the TAF may have had significant beneficial effects on financial markets….term funding rates have dropped substantially relative to OIS rates: The one-month spread exceeded 100 basis points in early December but has dropped below 30 basis points in recent weeks--though still above the low level that prevailed

[7] The spread between the auction stop-out rate and the minimum bid rate fluctuated between 2 and 82 basis points over the first dozen TAF auctions. Since then, this spread has been relatively stable at around 30 basis points, just above the contemporaneous discount window penalty rate of 25 basis points (above the target fed funds raet).

before the onset of the financial disruption last August." See also Board of Governors (2008) for similar comments regarding the purpose and early evaluation of the effects of the TAF. Soon thereafter, however, the spread widened again, and as shown in Figure 9, the spreads have remained high even as the outstanding amount of TAF loans has risen dramatically.

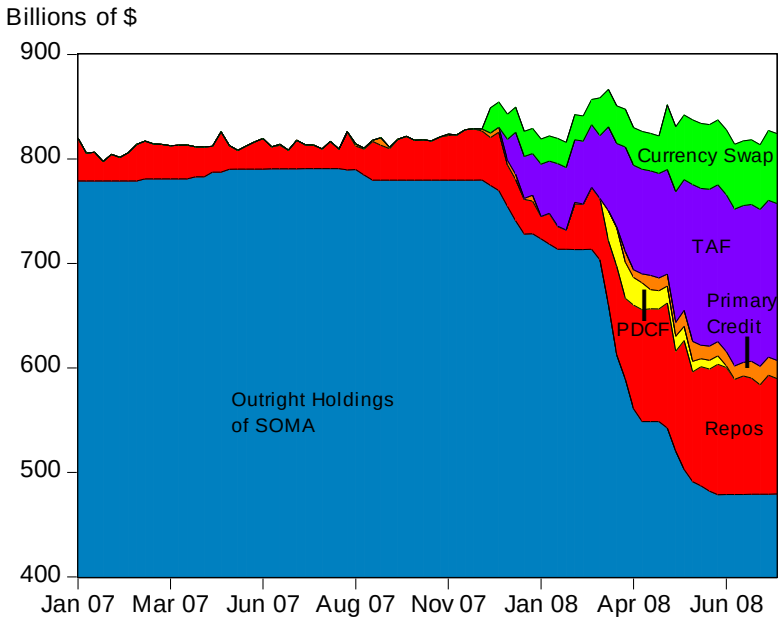

Figure 10. TAF did not increase the total amount of liquidity

VI. Econometric Tests

In this section, we test whether the risk measures and liquidity provisions of the TAF affect the Libor-OIS spread. The no-arbitrage term structure model described in this paper implies that risk measures should affect the spread and the TAF should not. To be sure, by focusing on the impact of the TAF on the spread we do not mean to imply that the Federal Reserve did not have other goals in creating the TAF, including reducing the

stigma associated with discount window borrowing by banks. Nevertheless, reducing the spread was one of the purposes of the TAF and one of the ways suggested to measure its success.

Our tests are performed using regressions with a wide range of specifications as summarized in Tables 2 through 6 in which standard errors with a Newey-West correction are reported in parentheses. In each regression we use daily data, as presented in the charts above, during the sample period from January 2, 2007 through August 8, 2008, a span of time that includes both the market turmoil period and the period leading up to the turmoil. The dependent variable is the three-month Libor–OIS spread, though for the reasons discussed earlier we also use the 3-month term federal funds rate spread over OIS and the CD rate spread over OIS as robustness checks. The independent variables are various measures of counterparty risk, including the median CDS rate, the Libor-Tibor spread, and the Libor-Repo spread. Each regression also includes a constant and measures of the TAF.

The main findings are presented in Tables 2 and 3 where the TAF is measured with five dummy variables, with one dummy variable set to 1 on the day of a TAF auction and the other four set to 1 on each of the four days following the auction. In our initial working paper (Williams and Taylor, 2008a) we used only a single dummy on the day of the auction; our current approach is more robust as it does not take a position on which exact day the effects take place. This specification is most appropriate when the effects of a TAF auction on spreads diminish over time. Below we consider specifications that allow for permanent effects of the TAF on spreads. For each of the risk measures, we report OLS regressions in Table 2 and regressions corrected for first-order serial

correlation (AR(1)) in Table 3 with the estimated serial correlation coefficient ρ reported.[8] To save on space, the estimated constants are not reported.

In all cases, the risk measures enter with the correct sign and are usually highly significant. The results are robust across the three different measures of the dependent variable and the three different measure of counterparty risk.[9] Based on the results reported in Table 2, a one percentage point increase in the median CDS rate is associated with between a 0.56 and 0.69 percentage point increase in spreads, indicating that variation in CDS rates has economically large estimated effects on spreads in our sample. Note that the corresponding estimated coefficients on the Libor-Tibor spread are relatively large. This finding is not surprising given the fact that the Libor-Tibor spread reflects risk in the Libor sample *relative* to that in the Tibor sample, rather than the absolute level of risk. The Tibor survey includes several banks in the Libor sample and the other banks in the Tibor survey were likely to have been affected somewhat by movements in counterparty risk that affected major international banks. As a result, the movements in the Libor-Tibor spread understate the magnitude of movements in the absolute level of counterparty risk, as seen by comparing CDS rates and the Libor-Tibor spread, shown in Figures 5 and 7, respectively. In summary, despite the doubt expressed by many people in the markets, especially in the early states of the crisis, that

[8] In all the regressions reported in this paper, the following timing conventions are followed. Because the Libor survey is taken late in the morning in London, in regressions where the Libor spread is the dependent variable, all other variables in the regression equation (including the OIS rate) are lagged by one day to reflect the difference in timing between London and New York. For the regressions where term fed funds and CD spreads are the dependent variable, only the TAF variables are lagged by one day, reflecting the fact that TAF press releases are released late in the morning, after bank lending rates have been set.

[9] The estimated coefficients on the risk measures are smaller in the AR(1) regressions, which may reflect high-frequency measurement error, reflecting timing and compositional differences between the independent variable and the measures of counterparty risk..

counterparty risk as distinct from liquidity was driving the spreads, the regression evidence is robust as well as statistically and economically significant.

In contrast, the liquidity provisions, measured by the sum of the TAF dummy variable coefficients, do not show robust significant effects. As seen in Tables 2 and 3, the signs of the sum of the TAF coefficients are in some cases positive and in other negative. In no case of this regression specification do we find that the estimated sum of coefficients on the TAF variables is both negative and statistically significant. Note that if the TAF grew to be so large that a significant number of banks facing high borrowing rates completely dropped out of the interbank market in favor of borrowing from the TAF, we might expect to see some reductions in spreads based on CD and term fed funds rates due to such a compositional effect. (The Libor survey sample did not change during our sample so Libor spreads should not be influenced by a compositional effect.) However, even at the current size of the TAF, it is most likely too small compared to the overall interbank market to have such significant compositional effects. In any case, we do not find such effects with our regressions. The common theme of these results is that (1) one can easily reject the null hypothesis that the counterparty risk factors are not significant in the Libor OIS spread and (2) one cannot reject the null hypothesis that the liquidity provisions of the TAF have no effect.

Since our initial working paper on this subject others have run similar regressions to test for the impact of the TAF, but have used alternative specifications and dummy variables for the TAF. For example, Tao Wu (2008) defined a TAF dummy that equals 0 before the TAF was first announced on December 12, 2007 and 1 since then. This specification is based on the hypothesis that the introduction of the TAF would

permanently reduce liquidity risk affecting inter-bank lending markets. Based on a shorter sample than ours and using a different measure of counterparty risk, Wu found that such a dummy variable indicated a significant and negative effect of the TAF, reflecting the decline in spreads near the end of 2007 and in early 2008.[10] We consider such a specification using our risk measures. Table 4 shows the results using data that goes through August 8, 2008.

Observe that the OLS regressions do not show a significant negative impact and are sometimes significantly positive (spuriously we presume), reflecting the unusually high spreads since March 2008 despite the existence of the TAF. In Table 5 we report results where the TAF dummy variable is defined as in Wu (2008), but for the AR(1) regressions. For this specification we find small negative and significant effects of the TAF on the Libor-OIS spread, with the estimated effect of the TAF never more negative than -8 basis points. But, these findings of a negative effect of the TAF on spreads are not robust to other two measures of the dependent variable. These results suggest that the TAF has had little or no permanent effect on bank lending spreads.

Another alternative to our initial regressions was suggested by James McAndrews, Asani Sarkar, and Zhenyu Wang (2008) who defined the TAF dummy in yet another way. The primary innovation in their work, which has subsequently been used by William Dudley (2008), is to focus on the changes in spreads on days of announcements and auction operations related to the TAF. In one of their specifications, they also include the lagged spread in the regressions rather than an AR(1) specification and include a dummy variable for the dates of major TAF announcements and a dummy

[10] Brian Sack and Laurence Meyer (2008) analyze a similar specification and obtain results consistent with Wu (2008).

variable for the dates of TAF operations (typically the dates that auctions are announced, bids are collected, and results are announced). They set the TAF announcement dummy to 1 on the days that the TAF was first announced and on other days of major TAF-related announcements, such as when the size of the TAF auction was increased. They found that both these announcement dummies and the operations dummies had a significant negative effect on the spread.

In Table 6, we replicate their main results for the period going through August 8, 2008. However, we find that the results are not robust to using alternatives to the Libor measure, which, as discussed above has been criticized for its accuracy during the crisis period (Mollenkamp, 2008). For both the term fed funds variable and the CD spread variable, the TAF announcement coefficients are statistically insignificant and. In addition, the evidence for a significant effect of TAF auctions on spreads depends on the particular choice for the TAF operations dummy variable. To examine the robustness of the results regarding the TAF operations variable, we report results for a modified TAF operations dummy variable that includes TAF operations as defined above and the dates on which auctions are settled (that is, the day the loans are distributed). In all cases, the estimated effect of this dummy variable is smaller than found using the McAndrews, Sarkar, and Wang (2008) specification and is statistically insignificant, indicating that results regarding the effects of TAF operations are not robust to relatively small changes in specification.

Table 2
Alternative OLS Regression Specifications

	(1)	(2)	(3)
	Panel A. Libor-OIS		
Median CDS	0.56		
	(0.07)		
Libor-Tibor Spread		4.58	
		(0.45)	
Libor-Repo Spread			0.70
			(0.04)
TAF Dummies			
(sum of coefficients)	-0.09	0.93	0.07
	(0.27)	(0.18)	(0.15)
Adj. R^2	0.52	0.59	0.84
	Panel B. Term Fed Funds-OIS		
Median CDS	0.62		
	(0.09)		
Libor-Tibor Spread		4.59	
		(0.52)	
Libor-Repo Spread			0.73
			(0.05)
TAF Dummies			
(sum of coefficients)	0.21	1.38	0.47
	(0.32)	(0.21)	(0.18)
Adj. R^2	0.57	0.54	0.80
	Panel C. CD-OIS		
Median CDS	0.69		
	(0.10)		
Libor-Tibor Spread		5.28	
		(0.55)	
Libor-Repo Spread			0.81
			(0.06)
TAF Dummies			
(sum of coefficients)	0.14	1.45	0.45
	(0.31)	(0.23)	(0.24)
Adj. R^2	0.52	0.53	0.75

Table 3
Regressions with First Order Autoregressive Errors

	(1)	(2	(3)
	Panel A. Libor-OIS		
Median CDS	0.15		
	(0.08)		
Libor-Tibor Spread		0.53	
		(0.26)	
Libor-Repo Spread			0.08
			(0.04)
TAF Dummies			
(sum of coefficients)	-0.06	-0.08	-0.13
	(0.05)	(0.06)	(0.05)
AR(1)	0.99	0.99	0.99
	(0.01)	(0.01)	(0.01)
Adj. R^2	0.98	0.99	0.98
	Panel B. Term Fed Funds-OIS		
Median CDS	0.10		
	(0.08)		
Libor-Tibor Spread		0.75	
		(0.36)	
Libor-Repo Spread			0.04
			(0.04)
TAF Dummies			
(sum of coefficients)	-0.04	-0.06	-0.07
	(0.07)	(0.06)	(0.06)
AR(1)	0.99	0.99	0.99
	(0.01)	(0.01)	(0.01)
Adj. R^2	0.98	0.98	0.98
	Panel C. CD-OIS		
Median CDS	0.60		
	(0.15)		
Libor-Tibor Spread		1.00	
		(0.37)	
Libor-Repo Spread			0.12
			(0.10)
TAF Dummies			
(sum of coefficients)	-0.20	-0.29	-0.14
	(0.20)	(0.25)	(0.21)
AR(1)	0.91	0.95	0.94
	(0.04)	(0.02)	(0.02)
Adj. R^2	0.92	0.91	0.92

Table 4
OLS Regressions with a Single TAF Dummy

	(1)	(2)	(3)
	Panel A. Libor-OIS		
Median CDS	0.58		
	(0.15)		
Libor-Tibor Spread		4.26	
		(0.41)	
Libor-Repo Spread			0.66
			(0.04)
TAF Dummy	-0.03	0.29	0.06
	(0.11)	(0.04)	(0.04)
Adj. R^2	0.52	0.74	0.85
	Panel B. Term Fed Funds-OIS		
Median CDS	0.52		
	(0.16)		
Libor-Tibor Spread		4.16	
		(0.43)	
Libor-Repo Spread			0.64
			(0.05)
TAF Dummy	0.13	0.40	0.18
	(0.12)	(0.04)	(0.04)
Adj. R^2	0.58	0.77	0.84
	Panel C. CD-OIS		
Median CDS	0.59		
	(0.18)		
Libor-Tibor Spread		4.83	
		(0.48)	
Libor-Repo Spread			0.71
			(0.06)
TAF Dummy	0.11	0.44	0.20
	(0.13)	(0.05)	(0.06)
Adj. R^2	0.53	0.73	0.78

Table 5
AR(1) Regression Results with a Single TAF Dummy

	(1)	(2)	(3)
	Panel A. Libor-OIS		
Median CDS	0.15		
	(0.08)		
Libor-Tibor Spread		0.55	
		(0.26)	
Libor-Repo Spread			0.08
			(0.04)
TAF Dummy	-0.08	-0.08	-0.05
	(0.01)	(0.00)	(0.02)
AR(1) Error	0.99	0.99	0.99
	(0.01)	(0.01)	(0.01)
Adj. R^2	0.98	0.99	0.98
	Panel B. Term Fed Funds-OIS		
Median CDS	0.11		
	(0.08)		
Libor-Tibor Spread		0.79	
		(0.36)	
Libor-Repo Spread			0.03
			(0.04)
TAF Dummy	0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)
AR(1) Error	0.99	0.99	0.99
	(0.01)	(0.01)	(0.01)
Adj. R^2	0.98	0.98	0.98
	Panel C. CD-OIS		
Median CDS	0.54		
	(0.15)		
Libor-Tibor Spread		1.21	
		(0.44)	
Libor-Repo Spread			0.16
			(0.12)
TAF Dummy	0.04	0.14	0.14
	(0.07)	(0.15)	(0.14)
AR(1) Error	0.91	0.92	0.92
	(0.04)	(0.04)	(0.05)
Adj. R^2	0.92	0.91	0.91

Table 6
Regression Results with Announcement Effects

	(1)	(2)
	Panel A. Libor-OIS	
Lagged spread	1.00	1.00
	(0.01)	(0.01)
Median CDS	0.18	0.18
	(0.07)	(0.07)
TAF Announcements	-0.05	-0.05
	(0.02)	(0.02)
TAF Operations	-0.02	
	(0.01)	
TAF Operations including settlement		-0.01
		(0.01)
Adj. R^2	0.98	0.98
	Panel B. Term Fed Funds-OIS	
Lagged spread	1.00	1.00
	(0.01)	(0.01)
Median CDS	0.12	0.11
	(0.08)	(0.08)
TAF Announcements	-0.02	-0.03
	(0.02)	(0.02)
TAF Operations	-0.02	
	(0.01)	
TAF Operations including settlement		-0.01
		(0.01)
Adj. R^2	0.98	0.98
	Panel C. CD-OIS	
Lagged spread	0.96	0.96
	(0.02)	(0.02)
Median CDS	0.43	0.44
	(0.17)	(0.18)
TAF Announcements	0.02	0.01
	(0.04)	(0.04)
TAF Operations	-0.03	
	(0.03)	
TAF Operations including settlement		-0.02
		(0.03)
Adj. R^2	0.92	0.92

Conclusion

The highly unusual developments in the money markets during the recent financial crisis have deep implications for macroeconomic research and policy. The money markets are where the Fed's decisions about the federal funds rate first impact the real economy. They are where the overnight federal funds rate is determined and where it begins to transmit its effects through the broader economy starting with longer-term interbank lending rates.

In this paper we documented how these markets first started behaving strangely in August 2007 when the longer term interbank interest rates seemed to disconnect from the overnight rate. Based on interviews with market participants and statements by policy makers, we delineated two main possible causes for the unusual behavior, both associated with the broader financial crisis: (1) an increase in counterparty risk and (2) an excess demand for liquidity. We used recently developed no-arbitrage models of the term structure as a framework to measure and test these alternatives. The null hypothesis that emerged from this framework is that the spread should be related to expectations of future overnight rates and to counterparty risk, with no additional role for liquidity effects. We then used a number of market-based measures of expectations and risk as well as the Fed's recently created term auction facility (TAF) to construct straight-forward regression tests of the hypothesis without having to estimate a structural no-arbitrage model.

Our empirical results show that expectations of future interest rates and counterparty risk are the major factors in explaining the spread between interest rates on

term lending and the overnight rate. We do not find robust evidence of a significant effect of the liquidity provision of the TAF on spreads.

Our results have implications for macroeconomic research. First, it is important to extend macro models of monetary policy evaluation so that they can explain the spreads between the interest rate set by the central bank and other market interest rates. Second, the no-arbitrage pricing model, which tested well in our empirical work, should be the cornerstone of such extensions. Third, the lack of a formal treatment of liquidity effects in these models is a potential disadvantage which future research should try to remedy; market participants often speak of such liquidity effects and bringing them into a formal model would be very useful.

Our results also have implications for policy. One is that interest rate rules or guidelines might be adjusted for such changes in spreads in the money market as proposed by Taylor (2008) and investigated by Curdia Vasco and Michael Woodford (2008). Second, our policy evaluation of the TAF suggests that the other new facilities created by the Fed during the financial crisis could be usefully evaluated in similar ways.

Postscript

Just after this paper was completed in August 2008, the three-month Libor-OIS spread spiked and reached another record level in October 2008. As shown in Figure 11, the three month Libor-Repo spread, one of our measures of counterparty risk, continued its close correlation with the Libor-OIS spread, providing "post-sample" evidence that movements in the Libor-OIS spread likely reflect counterparty risk. The other two measures of counterparty risk—the yen Libor-Tibor spread and the median CDS rate for banks—also rose significantly in September and early October 2008.

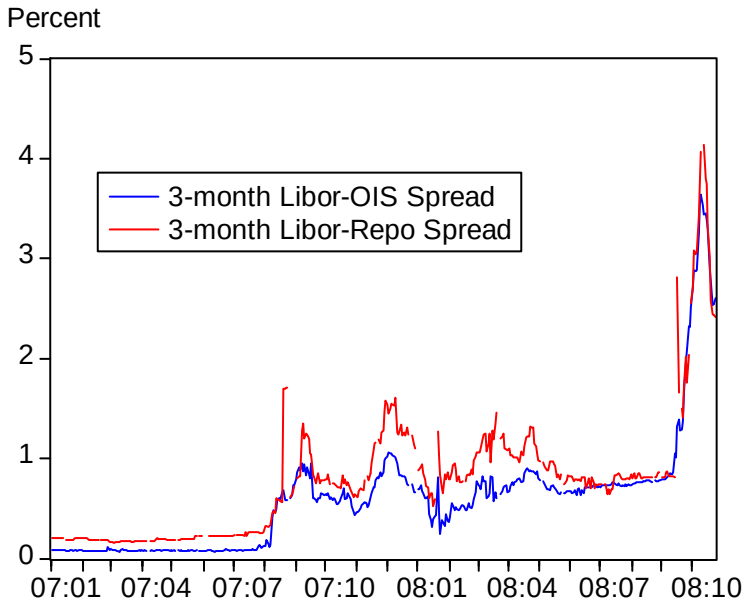

Figure 11. Libor-OIS and Libor-Repo spreads including post-sample data from August 10 to October 24, 2008.

The Federal Reserve, the U.S. Treasury, and central banks and finance ministries in other countries responded to the escalation of stresses in money markets and financial markets more generally with a number of policy actions. The Federal Reserve started

paying interest on reserves, implying that increases in TAF lending need not be sterilized in order to keep the overnight fed funds rate near its target. The size of the Federal Reserve TAF auctions increased dramatically, with the scheduled amount of TAF auction funds available at the end of 2008 reaching $900 billion. The European Central Bank and Swiss National Bank TAF auctions were changed to a fixed-rate format with no limit on the total amount that can be allotted. The Bank of England and the Bank of Japan introduced similar term dollar funding programs as well. In addition, several governments, including the United States, took actions to recapitalize banks and to provide insurance for bank debt and inter-bank loans. These policy interventions have potentially significant implications for counterparty and liquidity risk and should be the subject of future research.

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Appendix

Appendix Tables 1 and 2 report the list of banks participating in the various Libor surveys and the Tibor survey in 2007 and 2008. The U.S., Euro, and UK lists each include the same 14 banks (out of 16 banks in each survey). The Libor is computed taking the average of rates in the survey, after dropping the 25 percent highest and 25% lowest rates. The Tibor is computed by averaging the rates in the survey, after dropping the two highest and two lowest rates.

Appendix Table 3 summarizes the results from the TAF auctions held by the European Central Bank (ECB) and the Swiss National Bank (SNB) during our sample period. Note that the ECB TAF auction was structured so that the interest rate on the TAF loan was identical to that from the corresponding TAF auction held by the Federal Reserve. The SNB auction is a multiple price auction; the table reports the weighted average rate of successful bids. The bid/cover ratio is the ratio of the total dollar amount of bids at or above the minimum bid rate divided by the dollar amount being auctioned.

Appendix Table 1. Banks in Libor Survey (2007)

United States	Euro	UK
Bank of America	Bank of America	Bank of America
Bank of Tokyo – Mitsubishi UFJ	Bank of Tokyo – Mitsubishi UFJ	Bank of Tokyo – Mitsubishi UFJ
Barclays Bank	Barclays Bank	Barclays Bank
Citibank NA	Citibank NA	Citibank NA
Deutsche Bank	Deutsche Bank	Deutsche Bank
HSBC	HSBC	HSBC
JP Morgan Chase	JP Morgan Chase	JP Morgan Chase
Lloyds TSB Bank	Lloyds TSB Bank	Lloyds TSB Bank
Rabobank	Rabobank	Rabobank
Royal Bank of Scotland Group	Royal Bank of Scotland Group	Royal Bank of Scotland Group
UBS AG	UBS AG	UBS AG
West LB AG	West LB AG	West LB AG
HBOS	HBOS	HBOS
Royal Bank of Canada	Royal Bank of Canada	Royal Bank of Canada
Credit Suisse	Credit Suisse	Abbey National
Norinchukin Bank	Société Générale	BNP Paribas

Appendix Table 2. Banks in Japan's Libor and Tibor Surveys (2007)

Libor	Tibor
Bank of Tokyo –Mitsubishi UFJ	Bank of Tokyo – Mitsubishi UFJ
Mizuho Corporate Bank	Mizuho Corporate Bank
Norinchukin Bank	Norinchukin Bank
SMBCE	SMBCE
Bank of America	Mizuho Bank, Ltd.,
Barclays Bank	Resona Bank
Citibank NA	Saitama Resona Bank
Deutsche Bank	The Bank of Yokohama
HSBC	Mitsubishi UFJ Trust and Banking Corporation
JP Morgan Chase	Mizuho Trust and Banking Co
Lloyds TSB Bank	The Chuo Mitsui Trust and Banking Co.
Rabobank	The Sumitomo Trust and Banking Co.
Royal Bank of Scotland Group	Shinsei Bank
UBS AG	Aozora Bank
West LB AG	DEPFA Bank
Société Générale	Shinkin Central Bank

Appendix Table 3. ECB and SNB TAF Auctions

Day of Bid	Settlement	Term (days)	Amt ($B)	Min. Rate	Ave. Rate	1-Month Libor	Bid/Cover Ratio
Swiss National Bank							
12/17/07	12/20/07	28	4	4.17	4.790	4.949	4.25
01/14/08	01/17/08	28	4	3.88	3.910	4.023	2.72
03/25/08	03/27/08	28	6	2.19	2.630	2.654	2.47
04/22/08	04/24/08	28	6	2.05	2.940	2.895	2.56
05/07/08	05/08/08	28	6	2.00	2.410	2.674	1.62
05/19/08	05/22/08	28	6	1.99	2.080	2.430	1.28
06/03/08	06/05/08	28	6	2.00	2.180	2.451	1.89
06/17/08	06/19/08	28	6	2.05	2.360	2.483	3.04
07/01/08	07/03/08	28	6	2.01	2.250	2.461	2.75
07/15/08	07/17/08	28	6	2.01	2.290	2.458	2.74
07/29/08	07/31/08	28	6	2.01	2.360	2.463	1.87
European Central Bank							
12/17/07	12/20/07	28	10	4.17	4.650	4.949	2.21
12/21/07	12/27/07	35	10	4.15	4.670	4.865	1.41
01/14/08	01/17/08	28	10	3.88	3.950	4.023	1.48
01/28/08	01/31/08	28	10	3.10	3.123	3.271	1.24
03/25/08	03/27/08	28	15	2.19	2.615	2.654	2.08
04/07/08	04/10/08	28	15	2.11	2.820	2.722	2.05
04/21/08	04/24/08	28	15	2.05	2.870	2.895	2.01
05/05/08	05/08/08	28	25	2.00	2.220	2.674	1.58
05/19/08	05/22/08	28	25	1.99	2.100	2.430	2.36
06/02/08	06/05/08	28	25	2.00	2.260	2.451	2.59
06/16/08	06/19/08	28	25	2.05	2.360	2.483	3.14
06/30/08	07/03/08	28	25	2.01	2.340	2.461	3.39
07/14/08	07/17/08	28	25	2.01	2.300	2.458	3.60
07/28/08	07/31/08	28	25	2.01	2.350	2.463	4.07

Note: 1-month labor rate refers to rates on the day after bids were submitted in the Federal Reserve TAF.