Segmentation in the U.S. Dollar Money Markets During the Financial Crisis

James J. McAndrews*

May 19, 2009

Abstract

The U.S. dollar unsecured money market consists of two segments, Eurodollar deposits and federal funds purchases and sales. A previous study by Bartolini, Prati, and Hilton showed that the two market segments were highly integrated for trades arranged in New York in the period 2002-2004. Using another transaction-level dataset that identifies Eurodollar and fed funds trades, as well as the Libor panel of overnight interest rates, I find evidence of significant rate differences between the two market segments during the financial crisis period beginning in August 2007. Furthermore, during this period significant differences arose within the market segments. In general, the Libor rate is significantly higher than the U.S. rates at times of market distress; moreover the interest rate changes between the two market segments became uncorrelated at times. Central banks moved to make available official U.S. dollar liquidity backstops in London and other market centers. Evidence supports the hypothesis that access to these sources of funding reduced the spread between the Libor and federal funds rates.

JEL classification: G21, C78, L14
Keywords: Money market trading, market integration, federal funds, Eurodollar

*Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045, USA. The views expressed here are those of the author and do not necessarily reflect those of the Federal Reserve Bank of New York or of the Federal Reserve System. I thank Enghin Atalay, Ian Adelstein and Jeffrey Shrader for outstanding research assistance. I also thank Florian Heider, Philipp Hartmann, Cornelia Holthausen, Joshua Rosenberg, Michael Fleming, and participants in a seminar at the European Central Bank for comments.

1 Introduction

The U.S. dollar unsecured money market ties together lenders and borrowers of very short-term credit. The market's main maturity is of overnight duration, and the market has both federal funds and Eurodollar deposit segments. These market segments are highly integrated in normal times. How well integrated have they remained during the period of financial crisis starting in August 2007? This is an important question as both segments are very large markets in which banks and other financial institutions manage their funding resources. They are markets through which the monetary transmission mechanism operates by manipulating the marginal cost of bank funding, the marginal source of which is overnight borrowing.

While the rates in the two markets are similar during normal times, the data reveal extreme divergences in rates and the direction of rates during the period beginning in August 2007 and continuing through late 2008. The divergence between Libor rates set in London and both New York Eurodollar rates and federal funds rates is much sharper than the divergence between New York Eurodollar rates and federal funds rates (both of which are set in the U.S.). This divergence suggests that either the time zone or geographical segmentation in the London and New York markets may be more important than the segmentation between the Eurodollar and federal funds markets per se.

The breakdown in correlation between the Libor and fed funds rates suggests that the usual intermediation between the markets that keeps the two rates tethered to one another broke down completely at times during the financial crisis. This divergence can serve as one measure of the depth of the crisis, and reflects the difficulty of ensuring that the monetary policy transmission mechanism functions adequately.

The findings of this study also suggest that increased access to official sources of U.S. dollar liquidity, in the form of the central bank liquidity swaps[1], has moderated the divergence

[1]Foreign exchange swap lines (FX swaps) were established with the Bank of England, Bank of Canada, European Central Bank, and the Swiss National Bank on December 12, 2007 to provide a source of U.S. dollar funding to overseas banks. The FX swaps have expanded in size

in Eurodollar and federal funds rates. This result suggests that term lending by central banks can influence and moderate divergences in overnight rates, improving the monetary policy transmission process. This view widens the focus for implementation of monetary policy to include term markets, and to consider the time zones and jurisdictional differences in money markets.. If banks are uncertain regarding their future access to funding, a situation that was widespread beginning in August 2007, that can reduce the efficiency of the overnight market as banks rely excessively on that market for the shortest of terms. Furthermore, even very similar market segments, but ones separated by geography and time zones, can become distinct markets in times of crisis, requiring the monetary authority to conduct operations in ways that more directly make funds available in the times and places in which markets are active.

In the next section, I review the two segments of the money market. In section 3, I describe data and the method used to identify the two segments. In section 4, I present a number of descriptive tables and charts that outline the relative behavior of the two market segments. In section 5, I present estimations that attempt to isolate various factors that account for the differences observed between the two market segments, and section 6 concludes.

2 Fed funds and Eurodollar trades

The U.S. market for unsecured short-term loans consists of federal funds (or fed funds, for short) trades (often called "purchases") and Eurodollar trades (often called "deposits"). Fed funds trades, as we pointed out, are unsecured loans between banks that have accounts at Federal Reserve Banks, which include domestic depository institutions, the branches of foreign banks, government-sponsored enterprises, foreign central banks, and monetary authorities. Fed funds trade daily on an overnight basis to assist banks in managing their

and number of participating Central Banks over the course of the program. For more information, see the following releases: http://www.federalreserve.gov/newsevents/press/monetary/20071212a.htm and http://www.federalreserve.gov/monetarypolicy/bst_liquidityswaps.htm

balance sheets, and, importantly for many of the banks, to maintain sufficient reserves on average over a two-week reserve maintenance period to meet their reserve requirements. Every day a bank's normal business, including making payments on behalf of customers, causes inflows and outflows of balances in their Federal Reserve Bank accounts. To make use of any excess reserve balances to earn interest, or simply to make sure that their balances are both positive and sufficient to meet their reserve requirements, banks can choose to either sell or buy fed funds. Although participants in the fed funds market are domestic depository institutions that can maintain accounts at the Federal Reserve Banks, some participants choose to arrange their trades using correspondent banks, presumably because their scale of operation is so small.

Eurodollar trades are similar to fed funds trades, but are made among a different, but overlapping, set of counterparties. European banks that maintain dollar liabilities trade Eurodollar deposits. In addition, nondepository institutions, such as domestic finance companies trade Eurodollars. Finally, deposit liabilities of domestic institutions that have set up segregated sets of "foreign" accounts (so called International Banking Facilities) also qualify as Eurodollars. For a fuller discussion of differences and similarities between the markets for federal funds and Eurodollars, see Bartolini *et al.* (2007). Some European banks, for example, that maintain a branch in the U.S. could trade in both market segments, as can domestic banks that also maintain an International Banking Facility. Because of this partial overlap in the parent institutions of those eligible to participate in the different market segments, arbitrage opportunities would work to make the two markets highly integrated.

A key difference between fed funds trades and Eurodollar trades is that fed funds trades can be settled directly between the borrower and lender using the Federal Reserve's *Fedwire Funds Service*. To make a Eurodollar trade, by contrast, some intermediary or correspondent bank or banks must be used to complete the transfer of dollar liabilities. The correspondents often settle the Eurodollar trade by also using the Federal Reserve's *Fedwire Funds Service* (although they can use other settlement methods as well, such as the *CHIPS* payment system, or, if the two parties to the trade use the same correspondent bank, a book transfer

on the books of the correspondent bank). Using data from the transactions journal of the *Fedwire Funds Service*, we identify overnight loans that are likely Eurodollar loans, and those that are likely fed funds loans, and investigate the interest rate differentials between these two segments. We utilize the distinction that Eurodollar loans are made via correspondent banks (on the delivery side of the loan) with a much higher probability than are fed funds loans.

In addition to utilizing the transaction-based interest rates generated from likely overnight money market trades on the Federal Reserve's *Fedwire Funds Service*, I compare the transaction-based interest rates with those reported by the Libor panel of banks and published by the British Bankers Association as the overnight, U.S. dollar Libor rate. Libor rates are indicative of the rates at which banks on the U.S. dollar Libor panel can borrow for an overnight duration. The Eurodollar rates I calculate from the *Fedwire Funds Service* are trades typically arranged during the New York session (as trades arranged in London typically settle either on correspondent banks' books, or via the CHIPS service). As a result, comparing Libor rates and the Eurodollar rates generated from transactions on the *Fedwire Funds Service* allows one to determine the effects of the time zone and geographical differences (and here geographical differences also likely reflect differences in the identities of borrowers, which we don't observe) on rates in the *same* market, namely the Eurodollar market.

Trading in the New York markets begins daily at about 8:00 (ET), when major New York brokers begin receiving requests from customers to match orders to lend or bids to borrow funds (trades for Eurodollars also are made in London earlier in the U.S. day). The market effectively closes at 18:30, when the Federal Reserve's large-value electronic payments system, the *Fedwire Funds Service*, closes for the day, at which point it becomes impossible for financial institutions to trade loans of federal funds for same-day settlement, the market for Eurodollars effectively winds down, and bank reserve holdings are fixed for the day.[2]

[2]Technically, it is possible to execute and settle Eurodollar trades outside the United States after the closing of the New York market, although the amount of Eurodollar trading is minimal after Eurodollar settlement closes on *Fedwire* at 18:00, until markets in East Asia open several hours later.

Brokers often play the role of establishing contact between interested buyers and sellers of short-term loans. Trades are normally arranged anonymously between interested parties, and only after the interest rate is agreed to by both parties is the borrower's identity disclosed. After that disclosure, and if the lender accepts to lend to the borrower (a decision usually conditioned on the presence of a predetermined credit line between the two parties), the trade is deemed "executed" by the broker, and entered into a time-stamped record with information on counterparts, amount traded, settlement and maturity dates, and an identifier of whether the trade was executed as a "federal funds" or a "Eurodollar" trade. Many trades are also arranged directly between the two banks.

The next stage in the trading process is "settlement," in which the loaned funds are delivered by the lender to the borrower. Federal funds loans settle almost exclusively on the *Fedwire Funds Service*. *Fedwire* settlement occurs when the lending institution instructs its Reserve Bank to debit its reserve account and credit the reserve account of the borrowing institution (via *Fedwire*). *Fedwire* provides near instantaneous, irrevocable settlement as soon as the payment instruction is received by the Federal Reserve Bank of the sender's district, provided that sufficient funds are available in the sender's account. *Fedwire* also handles the vast majority of short-term, unsecured, Eurodollar loans traded in the New York market, with the residual settling on other systems, such as the *Clearing House Interbank Payments System* (CHIPS), a private payment system. Eurodollar loans arranged in other market venues, such as London, tend more often to be settled on CHIPS.

At maturity, settlement of loan returns works almost identically to that of loan deliveries, except that borrowing banks now act as "senders," and are expected to instruct the Federal Reserve to move balances out of their accounts and back into the accounts of lending banks (who now act as funds "receivers"), for an amount including both principal and due interest.

3 Data

Three interest rates are used in this study. The easiest to describe is the overnight U.S. dollar Libor rate as published by the British Bankers Association. The next two are rates calculated from measures of federal funds trades and Eurodollar trades that are settled on the *Fedwire Funds Service*, the Federal Reserve System's large-value payment service. These rates are described in more detail below.

Settlement data. The data we employ is gathered from the transactions journal of the *Fedwire Funds Service*, the large-value payment system operated by the Federal Reserve, on which the vast majority of money market trading between U.S. institutions settles. The data include information on senders' and receivers' identities, dollar amounts (in dollars and cents), and time stamps (in day/hour/minute/second format).

Using this data set, we filter the data to identify likely overnight loans from *Fedwire* payments. This technique was pioneered by Furfine (1999) and has been used in many subsequent studies, including Furfine (2001, 2003, 2006), Demiralp *et al.* (2004), Millard and Polenghi (2004), Ashcraft and Bleakley (2006), Ashcraft and Duffie (2007), and Hendry and Kamhi (2007). The essence of these studies' methodology is to identify as overnight loans all *Fedwire* payments that satisfy criteria such as matching bilateral payments (consisting of a delivery of payments on one day, followed by a return of funds on the following business day) for round dollar lots, in which return payments can be reasonably construed as including principal plus due interest. See Furfine (1999) and Demilrap *et al.* (2004) for full descriptions.

Once we have the set of measured overnight loans, we classify them as likely federal funds trades or likely Eurodollar trades. To do that, we make use of a prior study, that employed another data set of overnight money market trades provided by a broker. After examining that data set, it became clear that a particular variable in the *Fedwire Funds Service* records was highly predictive of whether an overnight loan was a federal funds trade or a Eurodollar trade. Here we go into further detail on this method of classification.

Trade data. Three previous studies, Bartolini et al (2005), Bartolini, Hilton and Prati (hereafter PBHP, forthcoming), and Bartolini, Hilton, and McAndrews (2007) use data provided by a broker, *BGC Brokers* (formerly *Eurobrokers*), one of the four largest interbank dollar brokers. The data include all federal funds trades during the sample period, as well as all Eurodollar trades arranged by *BGC Brokers*' New York headquarters over the same period. For each transaction we obtained amount traded, applicable interest rate, loan delivery date, term, trade completion time (in date/hour/minute/second format), and a 'federal funds' vs. 'Eurodollar' identifier.

The trade data consist of data on overnight interbank loans for 660 business days, from February 11, 2002, until September 24, 2004. No information on the institutions involved in each trade was included.

Matching brokered trades with settlement orders In the study by Bartolini, Hilton, and McAndrews (2007) the two sets of data, brokered trade data and Fedwire settlement data, were matched. The set of matched trades consisted of approximately 38,000 trades arranged between 2002 and 2004. The matching process is briefly described below:

For each brokered trade record, we searched for a *Fedwire* payment order that:

1. involved the same dollar amount specified for the loan in the brokered trade record;

2. settled at any time after the execution time reported in the brokered trade record, but before that day's closing of *Fedwire*;

3. matched a payment order between the same two banks in the opposite direction on the following business day, for an amount equal to the sum of the principal and interest reported in the brokered trade record;

4. was *uniquely* matched, in the sense that no other *Fedwire* order also satisfied 1, 2, and 3, between the same or any other pair of banks.

The previous study recognized various potential biases with this matching process. The algorithm yielded 38,358 uniquely matched records, each including information on trading,

	Customer	Non-Customer	Total
Fed Funds	1005	23579	24584
Eurodollar	10886	2861	13747
Total	11891	26440	38331

delivery, and return times, loaned amount, interest rate, a federal funds / Eurodollar identifier, and information on trading counterparts.

Identifying Eurodollar loans in the Fedwire Transaction Journal A striking consistency was found in the matched data. When examining the matched trades, it is clear that those trades that contain a certain code in the *Fedwire* transactions journal on the delivery leg of the loan are much more likely to be a Eurodollar trade. Specifically, for each *Fedwire* payment, the sending bank enters a code on the payment message indicating whether the payment is made on behalf of a customer. Of the 38,331 trades, approximately 36 percent are identified as Eurodollar trades by *BCG Brokers.* Only 4 percent of the federal funds loans were coded as having been initiated by a customer of the sending bank ($\frac{1,005}{24,584}$), while 79 percent of the Eurodollar loans were coded as customer loans ($\frac{10,886}{13747}$).

Consequently, using the customer code as a proxy for a Eurodollar loan will result in a 92 percent chance of correctly identifying Eurodollar loans ($\frac{10,886}{11,891}$), with an 8 percent chance of Type 1 error of counting fed funds loans as Eurodollars, and a 21 percent level of Type 2 error of falsely excluding Eurodollar loans counted as fed funds ($\frac{2,861}{13,747}$), if the matched sample is representative of the population as a whole. By using the absence of a customer code as a proxy for a fed funds loan we have an 89 percent chance of correctly identifying a fed funds loan, ($\frac{23,579}{26,440}$) with an 11 percent Type 1 error of counting Eurodollar loans as fed funds, and a 4 percent Type 2 error of incorrectly excluding fed funds loans ($\frac{1,005}{24,584}$). Using this regularity in the data, I assign overnight transactions identified on Fedwire to the Eurodollar category if the sending institution has the transaction marker as one made on behalf of a customer, and as a federal funds loans otherwise.

Finally, I use the Libor panel banks and their U.S. dollar overnight rate quotes to provide

an interest rate series indicative of rates on Eurodollar trades in London. I will compare both the spreads between the New York Eurodollar rate and the transaction-based weighted average federal funds rate, and the spread between the Libor rate and the transaction-based weighted average federal funds rate.

4 Market Segmentation

It is useful to view some trends that can be observed in the market segments during the sample period. In Figure 1, the value of the trades in Eurodollar deposits and in fed funds (both from the Fedwire data) are shown in yellow and blue, respectively. There has been a rapid rise in the values of Eurodollar trades conducted over the period, from an initial level of approximately $100 billion in 2001 to an amount in excess of $300 billion in the second half of 2008, with a rapid rise occurring in August 2007. The value of federal funds transactions increased as well but by a lesser amount, from around $150 billion to about $200 billion in the second half of 2008. Values of both Eurodollar and fed funds trades have fallen since late 2008, with a significant fall when the FOMC moved to the 0 to 25 basis point range for the target federal funds rate in December 2008.

The next series of figures show the extraordinary volatility that emerged in the rates of the market segments, starting on August 9, 2007. Figure 2 displays the differences between the three overnight interest rates used in this study and the daily effective federal funds rate as measured and publicly reported by the Markets Group of the Federal Reserve Bank of New York. The three rates are the U.S. dollar Libor rate, the fed funds rate (measured as the weighted-average calculated from the Fedwire transactions journal extracts), and the New York Eurodollar rate (measured as the weighted average rate as calculated from the Fedwire transaction journal extracts, for the trades classified as Eurodollars or fed funds). As one can see, the rates became much more volatile beginning on August 9, 2007. It is especially interesting to consider the differences in these three rates when plotted versus the *target* federal funds rate (Figure 3) or the *effective* federal funds rate (Figure 2). When

plotted against the effective rate (Figure 2), one can see that the Eurodollar rate moves with the Libor rate (spiking when the Libor rate spikes) but with a reduced amplitude. When plotted against the target rate (Figure 3) one can see that the two "New York" session rates move quite closely together, often moving away from the Libor rate, so that when the Libor rate spikes, the two other rates sink. I will discuss this geographical and time-zone variation at greater length in the conclusion.

The next figures, Figure 4-Figure 7, display the daily and the four-week average interest rate spreads between Libor (Figures 4 and 5) and the weighted-average fed funds rate, and between the Eurodollar rate and the weighted average fed funds rate. The spreads are shown for the whole period from January 1, 2001 through March 31, 2009, and for the more recent sub-period from January 1, 2007 to March 31, 2009. The spike in the overnight Libor–fed funds rate spread, which began abruptly on August 9, 2007 reached over 400 basis points in September 2008, in the wake of the bankruptcy of Lehman Brothers Holdings Co. It has remained volatile in most of the period since that initial spike, although more recently, since the implementation of the 0 to 25 basis point range for the target federal funds rate, the volatility has subsided.

For the Eurodollar–fed funds rate spread, a slightly different pattern emerges. First, the spread is much less volatile than the Libor–fed funds spread, never reaching the heights of the Libor spread. Second, the spread displays a persistent slump in the period following the Lehman Brothers bankruptcy.

The Figures also show that the sample period used in the study of Bartolini, Hilton, and Prati, from 2002-2004 was characterized by a relatively less volatile spread between the rates on Eurodollar and fed funds trades, and that the spread may have been relatively low during that period in comparison with both of the periods around 2000 and the most recent period. These observations make our investigation of the whole sample of more interest.

4.0.1 Correlation breakdowns between rates

A clear way of measuring the level of dis-integration among the rates is to calculate the correlation between the different rates, both in their levels, and in their daily changes. A series of figures presents these correlations. All of the correlations are shown as smoothed moving-averages of daily correlations measured over a 22 day moving window. The correlation on day t is the correlation between the two rates over the *subsequent* 22 (business) days. Finally, this measure is smoothed by taking a 66-day, moving-average starting on date t.

The first two of these figures, Figures 8 and 9, display the correlations between the changes in the Eurodollar and fed funds rates, and the levels of Eurodollar and fed funds rates, respectively. It is clear that these rates became less correlated during the sample, but both their changes and levels maintained a correlation of approximately 0.7 throughout the period.

The next two figures, Figures 10 and 11, display the correlations between U.S. Eurodollars and the Libor rate. While the changes in these rates have maintained about a 0.8 correlation in the years from 2002 to 2007, they became much less correlated during the financial crisis, falling markedly on August 9, 2007, and having 0.0 correlation in late 2008 following the bankruptcy of Lehman Brothers. Similarly, their levels (Figure 11) also became much less correlated. In this figure we can also see how they became much less correlated following September 11, 2001, another period of unsettled money markets, and also a period in which significant dollar liquidity was provided to U.S. banks, but not to banks in London.

Finally, in Figures 12 and 13 we see the correlations between the Libor and fed funds rates. Again we see the correlation between their changes falling to zero around the period of August 9, 2007, and to low levels (approximately 0.3) after the Lehman bankruptcy. Here too we see a sharp spike downward in the correlation around September 11, 2001.

These measurements show how unsettled these markets were, as well as pointing out the lack of integration in the markets. A zero correlation in the rates in the two markets suggest no integration, and with levels being only correlated at levels of 0.2 for a month-long period, it reinforces that conclusion. Such low levels of correlation in rates is a sign that

the markets are segmented, that is, that funds are not flowing between markets well, and that participants cannot easily arbitrage rate differences between markets. An interesting and disturbing difference between the correlations in the financial crisis, starting in August 2007 is that not only did the correlations between the levels of Libor and fed funds fall to low levels, as occurred after September 11, 2001, but the correlation between the changes in rates fell to zero at times during the crisis.

The fall in the correlations between the changes in rates to zero or near zero (in addition to the low correlation between the rates) is a clear sign of lack of integration between the markets. When, after September 11, 2001, the correlation in rates fell to a low level (of approximately 0.4), that likely indicated an increase in the costs of intermediation between the two markets. In the 2007-2008 crisis, in contrast, not only did the correlation in rates fall, but in addition the correlation between changes in rates fell to zero or near zero. In other words, although the rates might have been quite different on a particular day, the rise or fall in the rate in one market was just as likely to be accompanied by a change in rates in the other market in the opposite direction. This indicates that market forces were not working to intermediate rate differences between markets. That high level of dysfunction in overnight markets suggests a highly illiquid condition for many banks; a situation that likely contributes to banks' needs to shed assets, as their ability to source funds in the market is impaired.

5 Explanatory factors associated with rate spreads

In this section the pairwise spreads between the three rates are examined to determine the contribution of various explanatory factors associated with the rates. I conduct estimations that are very similar to the ones conducted by BHP (but using our settlement system data to identify Eurodollar trades and federal funds trades, and using the Libor rate data, rather than broker data). By using the Fedwire data, I am able to include a much longer sample period, from January 1, 2001 to March 30, 2009. I find that the Eurodollar and federal funds

rates are very close to one another in the "baseline" period from 2001 through July 2007, largely confirming the results of BHP. These results suggest that the two market segments were highly integrated over the baseline period. In addition, I use the Libor series to examine differences between the Libor rate and the fed funds rate, and to examine the differences between the London and New York Eurodollar markets.

Table 1 below shows the sample statistics of the three different data series used: the Libor rates, and the rates and values of the fed funds and Eurodollar trades derived from the *Fedwire Funds Service*. The fed funds trades are more numerous, accounting for larger overall values lent, but are of smaller average size than the Eurodollar trades. The fed funds rates calculated using these data fall within 3 tenths of a basis point of the effective federal funds rate as reported by the Federal Reserve Bank of New York. The Eurodollar rate displays a similar mean and standard deviation as the federal funds rates, with the average rate lying just one basis point above the effective federal funds rate. The Libor rate is both more volatile, with a higher standard deviation, as well as having a mean spread of 7 basis points above the effective federal funds rate.

Next we conduct estimations of the spreads using a similar method as that used in BHP. We let $\Delta_t = r_t^{Libor} - r_t^{fedfunds}$, where t is a daily index of time, and r_t^{Libor} is the Libor rate on day t, and $r_t^{fedfunds}$ is the fed funds rate on day t. Similarly, we will consider two other spreads, $\Delta_t^{'} = r_t^{Eurodollar} - r_t^{fedfunds}$, and $\Delta_t^{''} = r_t^{Libor} - r_t^{Eurodollar}$. We will consider the evolution of the spreads by the same model.

$$\Delta_t = \mu_t + \sigma_t \nu_t$$

where ν_t is a mean-zero, unit variance i.i.d. error term; μ_t is the conditional mean of Δ_t; and σ_t is its conditional Exponential GARCH (EGARCH) volatility parameter.

Again, following BHP and standard EGARCH models of interest rates, we'll include a set of n autoregressive terms in the equation for μ_t, $\sum_{i=1}^{n} \rho_i \mu_{t-i}$, and define σ_t as a function of a distributed lag of a set of independent variables.

Our equations for μ_t and σ_t include a set of deterministic and stochastic factors that BHP

and other studies have identified as determinants of overnight interest rate dynamics. We include two sets of calendar date dummies, δ_{ct} and $\epsilon_{ct}$to capture the effect on rate behavior of holidays, mid-months, month-ends, quarter-ends, FOMC meeting days, and some other days of predictable rate dynamics, such as the New York blackout of August 14, 2003, and September 11, 2001, both of which interrupted federal funds trading.

To include the effect of the required reserve regime in the United States, we include dummies δ_{dt} and $\epsilon_{dt}$with $d_t = 1, ..., 10$ identifying days in the reserve maintenance period.

Next, we include variables measuring the intraday cross-sectional variation in rates, namely the standard deviation of the rates the Markets Group used to calculate the effective fed funds rate, θ^{desk}, and the standard deviation of the rates reported by the Libor panel, θ^{Libor}, and the standard deviations of the fed funds and Eurodollar rates calculated from the *Fedwire Funds Service,* $\theta^{fedfunds}$, $\theta^{Eurodollar}$.

To measure the unsettled trading in the markets during the crisis periods, we also estimate the model using dummy variables for the crisis periods. We use four such dummy variables: $\delta^{ElevatedLibor-OIS\ Spread}$, for the period from August 9, 2007 to September 15, 2008; $\delta^{PostLehmanBrosBankruptcy}$, for the period from September 16, 2008 to October 8, 2008, $\delta^{Interestonreserves}$, for the period from October 9, 2008 to December 4, 2008, and $\delta^{Zeroto25rate}$, for the period from December 5, 2008 to March 31, 2009.

Finally, to measure any possible effects of the TAF[3] and FX swaps, we include variables that measure the outstanding dollar amounts of TAF borrowing and borrowing under the Federal Reserve's swaps program, β^{TAF}, and β^{Swaps}. These programs could have different effects in the Libor, Eurodollar, and fed funds markets as the TAF credit was only directly available to depository institutions in the U.S., while the borrowing under the swaps credit was available only to depositories outside the U.S. in the countries in which the central bank participated in the swaps program. In addition, we include a full panel of dates for the TAF

[3]The Term Auction Facility (TAF) began on the same day as the FX swaps to alleviate term funding pressure in the U.S. For more information on the facility, see the following: http://www.federalreserve.gov/newsevents/press/monetary/20071212a.htm and http://www.federalreserve.gov/monetarypolicy/tafterms.htm

and swaps announcements, as well as dates for all the operations of the TAF and the swaps program during the sample period.

The model was estimated using Stata, where the residuals were examined to select the autoregressive structure, resulting in many autoregressive terms (as many as eight) being included to eliminate any residual autocorrelation.

The results are summarized by presenting two specifications of the model, one in which the rates are measured (as they are in the correlations presented above) using the Libor panel convention in which the upper and lower quartiles of rates are excluded, and the reported rate is based on the trimmed mean of rates. For the Eurodollar and fed funds rates, I discarded the upper and lower quartiles by value, so the top one-quarter of rates by total market value and the bottom one-quarter of rates by total market value were discarded. Next, I report the specification where all the rates are included in the rate estimated, an untrimmed mean, in other words. Again, for the fed funds and Eurodollar rates, the mean is a value-weighted average of rates.

The motivation for examining both the trimmed and untrimmed mean measures of rates is suggested by examining Figures 14 and 15, which display both trimmed and untrimmed means for Libor and fed funds rates, respectively. As can be seen, the untrimmed mean for Libor moves systematically above the untrimmed mean starting in August 2007, which presents quite a different pattern for fed funds, whose alternative mean estimates remain quite close throughout the period. This divergence between the untrimmed mean and the trimmed mean for Libor suggests that they should be treated as a separate series.

The full results of the estimations are presented in a series of tables (Tables 3, 4, and 5), but the estimates of special interest are summarized in Tables 2. Table 2 presents the estimated coefficients for predicted μ_t and σ_t for the $\Delta_t = r_t^{Libor} - r_t^{fedfunds}$both trimmed-mean and untrimmed mean equations and the $\Delta_t' = r_t^{Eurodollar} - r_t^{fedfunds}$ equations. The first two columns include two crisis period dummy variables, while the second and third columns focus on the policy variables of TAF and the FX Swap program amounts. In general, the predicted spreads in the Libor rates are significantly higher than is the case for the

Eurodollar rates, which are, on average less than a basis point different from the weighted-average federal funds rate, while the Libor rate lies approximately 6 basis points above the weighted average federal funds rate. These levels suggest close, but not perfect integration. BHP suggest that the cost of arranging an identical overnight trade is approximately 1.8 basis points for each leg of the trade. The estimated persistent differences in Libor rates are just above the amounts that would suggest that it would be profitable, all else equal, to attempt to exploit these different rates; however, the persistence of different rates suggests that the costs could be somewhat higher than suggested by BHP. BHP were also using New York broker data, and their results are more comparable to our Eurodollar rate series, which estimates little difference from fed funds rates in normal circumstances. In addition, the identity of the counterparties makes many of the constituent trades that are represented by these rates quite different across the market segments. Nonetheless, the close levels of the different rates suggests significant integration of the market segments, as does the similar behavior across many of the other calendar and standard deviation variables in the model. It is also striking how much closer the New York Eurodollar rates are to the fed funds rates than are the Libor rates.

5.0.2 Crisis periods

Trimmed mean estimates The estimates in Table 2 suggest that the market disruptions that occurred after August 2007 significantly increased the level, and, in some cases, the variability of the spread between the rates. Consider two major crisis periods, the "Elevated Libor-OIS Spread Period", from August 7, 2007 to September 14, 2008, and the "Post Lehman Bros. Bankruptcy Period," from September 15, 2008 to October 9, 2008, and focus on the trimmed mean estimates. In the Post Lehman Bros. Bankruptcy Period one can see that the Libor-fed funds spread widened by 88 basis points, while volatility was slightly reduced. In contrast the Eurodollar-fed funds spread did not change. A similar pattern held for the Elevated Libor-OIS Spread Period, although with a smaller magnitude–the Libor-fed funds spread widened by 4.6 basis points, and the volatility rose a bit.

The behavior fo the Eurodollar-fed funds spread was quite different, with no significant differences in spread levels in these periods (although there was an increased volatility in the Elevated Libor-OIS spread period). These measurements again confirm that the New York Eurodollar trades and fed funds trades never became as untethered from one another as was the case for Libor-fed funds. This fact suggests that the location and time zone of trade matters signficantly in terms of willingness to transact, notwithstanding the type of trade or intermediary, and perhaps matters even more in times of crisis.

Untrimmed mean estimates Recall Figure 14, which shows the significant divergence between the untrimmed and trimmed means in the Libor panel during the financial crisis. During the crisis, the upper quartile of rates, which are not included in the trimmed mean Libor, are so much higher than the remainder of the panel's quotes that the averages sometimes diverge persistently by more than 200 basis points. Consider the estimated coefficients for the Untrimmed Mean Estimates in Table 2. There, the Post Lehman Bros. Bankruptcy Period suggests a 1680 basis point spread in the Libor-fed funds rates, with no change in volatilities, while the spread between Eurodollars and fed funds actually falls by 40 basis points. The Elevated Libor-OIS Spread Period, in contrast, does not raise the spreads.

These results suggest that the untrimmed Libor panel mean measures something quite different to the trimmed-mean Libor rate. This is an important difference when interpreting the coefficients for the TAF and Swap programs.

It appears that in the unsettled market periods the willingness, and perhaps the ability, to intermediate credit across these markets fell markedly, resulting in significantly less integration across the markets.

Why is it the Libor market seems to pay higher rates, and have more variability in rates? I offer two hypotheses. First, depository institutions outside the U.S. do not face dollar reserve requirements, but at the same time, are not able to take advantage of the demand smoothing provided by the reserve maintenance periods. Second, the depository institutions outside the U.S. do not have access in normal times to official sources of U.S. dollars, such

as the discount window of the Federal Reserve Banks. These features leave the depository institutions with a greater level of liquidity risk and with demands for liquidity that are far more inelastic than for a comparable U.S. based institution. As supply of funds is provided by banks that have excess of funds, the elasticity of the supply of funds is influenced by similar forces as the demand, and is therefore also less elastic than for a comparable U.S. institution. Consequently, one would expect the market to display a great deal more variability, and to have higher interest rates. These features would likely be exaggerated in a crisis.

5.0.3 Effects of TAF and Swap Programs

Following the hypothesis that depository institutions outside the U.S. face more funding risk as a result of not having access to official sources of U.S. dollar funding, such as the discount window, it is important to test the effect of the implementation of the TAF program, and the FX swap programs that were instituted by the Federal Reserve and several other central banks, including the Bank of England, the European Central Bank, the Swiss National Bank and the Bank of Japan. All of these jurisdictions contain banks active in the Eurodollar market, whose quotes are likely reflected in the Libor rates.

Trimmed mean estimates We find that the FX swaps program lending had the effect of reducing the two spreads, $\Delta_t = r_t^{Libor} - r_t^{fedfunds}$, and $\Delta_t' = r_t^{Eurodollar} - r_t^{fedfunds}$, while the TAF lending tended to widen them (the TAF coefficient is positive, but insignificant for the trimmed Libor-fed funds spread). For the Libor–fed funds spread, a billion dollars of lending through the Swaps program tended to reduce the spread by 3 one-hundredths of a basis point, so $400 billion of lending would be expected to reduce the spread by approximately 12 basis points. Perhaps surprisingly, the two lending programs did not raise the variability of the spreads, once the crisis periods are accounted for by their dummy variables. It is notable that these effects are seen, as these are *overnight* rate spreads, and the TAF program has always lent only at either 28-day or 84-day terms (some of the lending in the swaps programs was for overnight durations, for example, the Bank of England began lending overnight on

September 18, 2008). It is important that programs that offered term financing, such as the TAF, affected overnight rates. This is understandable as overnight rates are influenced by the availability of term financing to a bank: with term financing unavailable, a bank has a higher willingness to pay for overnight funds.

A second set interesting findings in the estimations are the effects of the TAF and FX swaps programs on the $\Delta_t'' = r_t^{Libor} - r_t^{Eurodollar}$ spread. Here we find that there was no significant effect on the level of the spread between the two rates. These results are consistent with the Libor and the Eurodollar borrowers having in common that they do not have direct access to official sources of funding. Consequently, the implementation of the TAF and FX swaps program affects their rates in the same manner, leaving their spread unchanged. This impact occurs accross periods even though the rates behaved quite differently in the crisis.

Untrimmed mean estimates The estimated coefficients for the untrimmed means of the spreads do not suggest that the FX swaps program reduced Libor-fed funds spreads; in fact, the Libor-fed funds spread coefficient is positive, suggesting that the spread widened with the increase in value lent through the swaps program. The coefficient on the FX swaps program for the Eurodollar-fed funds rates is negative, and for the TAF program positive. Both are significant, as was the case for the trimmed mean. These results suggest two points: first, the Eurodollar-fed funds rate spread has similar estimates for either the trimmed or untrimmed mean, but those means do not vary from one another very much; second, the Libor-fed funds spread behaves differently depending on whether we are using the trimmed or the untrimmed means, which vary greatly for the Libor panel.

One interpretation of these results is that the Swaps program improved the liquidity of the Libor market, resulting in lower rate spreads to fed funds for the majority of banks. However, for banks whose borrowing costs were extremely high, possibly signalling credit concerns, the Swaps program had no effect on their borrowing rates in the market. That interpretation would caution that care must be exercised when examining rate dynamics and the official programs. Another point is that the Libor panel rates are published daily. A

bank with a self-announced high borrowing rate may not benefit greatly in the market from an ample source of official financing, as market counterparties can observe that its recent borrowing rates were elevated. In general, it may be that the Swaps program improved liquidity in the market generally (and certainly assisted banks in meeting commitments as hundreds of billions of dollars were lent under the program) but may not have lowered the market borrowing costs of banks whose borrowing costs might have some elevated concern about credit risks reflected in their rates.

5.0.4 Other Results

The results of the estimation suggest that Libor rates are typically higher, although only a few basis points higher, than federal funds rates (again, in normal market conditions). An hypothesis for this persistently higher rate is that firms in the Eurodollar market have lower elasticity of both demand and supply. One source of the lower elasticity could arises from the lack of reserve requirements among Eurodollar borrowers and lenders. Absent the averaging feature of reserve maintenance periods, banks face higher penalties (failing to repay a loan, or denying a customer payment order, and the negative reputational effects associated with being unable to meet commitments) than simply falling short of one's required reserve for the period, and therefore, their daily demand is likely less elastic than for a U.S. bank that is subject to reserve requirements. Consequently, the banks in the Eurodollar market may face both greater volatility in rates (which they do, since most volatility coefficients are higher on the reserve maintenance day variables) and higher rates, which compensate for the reduced elasticity of supply. In order to lend funds banks must charge a slightly higher liquidity risk premium, since they could find that they need the funds (with greater urgency than a U.S. bank) later in the day.

Table 2 also shows results on the daily standard deviation of the fed funds and Libor rates, which generally shows that if the fed funds rates have a high standard deviation on a particular day, that is, the rates are more highly dispersed, then the Libor and Eurodollar to fed funds rate spreads are elevated, as is the volatility in the spread. So a high level of

dispersion in rates, presumably when market participants either vary greatly or when their perception of credit or liquidity risks vary, is correlated with a high average level of rates.

The full regressions, shown in Table 3, contained many other variables. One variable that was included was the time difference between New York and London, in an attempt to determine if the time difference (which varies from 4 to 6 hours) contributed to higher spreads. This coefficient was insignificant, so did not shed light on the source of the differences.

An alternative specification was tried in which a bank index of CDS prices was included to control for the overall industry level of credit risks. However, it is not at all clear if one wishes to control for credit risks in a specification of the spread, as banks in both markets are subject to credit risks (and the index does not properly distinguish between banks in the London from New York, and is, indeed, a U.S. index). The results of this specification were not highly differentiated from the basic specification: the main difference is that the TAF variable tended to raise the level of the Libor and Eurodollar spreads to fed funds more significantly than in the base specification.

Many other variables were included in the estimation, including the announcement and operation variables for TAF and Swaps. These variables had slight effects, with the TAF announcements associated with positive, but generally insignificant increases in spreads, and the Swaps announcements associated with negative but insignificant changes in spreads.

Shown in Table 2 are the results for the Libor-Eurodollar spread, which is of some independent interest as it shows the difference in rates on trades of the same type–namely, overnight Eurodollar loans–but made in different trading centers, London and New York. The results show that the New York Eurodollar rate fell away from the Libor rate during the periods of market stress. Again, this could well be the result of all trades in New York, both Eurodollars and fed funds, taking advantage of Open Market Desk moves to supply liquidity after learning of very high London rates in the early morning hours New York time. Another interesting result is that TAF and FX Swap program levels had no effect on the New York Eurodollar-Libor spread; this indicates that these programs affected the banks in those markets in a similar way, irrespective of the trading session in which they participated.

Consistent with previous studies, various calendar effects were significant, as were special dates, such as the New York City blackout period in 2003.

6 Concluding remarks

The period of unsettled money markets beginning in August 2007 and continuing for more than a year caused an extraordinary divergence in interest rates between two otherwise closely integrated money markets, the Eurodollar and federal funds uncollateralized overnight interbank markets. I have examined the level and variability of these market segments over the period. Clearly, the crisis period caused significant dis-integration of the market segments, especially in the post Lehman Brothers Bankruptcy period. The divergence between the two markets was unprecedented in size over the preceding nine years. The Swaps and the TAF programs to provide U.S. dollar funding to depository institutions both in the U.S. and in other nations had significant effects in the rate spreads, with the Swap program significantly reducing the rate spreads between Eurodollar rates and fed funds rates.

I have measured Eurodollar rates in two ways. The first is the Libor rate, published by the British Bankers Association, and reflecting rates in London during the London trading session. The second is derived from the *Fedwire Transactions Journal*, likely reflecting trades arranged in New York during its trading session. Capturing these market segments allows one to track the different behavior of the New York and London Eurodollar market, and we find that the New York market is more closely integrated with the fed funds market segment, perhaps especially during crisis periods in dramatic contrast to the London market..

There are several explanations for why the New York Eurodollar market would be more closely integrated with the federal funds market than the London market. First, the time zone mismatch could cause significant differences. The implementation of open market operations during the U.S. trading day can influence (and is designed to influence) rates in the U.S., but it occurs long after the London trading has wound down for the day. As an example, consider a situation in which the London trading session faced high rates, resulting

in a high Libor rate. When U.S. banks begin trading, and the Open Market Desk of the Federal Reserve Bank of New York canvasses dealers to determine market conditions, they might find that rates are high. Consequently, the Desk might then decide to inject greater quantities of liquidity than had rates been "soft." That would have the effect of lowering New York session rates, both Eurodollar and fed funds. Second, the greater geographic distance to London may impede the formation of relationships, and the revelation of information conducive to trading. Finally, different counterparties in the different geographic areas could explain differences in rates.

The crisis caused an extraordinary divergence in rates between the two market segments, as well as increases in variability of rates. These divergences played out differently in New York and London, however. In both Eurodollar markets the Swaps program tended to reduce the divergence in rates, suggesting that the program was effective in reducing liquidity risk for depository institutions outside of the U.S. that have U.S. dollar liabilities. The TAF program tended to be associated with a divergence in the rates, even though it offered only term funds to U.S. depositories. That result suggests term financing rates have a significant influence on overnight rates, a substitute source of funding for banks.

The results also highlight the extreme divergence within the Libor panel. The upper quartile of rates, which are the highest four rate quotes and which are excluded from the trimmed mean calculation of the Libor rate, drifted far above the trimmed mean Libor rates, resulting in a persistently high divergence between the trimmed mean Libor rate, and the rate found by averaging all 16 rate quotes of the panel. A similar divergence was not found in the fed funds or New York Eurodollar rates when weighted by market value. When examining the effect of TAF and the FX Swaps program it was found that the spreads measured in untrimmed means did not display the same consistent effects, likely reflecting that the central bank programs did not alter the market perceptions of counterparty credit risk that the high-rate reporting banks likely suffered.

This period of heightened volatility in money market rates has been extraordinary. Although there have been short periods, such as the period following September 11, 2001, in

which the overnight U.S. dollar Libor and the fed funds rate levels became less correlated, such periods were not accompanied by a decline in the correlation between the changes in rates. This result suggests that in previous periods intermediation between the two markets continued, but was somewhat more costly for banks to conduct. However, a rate rise in one market would be correlated with a rate rise in the other. In the crisis period following August 9, 2007, the correlation in levels fell, but, in addition, the correlation in changes in rates, the direction of rates, went to zero. A rate rise in one market (whose rates were already far apart) were just as likely to be accompanied by a decline as a rise in rates in the other market, suggesting that any intermediation that was occurring was ineffective in aligning rates in the two market segments. One conclusion might be that in a crisis, all markets are local.

With such a pronounced decline in market integration, monetary policy transmission is negatively affected. It is not surprising, given these circumstances, that central banks around the world cooperated to find improved ways of delivering liquidity to banks in more direct ways, in the places and times at which markets are active. Specifically, the Central Bank Swaps program allowed banks outside of the U.S. to borrow dollars on a collateralized basis from the ECB, BOE, SNB, BOJ, and other central banks, in their country at the normal time of trading in the market. This approach to providing liquidity found a large demand among banks, and, as the evidence here suggests, tended to narrow spreads in overnight rates between London and New York, improving the basic transmission mechanism for monetary policy.

References

Ashcraft, Adam, and Hoyt Bleakley (2006), "On the Market Discipline of Informationally-Opaque Firms: Evidence from Bank Borrowers in the Federal Funds Market" manuscript, University of Chicago.

Ashcraft, Adam, and Darrell Duffie (2006), "Systemic Illiquidity in the Federal Funds Market," *American Economic Review, Papers and Proceedings*, forthcoming.

Bartolini, Leonardo, Svenja Gudell, Spence Hilton, and Krista Schwarz (2005), "Intra-Day Trading in the Overnight Federal Funds Market," mimeo, Federal Reserve Bank of New York.

Bartolini, Leonardo, Spence Hilton, and James McAndrews (2007), "Settlement Delays in the Money Market," Mimeo, Federal Reserve Bank of New York.

Bartolini, Leonardo, Spence Hilton, and Alessandro Prati (2007), "Money Market Integration," *Journal of Money, Credit, and Banking*, forthcoming.

Demiralp, Selva, Brian Preslopsky, and William Whitesell (2004), "Overnight Interbank Loan Markets," manuscript, Board of Governors of the Federal Reserve.

Furfine, Craig (1999), "The Microstructure of the Federal Funds Market," *Financial Markets, Institutions & Instruments* 8:5, pp. 24-44.

Furfine, Craig (2001), "Banks as Monitors of Other Banks: Evidence from the Overnight Federal Funds Market," *Journal of Business* 74, pp. 33-55.

Furfine, Craig (2003), "Interbank Exposures: Quantifying the Risk of Contagion," *Journal of Money, Credit and Banking* 35, pp. 111-128.

Furfine, Craig (2006), "The Costs and Benefits of Moral Suasion: Evidence from the Rescue of Long-Term Capital Management," *Journal of Business* 79:2, pp. 593-622.

Hendry, Scott, and Nadja Kamhi (2007), "Uncollateralized Overnight Loans Settled in LVTS," Bank of Canada, Working Paper No. 2007-11.

Makrose, Sheri, Amadeo Alentorn, Stephen Millard, and Jing Yang (2006), "Designing Large Value Payment Systems: An Agent-Based Approach," Bank of England, working paper.

Millard, Stephen, and Marco Polenghi (2004), "The Relationship Between the Overnight Interbank Unsecured Loan Market and the CHAPS Sterling System," Bank of England Quarterly Bulletin, Spring, pp. 42-47.

Value in the Overnight Interbank Market

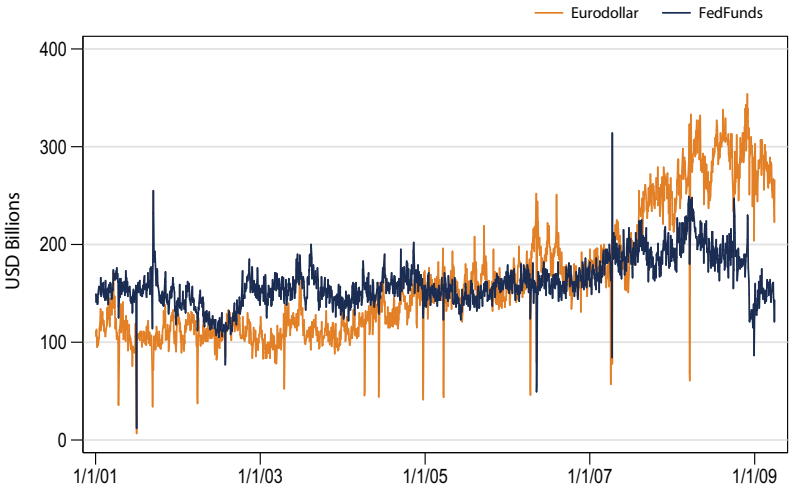


Figure 1

Spreads: Three Overnight Rates minus Markets Effective

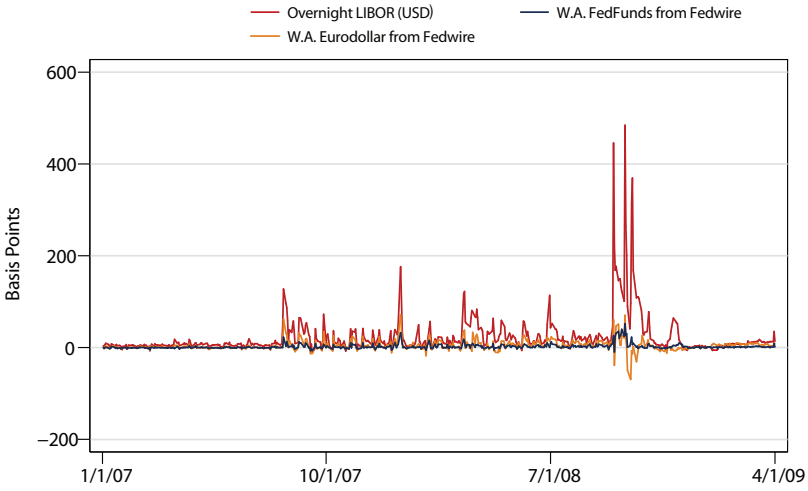


Figure 2

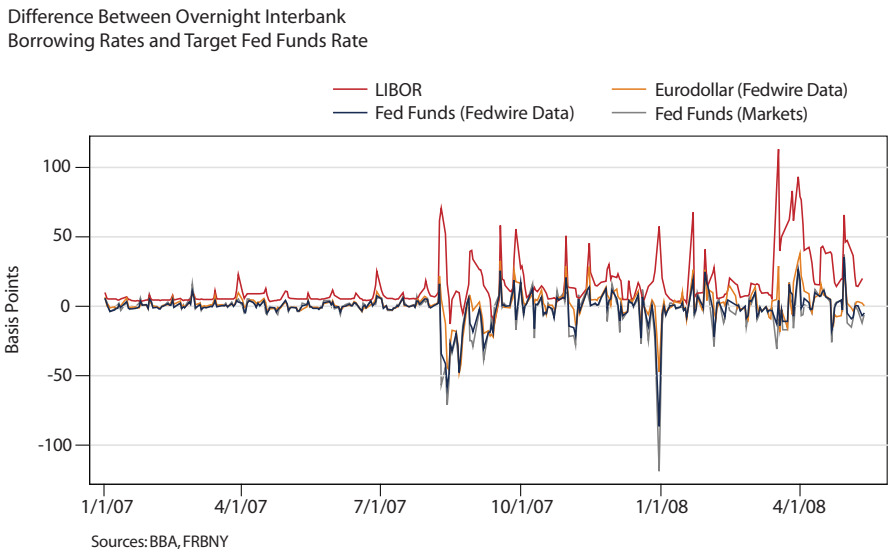


Figure 3

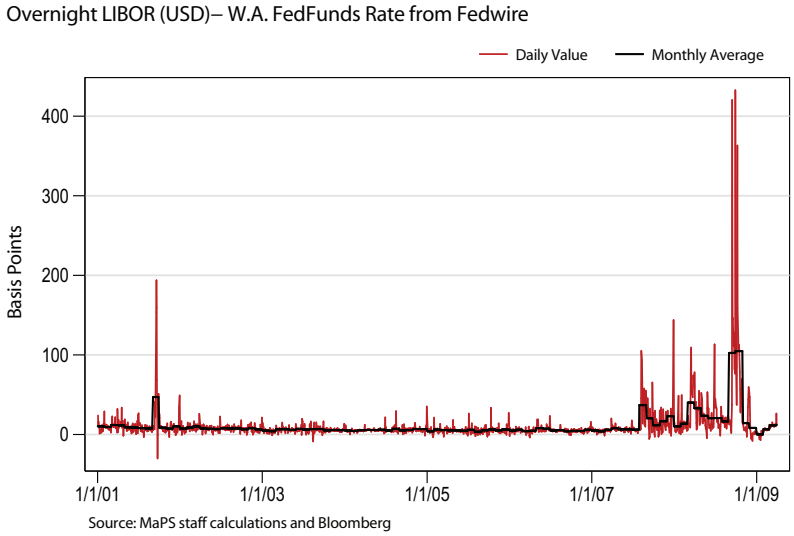


Figure 2

Overnight LIBOR (USD)– W.A. FedFunds Rate from Fedwire

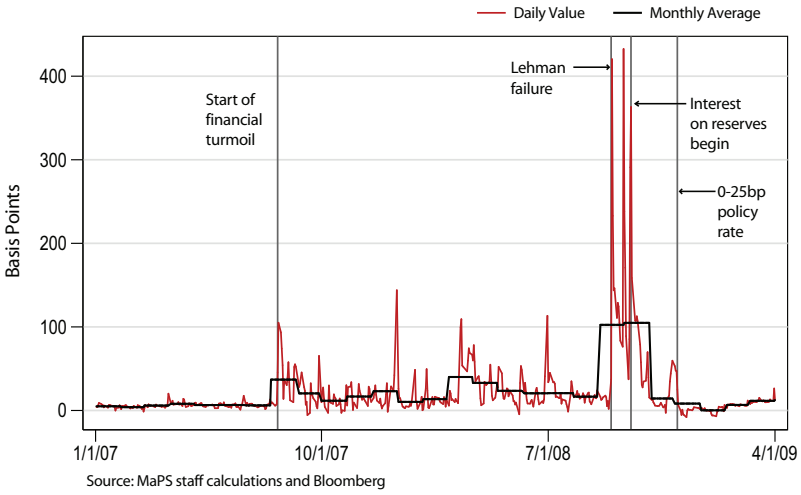


Figure 3

W.A. Eurodollar Rate from Fedwire– W.A. FedFunds Rate from Fedwire

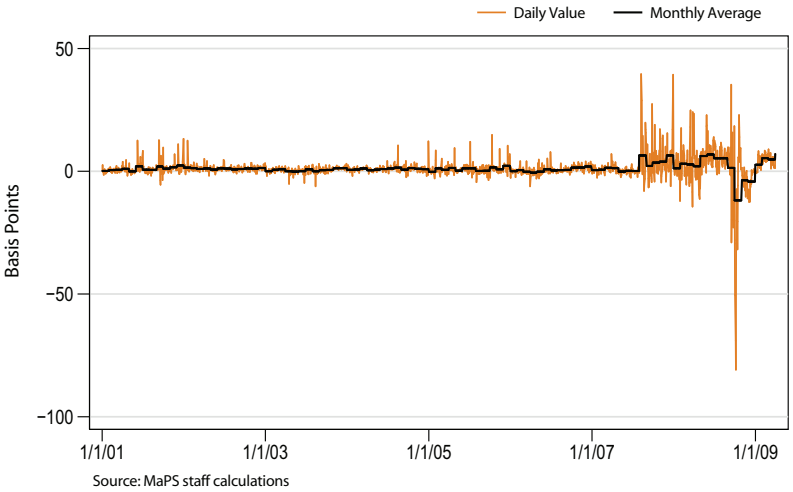


Figure 4

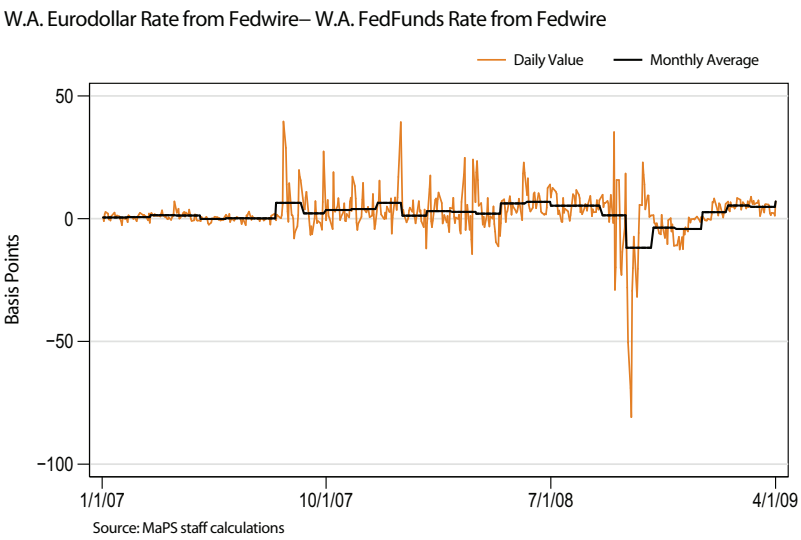


Figure 5

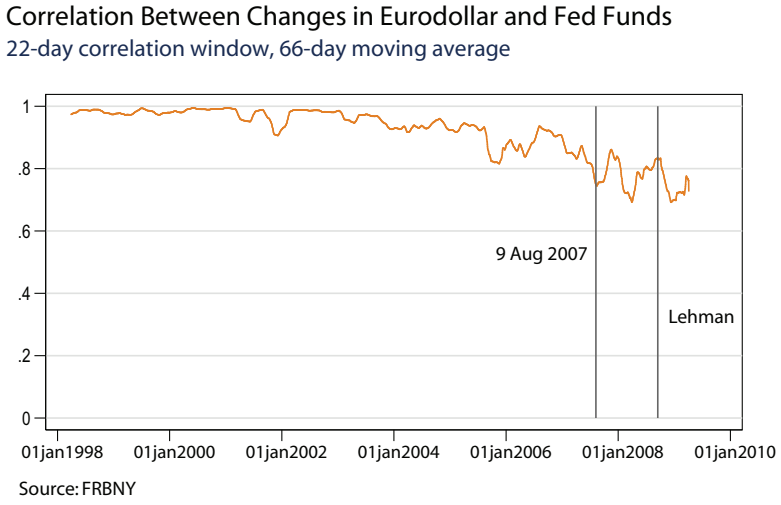


Figure 8

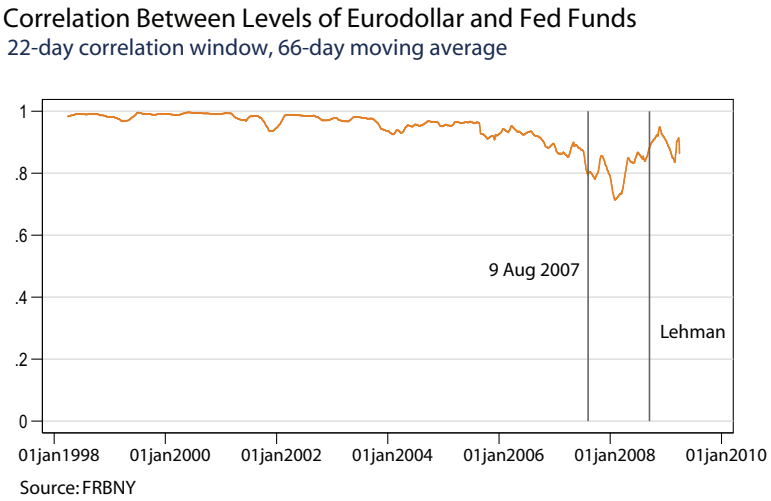


Figure 9

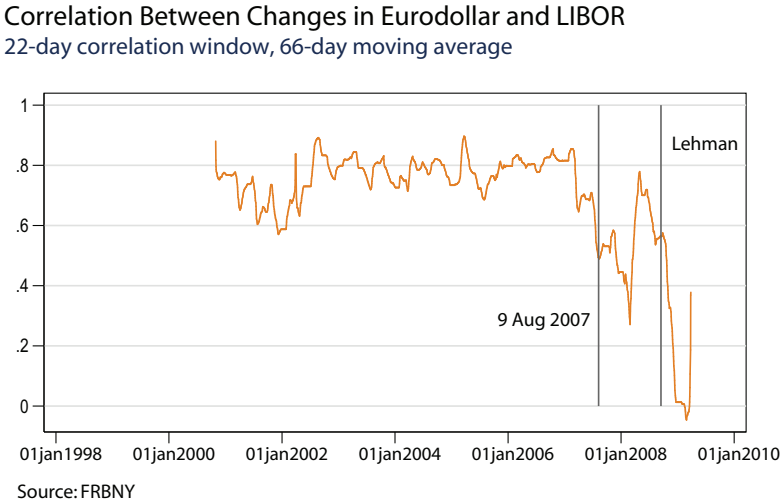
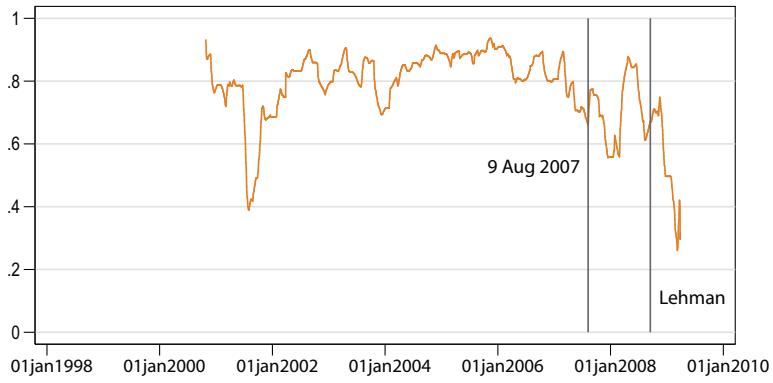


Figure 10

Correlation Between Levels of Eurodollar and LIBOR

22-day correlation window, 66-day moving average

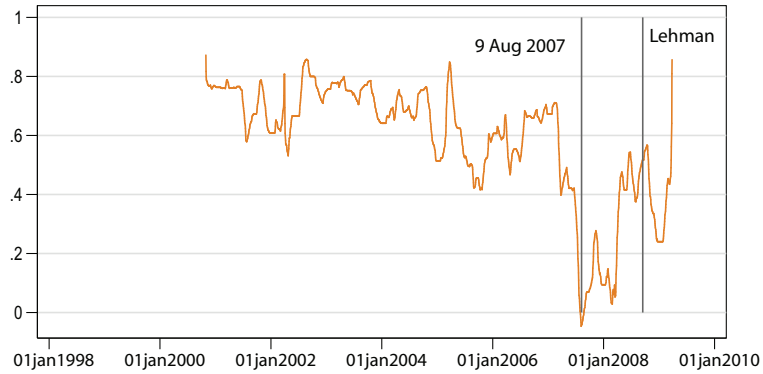


Source: FRBNY

Figure 11

Correlation Between Changes in Fed Funds and LIBOR

22-day correlation window, 66-day moving average

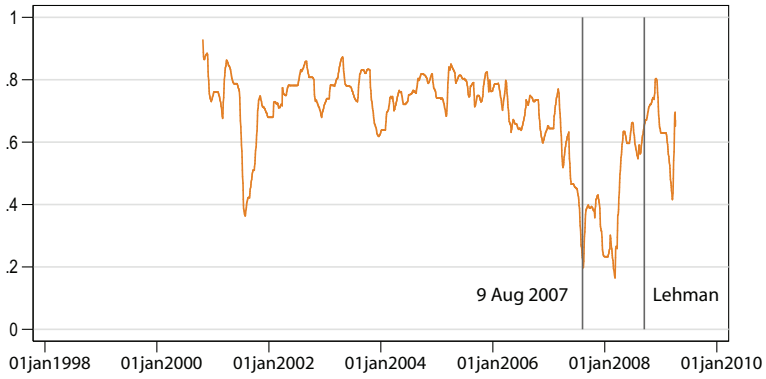


Source: FRBNY

Figure 12

Correlation Between Levels of Fed Funds and LIBOR

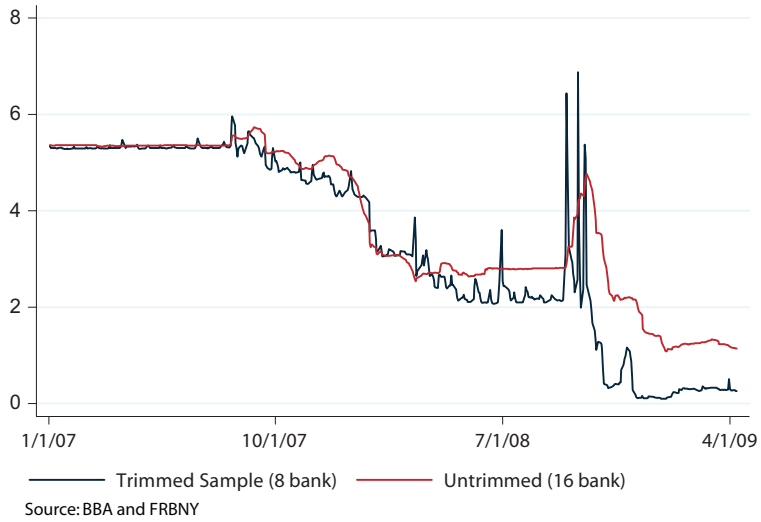
22-day correlation window, 66-day moving average



Source: FRBNY

Figure 13

Comparison of Trimmed and Untrimmed LIBOR Rates



Source: BBA and FRBNY

Figure 14

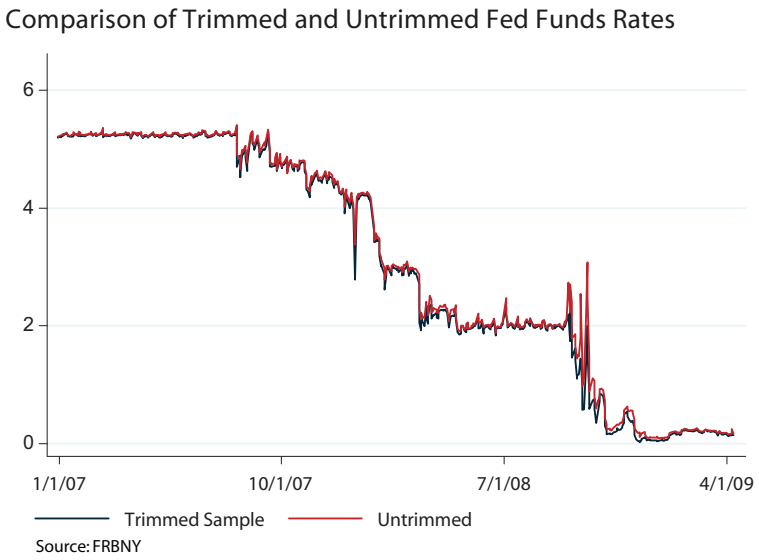

Comparison of Trimmed and Untrimmed Fed Funds Rates
6
4
2
0
1/1/07
10/1/07
7/1/08
4/1/09
Trimmed Sample
Untrimmed
Source: FRBNY

Figure 15

TABLE 1
Summary Statistics

	Eurodollar	FedFunds	LIBOR
Total Volume	1584111	2867514	
Avg Daily Volume	954	1726	
Avg Daily Value	$134,988,728,770	$156,020,191,574	
Mean Transaction Size	$141,540,760	$90,374,288	
Median Transaction Size	$74,920,048	$35,997,050	
Avg Deviation from Target	0.011	0.003	0.072
High Deviation from Target	8.343	8.121	0.715
Avg Standard Deviation	0.107	0.101	0.799

Note: Data come from MaPS staff calculations and Bloomberg for the period 1/1/2001 - 8/8/2007.

TABLE 2
Estimation Summary

	Post Lehman Bros Bankruptcy Period		Elevated Libor-OIS Spread Period		TAF Levels		FX Swap Levels	
	Level	Volatility	Level	Volatility	Level	Volatility	Level	Volatility
Trimmed Mean Coefficient Estimates								
LIBOR-Fed Funds	88.41***	-2.06***	4.60***	0.39***	0.013	0.001	-0.03***	-0.001
Eurodollar-Fed Funds	-6.89	0.43	0.35	1.20***	0.009**	0.002	-0.011**	-0.005**
LIBOR-Eurodollar	64.47**	-1.98***	2.32*	0.31**	0.010	0.002	-0.013	-0.002
Un-trimmed Mean Coefficient Estimates								
LIBOR-Fed Funds	1680***	0.13	2.74	0.12	-0.014	0.000	0.043*	-0.001
Eurodollar-Fed Funds	-40.54***	-0.73	-1.29**	1.08***	0.020***	0.000	-0.019***	0.002
LIBOR-Eurodollar	897.9***	-0.56	-2.04	0.05	0.012	0.000	0.058**	0.000

	Fed Funds Standard Deviation		LIBOR Standard Deviation	
	Level	Volatility	Level	Volatility
Trimmed Mean Coefficient Estimates				
LIBOR-Fed Funds	15.66***	6.034***	0.15	0.049**
Eurodollar-Fed Funds	1.545***	4.944***	0.01	0.02
LIBOR-Eurodollar	14.42***	5.566***	0.188*	0.042**
Un-trimmed Mean Coefficient Estimates				
LIBOR-Fed Funds	7.307***	4.452***	-0.142*	0.049***
Eurodollar-Fed Funds	5.960***	8.512***	0.01	-0.02
LIBOR-Eurodollar	0.13	2.877***	-0.303***	0.077***

Note: Significance indicated by *** p<0.01, ** p<0.05, * p<0.1

TABLE 3
Estimation Results

	Overnight LIBOR (USD) - W.A. FedFunds Rate from Fedwire		Overnight LIBOR (USD) - W.A. Eurodollar Rate from Fedwire		W.A. FedFunds Rate from Fedwire - W.A. Eurodollar Rate from Fedwire	
Variable	Mean	Variance (Het)	Mean	Variance (Het)	Mean	Variance (Het)
After a 3 Day Holiday	-3.377***	-0.381	-3.047***	-0.690***	-0.435***	-0.0951
	(0.31)	(0.24)	(0.28)	(0.23)	(0.09)	(0.25)
Before a 3 Day Holiday	0.215	0.221	0.0173	0.214	0.093	0.185
	(0.34)	(0.22)	(0.33)	(0.22)	(0.10)	(0.24)
15th of Month	-0.187	0.249	-0.397*	0.253	0.150***	-0.0925
	(0.24)	(0.16)	(0.22)	(0.15)	(0.06)	(0.17)
1st of Month	-0.990***	-0.401*	-0.906***	-0.476**	-0.149**	0.315*
	(0.28)	(0.21)	(0.23)	(0.21)	(0.07)	(0.17)
Last Day of Quarter	6.311***	0.760*	5.763***	0.527	0.449	0.63
	(1.66)	(0.40)	(1.43)	(0.37)	(0.42)	(0.41)
Maintenance Day=2	7.086**	0.517***	7.219**	0.759***	-0.0213	0.524***
	(3.32)	(0.18)	(3.33)	(0.18)	(0.79)	(0.17)
Maintenance Day=3	6.338*		6.560**		-0.0838	
	(3.32)		(3.33)		(0.79)	
Maintenance Day=4	7.876**	0.320*	8.069**	0.621***	0.00241	0.304*
	(3.32)	(0.19)	(3.33)	(0.20)	(0.78)	(0.18)
Maintenance Day=5	7.250**	0.175	7.489**	0.259*	-0.0902	0.278*
	(3.32)	(0.16)	(3.33)	(0.15)	(0.78)	(0.17)
Maintenance Day=6	5.888*	0.407**	6.176*	0.746***	-0.163	0.319*
	(3.32)	(0.17)	(3.33)	(0.17)	(0.78)	(0.16)
Maintenance Day=7	6.321*	0.255	6.475*	0.449***	-0.0768	0.408**
	(3.32)	(0.16)	(3.33)	(0.17)	(0.78)	(0.16)
Maintenance Day=8	5.922*	0.0412	6.199*	0.073	-0.0727	0.363**
	(3.32)	(0.17)	(3.33)	(0.17)	(0.79)	(0.17)
Maintenance Day=9	8.004**	0.586***	7.990**	0.896***	0.177	-0.00668
	(3.33)	(0.16)	(3.33)	(0.17)	(0.79)	(0.18)
Maintenance Day=10	7.403**	0.286*	7.462**	0.447***	-0.00104	0.555***
	(3.33)	(0.16)	(3.33)	(0.17)	(0.79)	(0.17)
Maintenance Day=1	6.180*	0.0402	6.321*	0.198	-0.0578	0.394**
	(3.32)	(0.16)	(3.33)	(0.17)	(0.79)	(0.17)
Last Day of Month	1.079**	0.711***	1.121***	0.752***	0.0675	0.620***
	(0.43)	(0.22)	(0.38)	(0.21)	(0.10)	(0.22)
Penultimate Day of Month	-0.299	0.444*	-0.217	0.167	0.0675	0.131
	(0.30)	(0.23)	(0.25)	(0.24)	(0.07)	(0.18)
First Day of Quarter	-0.597	0.661*	0.0249	0.599*	-0.336	0.432
	(0.93)	(0.34)	(0.83)	(0.34)	(0.26)	(0.29)
Penultimate Day of Quarter	2.149**	0.836***	2.048**	1.146***	0.103	0.0922
	(0.98)	(0.30)	(0.88)	(0.30)	(0.15)	(0.37)

Day of FOMC Meeting	0.367	-0.487*	0.498	-0.586**	0.0323	-0.0469
	(0.39)	(0.26)	(0.37)	(0.29)	(0.09)	(0.20)
Day After FOMC Meeting	-0.693***	-0.0725	-0.523**	-0.104	0.0328	-0.228
	(0.25)	(0.21)	(0.25)	(0.23)	(0.08)	(0.18)
Day Before FOMC Meeting	0.553	0.865***	0.486	1.092***	0.153	0.662***
	(0.47)	(0.21)	(0.44)	(0.20)	(0.09)	(0.18)
Blackout	29.17	4.432	-2.039	0.7	7.860***	5.201
	(22.40)	(19.70)	(5.14)	(5.13)	(2.37)	(3.95)
11-Sep-01	-4.097*	1.756***	2.22	1.925***	0.813	0.938**
	(2.49)	(0.46)	(2.02)	(0.44)	(4.39)	(0.47)
Post Lehman Bros Bankruptcy Period	88.41***	-2.062***	64.47**	-1.975***	-6.886	0.427
	(16.70)	(0.49)	(25.40)	(0.47)	(5.28)	(0.84)
Interest on Reserves Period	12.94*	0.882	8.202	0.774	-0.0317	2.599***
	(7.56)	(0.73)	(8.11)	(0.72)	(2.26)	(0.87)
Zero to 25 Basis Points Target Period	4.35	0.431	-1.129	0.398	1.687	2.364***
	(5.97)	(0.66)	(6.21)	(0.65)	(2.16)	(0.79)
Elevated Libor-OIS Spread Period	4.595***	0.389***	2.321*	0.310**	0.347	1.202***
	(1.40)	(0.13)	(1.38)	(0.13)	(0.44)	(0.20)
Change in Target Rate	-1.379		-3.797**		0.57	
	(1.78)		(1.83)		(0.43)	
Day After Fifteenth	0.547**	0.0233	0.282	-0.035	0.262***	0.268*
	(0.22)	(0.18)	(0.20)	(0.18)	(0.07)	(0.15)
Markets Reported Stdev	15.66***	6.034***	14.42***	5.566***	1.545***	4.944***
	(1.24)	(0.36)	(1.14)	(0.32)	(0.35)	(0.37)
Libor Panel Stdev	0.145	0.0491**	0.188*	0.0420**	0.0144	0.0177
	(0.10)	(0.02)	(0.10)	(0.02)	(0.02)	(0.03)
FX Swap Outstanding	-0.0252***	-0.00146	-0.0128	-0.00228	-0.0107**	-0.00485**
	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
TAF Outstanding	0.0132	0.000533	0.0104	0.00151	0.00918**	0.00153
	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
And 01	2.66	-0.0937	1.963	0.0122	0.0697	-0.488
	(2.45)	(1.10)	(2.36)	(1.11)	(0.77)	(0.83)
FX Swap Announcements	-0.987	0.491	-1.32	0.428	0.736	-0.871
	(3.56)	(0.86)	(3.43)	(0.90)	(1.18)	(0.64)
TAF Announcements	1.412*	0.0874	0.903	0.166	0.223	-0.612**
	(0.73)	(0.33)	(0.74)	(0.32)	(0.24)	(0.26)
ECB Announcements	-0.196	-0.912***	0.702	-0.483	-0.00967	0.502
	(0.55)	(0.31)	(0.62)	(0.29)	(0.40)	(0.34)
Time Zone	-0.115	-0.206	-0.194	-0.096	0.0188	-0.299*
	(0.66)	(0.19)	(0.67)	(0.17)	(0.16)	(0.17)
Constant		1.004		0.208		-0.0975

		(0.98)		(0.87)		(0.84)
Absolute Value of Change in Target Rate		3.721***		3.716***		1.413**
		(0.64)		(0.66)		(0.70)
	ARMA	ARCH	ARMA	ARCH	ARMA	ARCH
First Lag of Dep. Var.	0.602***		0.609***		0.394***	
	(0.02)		(0.02)		(0.02)	
Second Lag	-0.0671***		-0.0395*		0.0447**	
	(0.02)		(0.02)		(0.02)	
Third Lag	0.0306*		0.0291*		0.0595***	
	(0.02)		(0.02)		(0.02)	
Fourth Lag	0.0088		0.0091		0.0101	
	(0.01)		(0.01)		(0.02)	
Fifth Lag	0.0295***		0.0364***		0.00672	
	(0.01)		(0.01)		(0.02)	
Sixth Lag	-0.00395		-0.00789		0.0168	
	(0.01)		(0.01)		(0.02)	
Seventh Lag	0.000672		0.00951		0.00545	
	(0.01)		(0.01)		(0.01)	
Eighth Lag	0.0086		0.0148		0.0348**	
	(0.01)		(0.01)		(0.02)	
theta		0.0962***		0.0829**		0.0834**
		(0.04)		(0.04)		(0.04)
kappa		0.505***		0.563***		0.397***
		(0.06)		(0.06)		(0.06)
lambda		0.473***		0.513***		0.301***
		(0.02)		(0.02)		(0.04)
Observations	2025	2025	2025	2025	2026	2026

Note: Standard errors in parentheses, p-values given by (*** p<0.01, ** p<0.05, * p<0.1).