A comparison of Libor to other measures of bank borrowing costs

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Abstract

Libor is a survey-based measure of bank borrowing costs that plays a central role in fixed-income markets. There is an active discussion about how well Libor summarized funding conditions during the recent financial crisis. In this paper we match and compare bank Libor survey responses to two novel measures of borrowing rates: 1) bank bids at the Federal Reserve Term Auction Facility and 2) inferences of term borrowing from Fedwire payments data. We find that Libor survey responses broadly track these alternative measures between 2007-09, although Libor lies below them at certain times, particularly at the height of the crisis. Libor quotes are also less diffuse than rates from the matched TAF and Fedwire data. We discuss a range of factors that could account for these differences. We also find that other public data beyond Libor are moderately informative about bank funding costs.

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1. Introduction

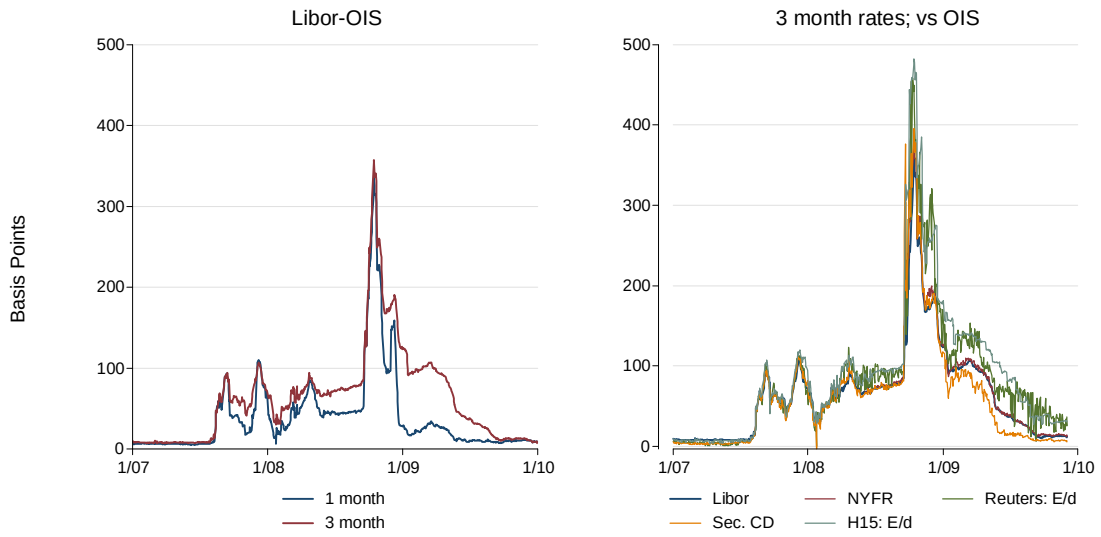
There is currently an active discussion about how well Libor (the London Interbank Offer Rate) summarizes bank funding costs, particularly during periods of stress such as the 2007-09 financial crisis. Libor is a survey-based measure of bank borrowing costs that is used to index some $360 trillion of notional financial contracts (source: British Bankers' Association, BBA), ranging from interest rate derivatives to adjustable-rate mortgages and corporate loans. Libor is also widely used in academic research, and market participants and policy makers rely on it to measure funding stress during crisis periods. Understanding the behavior of Libor is an important research topic, in light of the central role that Libor plays in fixed-income markets.

This paper presents new evidence on the properties of U.S. dollar Libor by comparing it to two novel micro measures of bank borrowing costs during the 2007–09 crisis period: 1) bank bids at the Federal Reserve Term Auction Facility (TAF) and 2) inferences of term borrowing from Fedwire Funds Service ("Fedwire") payments data. We analyze the size and direction of differences between Libor survey responses and these alternative funding cost measures over different phases of the crisis. We also study determinants of these observed differences, to help shed light on their cause.

Figure 1 documents the well-known spike in U.S. dollar Libor during 2007–09, reflecting credit and liquidity risk in bank wholesale funding markets.[1] Perhaps less well known is how Libor differed from other indexes of unsecured bank funding: the right-hand panel of figure 1 illustrates the significant dispersion (of up to 100 basis points or more) *across* measures of unsecured bank funding rates during this span. Measuring bank funding costs is challenging because interbank markets are relatively illiquid, and operate on a decentralized over-the-counter (OTC) basis. Reflecting these factors, Libor itself is not derived directly from actual loan transactions. Instead, the Libor fixing rate is computed as a trimmed mean of responses to a daily market survey, in which each member of a panel of large banks estimates the rate at which it could borrow on the interbank market at different maturities between overnight and one year.

[1] Libor is a measure of banks' unsecured term wholesale borrowing rates. The maturity-matched OIS (overnight index swap) rate measures risk-neutral expectations of unsecured overnight borrowing rates over the same term. The difference between the two yields reflects credit and liquidity risk. An interbank loan exposes the lender to much greater risk because they transfer the entire loan principal to the borrower, unlike an interest rate swap. Note that while Libor is measured in 10 currencies, this paper focuses on an analysis of U.S. dollar Libor (i.e., the estimated rate on interbank loans denominated in U.S. dollars).

Figure 1: Spreads of Libor and Other Unsecured Bank Funding Rates over OIS



A range of factors could cause Libor to diverge from other measures of bank funding costs, particularly during periods of market stress. One issue highlighted by market observers is that term interbank markets become less liquid during crisis periods, making it more difficult for banks to estimate their own borrowing costs. A second issue is that markets become more segmented; for example the Eurodollar borrowing costs of a U.S. bank holding company's foreign subsidiaries may differ significantly from the unsecured borrowing costs of same firm's parent holding company or domestic commercial bank. A third aspect of the debate is the claim that Libor survey responses may in some cases have been misreported, perhaps motivated by signaling concerns given that Libor survey quotes are released publicly[2] (see section 2 for a more detailed discussion).

Our main empirical strategy is to compare individual bank Libor survey responses to two sources: 1) banks' bids in auctions for funds at the TAF, and 2) putative term loans inferred from data on banks' payments settled over Fedwire. We match these two sources to the Libor survey responses by institution, maturity, and calendar day. While these alternative measures could diverge in either direction from Libor, several important factors would be expected to lead interest rates measured in

[2] For example, the Financial Times writes: "The Libor setting process is public and closely watched, so a bank that put in relatively high rate estimates could spark investor concern about its strength." ("Probe Reveals Scale of Libor Abuse," *Financial Times*, February 9, 2012), while the Wall Street Journal writes: "Citigroup interest-rate strategist Scott Peng raised similar questions in an April 10 report, writing that 'Libor at times no longer represents the level at which banks extend loans to others.'… If any bank submits a much higher [Libor] rate than its peers, it risks looking like it's in financial trouble. So banks have an incentive to play it safe by reporting something similar — which would cause the reported rates to cluster together." ("Study Casts Doubt on Key Lending Rate," *Wall Street Journal*, May 29, 2008).

the TAF and Fedwire data to lie weakly below the matched rate reported to the Libor survey. For example, Libor is an offer rate, and thus would be expected to lie above a bid or midmarket rate; furthermore, TAF loans are collateralized, while Libor is an unsecured rate. Thus, our analysis in part focuses on analyzing the frequency and magnitude with which these measures of funding costs exceed matched Libor survey responses (contrary to this prior), at different points during the crisis.

Overall, we find that Libor moves quite closely with the TAF and Fedwire measures of funding costs during the crisis. Furthermore, prior to the failure of Bear Stearns in March 2008, banks' Libor quotes only infrequently lie significantly below matched TAF auction bids or inferred loan rates from Fedwire. The prevalence of Libor survey quotes that are significantly below the TAF and Fedwire measures rises in the period between the failures of Bear and Lehman and is highest in the period directly after Lehman's failure. During this window, a majority of interest rate observations in the TAF and Fedwire microdata sources lie above banks' Libor quotes, and the average rate exceeds matched Libor quotes by 31 and 21 basis points respectively. Cross-sectionally, the frequency of observing Libor quotes below the TAF and Fedwire sources is generally greater for non-US banks and banks with higher CDS spreads, two proxies for banks' dollar funding costs.

To complement this evidence, we compare the Libor fixing rate to several alternative public measures of unsecured bank funding costs: the New York Funding Rate (NYFR) developed by interbank broker ICAP, secondary market certificate-of-deposit (CD) yields, and two Eurodollar deposit rate series. We find that this panel of rates moved together closely during the crisis, although Libor lies below these comparison series in the period after the Lehman bankruptcy, consistent with our micro regression estimates. Other public indexes, and particularly NYFR, also contain quantitatively modest but statistically significant incremental information for tracking movements in underlying bank funding costs, as measured by the term Fedwire inferences. This additional informational content may be partially due to the fact that the NYFR survey is conducted during the New York trading session, unlike Libor.

We also study the dispersion of funding rates measured in the TAF and Fedwire data sources, relative to Libor. Cross-sectionally, the distribution of Libor survey responses is significantly less diffuse than matched funding rates measured from either of these measures. Loan rates inferred from Fedwire become much more diffuse (normalized relative to the Libor fixing rate) at the crisis peak.

This result suggests that Libor, or any other aggregate market index, may become less representative of the funding costs facing any *individual* financial institution during a crisis period.

To sum up: overall we find that Libor co-moves closely with other indicators of bank funding costs during the 2007-09 crisis period, although these measures diverge much more around the crisis peak. We conclude that greater market segmentation during crisis periods is likely to make any one market index, such as Libor, less representative of funding conditions facing any individual firm during such periods.

Section 2 discusses reasons why Libor could deviate from the other indicators we consider. For instance, the TAF provided funding to U.S. depository institutions, while the Libor survey is conducted in London, and thus likely represents the funding costs of a different legal entity to the subsidiary bidding at the TAF. Also, Fedwire and TAF results for non-U.S. banks could reflect differences in borrowing costs between the foreign parent and its U.S. subsidiaries, for example because of the parent's greater size. In general, our results do not allow us to disentangle the different explanations discussed in section 2. For this reason, while misreporting by Libor-panel banks would cause Libor to deviate from other funding measures, our results do not indicate whether or not such misreporting may have occurred.

A particular source of variation between Libor and our Fedwire inferences is that matched Fedwire transactions used in this paper are noisy inferences based on a statistical algorithm, not direct observations of interbank loans. The type of algorithm we use was first developed by Furfine (1999, 2000) to study the overnight federal funds market[3]; our analysis makes use of a new algorithm extending this approach to *term* transactions (see Kuo, Skeie, Vickery, and Youle, 2012). As with overnight maturities, we emphasize that payment pairs identified by this approach may not correspond closely to actual interbank loans. The inferences from the algorithm may misclassify transactions as loans, may fail to identify some actual loans, or may misclassify the counterparties to some loans. As one robustness test, we compare the Fedwire evidence to results based on TAF bidding data, which is observed without error, and other public data such as NYFR. In general, our findings are similar across these approaches, although we also note some differences across them.

[3] Results of this overnight algorithm have subsequently been used for a range of other research. Recent examples include Afonso, Kovner and Schoar (2011), Ashcraft, McAndrews, and Skeie (2011) and Ashcraft and Duffie (2007).

We additionally note that the other comparison measures of funding costs we consider also have their own limitations; for example the interpretation of TAF bidding behavior is model-dependent, given that it reflects an indication of a willingness to pay, not the actual market-clearing interest rate paid by successful auction bidders.

2. The Controversy over Libor

Libor is the primary reference rate for the term U.S. dollar wholesale borrowing market. (Libor is published in 10 currencies in total; we focus on dollar Libor because of its importance and because our microdata measure U.S. dollar–funding costs.) The Libor fixing rate is computed as the interquartile trimmed mean of reported interbank offer (ask) rates provided each day by a panel of large banks in the London trading session (at 11 a.m. London time). During the period of this study, the dollar Libor panel consisted of 16 banks. It was expanded to 20 banks in 2009, in part to allow greater representation of U.S. banks, and as of November 2011 consists of 18 banks.

Each panel bank responds to the following question for different maturities: *At what rate could you borrow funds, were you to do so by asking for and then accepting interbank offers in a reasonable market size just prior to 11 a.m. [6 a.m. EST]?* Libor is collected for maturities of overnight, one week, two weeks, and monthly for 1 to 12 months. While Libor refers specifically to the rates at which banks can borrow from other banks, market participants interpret it more generally as the rate at which banks can broadly borrow unsecured short-term wholesale funds.

Throughout the crisis, a number of observers in the financial press and financial industry have argued that Libor at times lay below actual costs of interbank market funding. As early as September 2007, Wrightson, the research arm of interbank brokerage ICAP, reported claims by market participants that one-month Libor was lower than actual borrowing rates.[5] In the period after the collapse of Bear Stearns, the *Wall Street Journal* reported market claims that three-month Libor was understated by 20–30 basis points.[6] The *Wall Street Journal*'s follow-up analysis, based on comparing banks' CDS yields to their Libor quotes, estimates that banks underreported their cost of borrowing by 25 basis points on average.[7]

[5] Wrightson ICAP, *Money Market Observer*, September 3, 2007.
[6] "Libor Fog: Bankers Cast Doubt on Key Rate amid Crisis," *Wall Street Journal*, April 16, 2008.
[7] "Study Casts Doubt on Key Rate," *Wall Street Journal*, May 29, 2008.

Related academic literature on Libor has produced mixed results. Snider and Youle (2010) identify evidence of bunching in the statistical distribution of Libor quotes, which they interpret as evidence of manipulation. Related, Abrantes-Metz, Villas-Boas and Judge (2011) find that the statistical second-digit distribution of the Libor fixing deviates from the distribution implied by Benford's law. Abrantes-Metz et al. (2012), however, find no systematic evidence of Libor manipulation based on a comparison of Libor quotes to matched CDS spreads; similarly Schwarz (2010) finds no evidence of bias in euro Libor early in the crisis based on data from e-MID, an Italian interbank exchange. Cassola, Hortacsu, and Kastl (2011) find estimated willingness-to-pay for euro-denominated funds lies above Libor at a one-week maturity. Gyntelberg and Wooldridge (2008) note that dollar Libor differed from Eurodollar rates through January 2008 but do not conclude that Libor is mismeasured. Gefang, Koop and Potter (2011) develop a dynamic factor model of Libor-OIS spreads.

Reflecting the importance of ongoing concerns about Libor, recent media reports state that an international inquiry involving regulators in the United States, Europe, and Japan is investigating alleged Libor discrepancies during the 2007-09 financial crisis. As reported by the *Financial Times* and other media organizations in the first quarter of 2012, this inquiry is investigating whether banks underreported Libor, either individually or collusively.[8] Panel banks reportedly are also facing a range of civil legal action seeking damages relating to Libor manipulation. Initial investigations into Libor's quality by the BBA in 2008 and 2009 concluded that the index is reliable.[9] In March 2012 however, the BBA convened a steering committee to explore reforms to Libor, involving global banks, a wholesale broker and the Chicago Mercantile Exchange.[10]

Our paper contributes to the academic literature and media reports described above by matching Libor quotes directly to two novel alternative maturity-matched indicators of funding costs. As already emphasized, however, our results do not enable us to draw conclusions as to whether or not

[8] "Probe Reveals Scale of Libor Abuse," *Financial Times*, February 9, 2012. See also "Brokers Suspended in Libor Inquiry," *Financial Times*, February 8, 2012; "Bank Lending Probe Lights up Dark Financial Corners," *Financial Times*, February 9, 2012; "Libor Penalty," *Financial Times*, February 10, 2012; "Deutsche Bank Gets Data Request in Libor Probe", March 20, 2012, and "BBA To Launch Crackdown on Libor Rates", March 28, 2012. According to these articles, more than a dozen traders across several banks have already lost their jobs or been placed on administrative leave as a result of evidence uncovered thusfar. Media reports also speculate that eventual civil damages associated with Libor misreporting may prove to be very large.

[9] The Wall Street Journal reported on May 29, 2008 that: "The BBA says Libor is reliable, and notes that the financial crisis has caused many indicators to act in unusual ways. `The current situation is extraordinary,' said BBA Chief Executive Angela Knight in an interview. A BBA spokesman says there is `no indication' that the default-insurance market provides a more accurate picture of banks' borrowing costs than Libor."

[10] See "BBA To Launch Crackdown on Libor Rates", *Financial Times*, March 28, 2012.

Libor misreporting occurred during this period, given that other factors could also account for our empirical findings.

2.1 Factors affecting differences between Libor and other funding cost measures

This paper studies differences between Libor quotes and other measures of bank funding costs. Below, we consider a number of reasons why such differences may arise, particularly during periods of market stress:

1. **Libor is an offer rate.** Libor measures the rate at which banks estimate they would be *offered* unsecured funds, not the rate at which they would accept those offers. Given the presence of a bid-ask spread, this would lead Libor to be higher than the average *observed* loan rate. When bid-ask spreads are large, such as during a crisis period, this difference will widen. For example, Brunetti, di Filippo, and Harris (2010) find using e-MID data that Euro-denominated interbank bid-ask spreads widened significantly during the 2007–08 crisis.
2. **Imperfect internal capital markets.** Borrowing costs may vary significantly amongst different subsidiaries of the same bank holding company, especially when comparing bank or nonbank subsidiaries, or legal entities domiciled in different countries. This reflects frictions in a bank's ability to transfer funds internally. A range of research in economics has documented these frictions in "internal capital markets" – in the case of commercial banking, flows of funds and capital across subsidiaries are also explicitly limited by regulation. For example, regulations require a bank holding company to act as a "source of strength" for its commercial banking subsidiaries, but limit the extent to which a banking subsidiary can support non-banking subsidiaries. These differences are important in our setting, since TAF bids were placed by commercial banks in the U.S. and foreign branches of banks operating in the U.S., which would be generally expected to have different dollar borrowing costs than UK-domiciled affiliates.
3. **Borrower sample differences.** The Libor panel consists of large banks, most of which are non-U.S. firms. Borrowing in the broader U.S. dollar interbank market includes a larger cross-section of banks, which may be of higher or lower credit quality on average than banks in the panel. For example, foreign bank organizations may have less access to domestic retail dollar funding and thus greater need to borrow in wholesale markets than domestic banks.
4. **Lender sample differences.** The Libor panel is asked to report the rate at which they can borrow from another bank. Bank wholesale borrowing includes funding from nonbanks such

as money market funds, which may have less market power than large banks. This may affect the distribution of observed interbank rates. One way to test the importance of lender effects is to attempt to separately analyze lending in federal funds, which is defined to be lending by banks or government-sponsored enterprises (GSEs), from Eurodollar lending, which may originate from nonbanks.

5. **Selection effect within the Libor panel.** Even just restricting attention to borrowing by Libor panel banks, the Libor fixing rate is based on a trimmed mean across all institutions, some of which may not borrow in the term interbank market on a given day. The banks that do borrow may have a lower or higher cost of funds than the panel trimmed mean.
6. **Size effects.** The Libor survey asks banks to report a rate at which they could receive funds "in reasonable size." Thus, traded volumes at smaller sizes, or very large sizes, may deviate from Libor.
7. **Liquidity effects and hypothetical estimation.** The term interbank market became smaller and less liquid during the financial crisis, as documented in Kuo et al. (2012). This may make it more difficult for firms to reliably estimate their funding costs, generating noise in Libor.
8. **Timing and location effects.** Banks report their cost of funds in the London market at 11am London time. Many dollar interbank loans however are brokered in New York. The interbank market may be less liquid in London before the New York session opens. Dollar borrowing costs are expected to be lower in the New York session than in London, and the differences of borrowing costs for affiliated banks in New York and London may vary as explained in the point above on "Imperfect internal capital markets."
9. **Stigma.** Banks may face stigma associated with borrowing from particular funding sources, for example because such borrowing reveals information to counterparties about the bank's financial condition.
10. **Measurement error.** As discussed in the introduction, our matched Fedwire transactions are noisy inferences based on a statistical algorithm, not direct observations of interbank loans. Thus, misclassification or measurement error could generate differences between inferred rates from these matched transactions and bank Libor quotes. While our TAF data is measured without error, bidding mistakes by banks could generate differences between these bids and matched Libor quotes.

2.2 The New York Funding Rate

ICAP developed its NYFR index of bank funding costs as a complement to Libor. It has been published since June 2, 2008. NYFR's methodology is modified from the Libor survey design in several respects: (i) ICAP does not publish individual bank reported rates or the set of survey contributors; (ii) NYFR is based on a larger set of contributors and collects midmarket rates rather than an offer rate; (iii) rates are measured at 9:15 a.m. EST, when the New York session is active and Eurodollar trading in London is most active; and (iv) the survey asks contributors to estimate market borrowing rates for a representative A1/P1 institution rather than the contributor's own funding costs. NYFR also asks contributors to estimate the funding costs for a broader pool of unsecured funding instruments such as unsecured certificates of deposit and commercial paper, in addition to interbank loans, and from a broader range of lenders, including money market mutual funds and government-sponsored enterprises, in addition to other banks.

In section 5, we compare Libor fixings to NYFR and to several other public indexes of unsecured funding costs. These include secondary yields on large uninsured CDs; a Eurodollar-funding rate reported by Reuters FT based on an electronic-screen broker quote; and the H.15 Eurodollar deposit rate, an offered broker quote reported in the Federal Reserve's H.15 report based on data from ICAP.

3. Data

Our analysis focuses on two distinct but complementary microeconomic sources of information on bank funding costs, which we compare to Libor and to other public indexes. First, we use individual bid data from the Federal Reserve's TAF. This facility relied on an auction mechanism to lend secured funds to depository institutions during the financial crisis. Second, we examine inferred transaction rates that banks paid in the interbank market, using an algorithm that matches transaction pairs from payments settled over Fedwire, the predominant U.S. dollar large-value payment system. Although these inferences are likely to be noisier estimates of bank borrowing rates than the TAF bids, they cover a broader time period and maturity spectrum and are available continuously throughout 2007–09, not just on specific auction dates.

For Libor-panel banks, we match each observation from these two data sources to the bank's corresponding individual survey quote for the same bank, calendar date, and maturity. This matching

is done at the bank holding company level.[11] Our analysis then studies differences between banks' Libor quotes and our matched microeconomic measures of funding costs.

3.1 Term Auction Facility

The Federal Reserve announced the creation of the TAF on December 12, 2007, with a stated aim of relieving funding pressures in short-term money markets by auctioning secured funds to eligible depository institutions. The first TAF auction took place on December 17, 2007; auctions continued approximately once every two weeks until March 8, 2010, when the program was wound down. Initially, $20 billion was allocated per auction, with a loan term of 28 days. At the crisis peak, up to $150 billion was allocated per auction, and funds were auctioned at both 28- and 84-day maturities.

Eligible institutions could submit up to two bids at each auction, each consisting of an interest rate and a quantity of funds desired. Funds were then allocated to bidders in decreasing order of the interest rate, until either the amount of funds to be allocated was exhausted or all bids had been filled. A uniform-price auction mechanism was used (that is, each successful institution paid the same market-clearing interest rate, known as the "stop-out" rate, rather than its individual bid rate). Each TAF loan was secured based on the same range of allowable collateral as discount window loans. To ensure broad participation, TAF bidding by any individual participant was limited at each auction to 10 percent of the total amount of funds available. For more details of the design and effects of the TAF, see McAndrews, Sarkar, and Wang (2008) and Armantier et al. (2011).

Our analysis focuses on TAF bidding behavior by Libor-panel banks at auctions conducted before October 2008; this subsample includes 21 TAF auctions for 28-day funds and 2 auctions for 84-day funds. We exclude later auctions because they are consistently undersubscribed, primarily due to an increase in the amount of funds offered at each auction to $150 billion.[12] Since banks during this later period could consistently expect to borrow the full allotment of their bids at the TAF minimum bid rate, their individual bids are likely to be less informative about their actual cost of funds. (Armantier

[11] The 16 banks on the Libor panel during our sample period are Barclays Bank plc, Bank of Tokyo Mitsubishi UFJ Ltd, HSBC, Royal Bank of Scotland Group, UBS AG, Abbey National, Bank of America, Citibank NA, Mizuho Corporate Bank, Rabobank, Royal Bank of Canada, WestLB AG, BNP Paribas, Lloyds Banking Group, Deutsche Bank AG, and JP Morgan Chase.

[12] The TAF auction size increased from $75 billion to $150 billion, beginning with the auction on October 6, 2008. The last TAF auction before this one occurred on September 22, 2008. October 6 marked a sharp regime shift: none of the auctions before October 6 were undersubscribed, while each of the auctions from October 6 onward was undersubscribed.

et al., 2011, who also study TAF bidding, similarly disregard these later auctions for the same reason.)

As shown in table 1, many Libor-panel banks were active bidders for TAF funds in the period before October 2008. Of the 16 panel banks, 8.7 participated in an average individual auction, within a range of 3 to 13 panel banks. The average number of bids was 12.0, exceeding the number of bidders because banks were allowed to place up to two bids per auction. In cases where two bids were placed by a panel bank, our baseline analysis focuses on their higher bid, which reflects the bank's maximum willingness-to-pay for TAF funds. Our results are also robust to alternative treatments of multiple bids, however, as discussed in Section 6.

[Insert Table 1 here]

Bids placed by these Libor-panel banks provide useful information about banks' marginal cost of funds, which can be compared to the same bank's responses to the Libor survey for the same calendar day and loan maturity. As discussed in section 4, a bank's TAF bids are expected to lie below the rate at which they would be offered unsecured funds, as measured by their Libor quote, based on several factors and in particular because borrowing at the TAF requires pledging collateral, which is costly.

Note that our analysis focuses on banks' *bid* rates, not the auction stop-out rate. We do this because banks bid rates are likely to be a closer measure of their opportunity cost of funds. One disadvantage is that these bid rates do not represent the rate at which the bank actually received funds. This is because TAF was a single-price auction in which all successful bids borrowed at a common stop-out rate. In general, TAF stop-out rates lay below Libor, although there were a small number of auctions where this was not the case.

3.2 Fedwire inferences

Alongside TAF bids, we also analyze the results of an algorithm developed by Kuo et al. (2012) designed to identify term wholesale loans passing over Fedwire, the real-time gross settlement payment system operated by the Federal Reserve to settle large-value fund transfers among member financial institutions. Fedwire's membership consists primarily of U.S. domiciled depository institutions, including domestic branches and subsidiaries of non-U.S. banks; it also includes Federal

Reserve banks, Fannie Mae, Freddie Mac, the Federal Home Loan banks, the Bank for International Settlements, foreign central banks and certain other institutions and agencies.

The algorithm is applied to a dataset containing characteristics of each payment settled over Fedwire, including: (i) the identity of the sending and receiving institutions; (ii) the payment date and time; (iii) the dollar amount sent; and (iv) a business function code indicating the transaction type, which can be used to help distinguish term federal funds loans from Eurodollar deposits.[13] Within these data, the algorithm identifies back-and-forth payment pairs whose characteristics are consistent with a term interbank loan. Specifically, the algorithm searches for a large round-amount payment, followed by a return payment on a later date for a slightly larger amount, such that the implied annual interest rate is a round number of basis points and the transaction meets certain other criteria. The approach is an extension to term maturities of the approach developed by Furfine (1999, 2000) for studying the overnight federal funds market. This overnight algorithm has been used in a large body of subsequent research (e.g. Afonso, Kovner, and Schoar 2011; Ashcraft, McAndrews, and Skeie 2011; Ashcraft and Duffie 2007).

It is important to highlight that the output of both the Kuo et al. (2012) term algorithm and the Furfine overnight algorithm are *inferences* and do not represent direct data on term interbank loans. Furthermore, it is difficult to fully assess the size of type I and type II errors associated with these algorithms that match pairs of bank payments as term interbank loans. Kuo et al. (2012) do present a number of validation exercises for the inferences of the term interbank loan methodology. For example, the distribution of loan rates from transaction pairs identified by the algorithm is shown to be tightly clustered around the Libor fixing rate in the period before the onset of the financial crisis. This finding suggests the algorithm has a high signal-to-noise ratio in identifying related payment pairs. Even so, we emphasize that the transactions identified by the algorithm may not correspond closely to actual interbank loans, and that external validation of the algorithm is difficult.

[13] Eurodollar deposits are predominantly dollar deposits held outside the United States but also include deposits with domestic nonbanks (e.g., domestic finance companies) and with U.S. depository institutions in segregated international banking facilities. Matching Fedwire data to a direct dataset on interbank loans from a broker, McAndrews (2009) and Bartolini, Hilton, and McAndrews (2008) show that a Fedwire business function code value of "*CTR – Final beneficiary is not a bank*" is highly indicative of a Eurodollar trade settled over Fedwire (as opposed to a federal funds loan). We use this identifier in our empirical analysis as an indicator of a Eurodollar loan. This identifier is also used in a similar way by Afonso, Kovner, and Schoar (2010) and several other papers.

The Kuo et al. (2012) algorithm likely identifies several types of bank unsecured wholesale funding: (i) direct borrowing by domestic banks through the term federal funds market; (ii) Eurodollar deposits held with non-U.S. banks settled on Fedwire through their U.S. branches or subsidiaries; and (iii) dollar-denominated correspondent loans to other non-U.S. banks or nondepositories. We use the business function code identifier employed by McAndrews (2009) and Bartolini, Hilton, and McAndrews (2010) as a proxy for whether the transaction pair is a term Eurodollar deposit falling into category (ii) or (iii), rather than a term federal funds loan falling into category (i). In our empirical analysis, we focus on transactions flagged as term federal funds loans, although our results are generally robust to also including Eurodollar deposits in our analysis sample.

We also note that this matching procedure infers only putative interbank loans settled on Fedwire. While Fedwire is the primary U.S. dollar large-value payment system, a significant payment volume is also settled through the alternative platform, the Clearing House Interbank Payments System (CHIPS). Interbank loans may also be settled by a book transfer if the borrowing and the lending bank both hold accounts at a common bank.

Table 2 presents summary statistics for the transaction pairs identified by the Fedwire algorithm over four time periods corresponding to different phases of the financial crisis: (i) from January 1, 2007, to August 9, 2007, the date when BNP Paribas suspended convertibility on two hedge funds, marking the start of problems in interbank and commercial paper markets; (ii) between the BNP Paribas suspension event and the last trading day before the bankruptcy of Lehman Brothers; (iii) the crisis peak, from the Lehman bankruptcy on September 15, 2008, until November 11, 2008 (the first date when one-month Libor falls below its peak pre-Lehman level); and (iv) a "crisis easing" period from November 12, 2008, to March 30, 2009.

[Insert Table 2 here]

Table 2 reports the number of inferred loans at different maturities, average one-month interest rates as a spread to overnight indexed swaps (OIS), average one-month loan size, and loan volumes at different maturities.[14] Perhaps most notably, the one-month interbank loan spread to OIS is only

[14] To produce issuance volume statistics that reflect the market share of each maturity bucket, we multiply daily average issuance volume by the loan term in days. This weighting offsets the fact that short-maturity loans roll over more frequently. After this adjustment, the issuance values reported in table 2 correspond more closely to

around 10 basis points before August 2007 but then rises strikingly, to an average of around 200 basis points during the peak crisis period, before subsiding.

4. Analysis of Panel Survey Responses

This section analyzes individual banks' responses to the Libor survey; specifically, we compare survey quotes to matched TAF bids and Fedwire inferences matched by bank, maturity, and calendar day. We estimate variations on the following regression equation:

$$P\,(\text{Bid/loan rate}_{ijt} - \text{Libor quote}_{ijt} > 0) = a + b.\ \text{crisis dummies}_t + c.\ \text{bank characteristics}_{it} + e \quad , \qquad (1)$$

for a Libor survey quote by bank *i* at maturity *j* on date *t*, where "crisis dummies" is a set of indicator variables for different phases of the financial crisis and "bank characteristics" includes determinants of the bank's expected cost of unsecured dollar funds (including the bank's CDS spread and a non-U.S. bank dummy), and lagged values of the "spread to Libor quote" variable.

As discussed above, there are many reasons why interest rates from TAF and Fedwire could deviate from Libor. However, we note that a number of factors would suggest a prior that TAF bids and interest rates on inferred unsecured loans settled on Fedwire would lie at least weakly below a bank's Libor survey response (i.e., "Bid / loan rate_{jit} – Libor quote_{jit}" would generally be expected to be a negative number). This prior reflects a combination of factors, as follows (note that the final two of these arguments apply only to TAF bids):

1. The Libor survey requires banks to estimate an offer rate (i.e., the rate at which counterparties would offer to supply funds). These offers would not necessarily be accepted if uncompetitive. For this reason, the offer rate will be an upper bound for their marginal cost of unsecured funds, or for the average rate on completed transactions, as inferred in Fedwire.[15] It seems likely that this gap between offer and midmarket rates would increase

outstanding loan volumes (and would exactly correspond in steady state). A simple example: assume interbank lending consists of an overnight loan of size $1 and a two-day loan of $1, both of which are rolled over at maturity. Outstanding overnight loan volume is always $1, as is outstanding term loan volume. But term issuance each day is only $0.50, compared to $1 of overnight loan volume, since the two-day loan is rolled over only every two days.

[15] For example, assume the unsecured offer rate for a particular bank in three successive days is 1.4 percent, 1.8 percent, and 1.6 percent, and the bank's willingness-to-pay for a positive quantity of unsecured funds (i.e., the *y*-intercept of the bank's funding demand curve) is 1.5 percent. The average Libor quote in this example is 1.6 percent. However, the average rate on completed transactions is 1.4 percent, since the offer would be accepted only on the first trading day. On this day, the bank would borrow enough funds so that its marginal willingness-to-pay is 1.4 percent.

during the financial crisis, reflecting greater credit and liquidity risk during such periods (e.g. as documented by Brunetti et al., 2010).

2. TAF loans are secured, while the Libor survey measures banks' unsecured cost of funds. The requirement to pledge collateral for a TAF loan imposes an additional opportunity cost on the bank, relative to obtaining an unsecured loan in the interbank market, which would in turn reduce their willingness-to-pay.
3. Although the TAF is a single-price rather than a discriminatory auction, banks may still have incentives to bid strategically (i.e., to bid below their willingness-to-pay). This will be the case if there is a positive probability that the bank will be the marginal bidder at the auction and thus has a nonzero expected impact on the auction stop-out rate (see Armantier et al. 2011 for a more complete discussion of this issue).[16]

4.1 Baseline results

Table 3 presents results from estimating variants of equation (1) for both the TAF bid data and the matched Fedwire loans, including as explanatory variables a simple set of time dummies tracing out different phases of the crisis.[17] In each case, we estimate three specifications, where the dependent variable in turn is: (i) a dummy indicating whether the bid or loan rate exceeds the matched Libor quote; (ii) a dummy for whether this "spread to Libor quote" exceeds +20 basis points; or (iii) the spread itself.

[Insert Table 3 here]

Note that no constant term is included, so that the coefficients in table 3 directly measure the average value of the dependent variable during each subperiod. Before the failure of Bear Stearns, the average "spread to Libor quote" is insignificantly different from zero, and the TAF bid or loan interest rate exceeds the bank's matched Libor quote only rarely. For example, reading off the first three columns of table 3, the average TAF bid by Libor-panel banks was 23.6 basis points below the bank's same-day Libor survey response before March 15, 2008; during this period, the Libor quote

[16] Moreover, TAF auctions were offered approximately only once every two weeks, whereas interbank loans could in principal be arranged on any day; furthermore, TAF auctions settled on a T+3 basis rather than the T+2 basis standard in the interbank market (Stigum and Crescenzi, 2007). TAF may thus be slightly less timely as a source of liquidity, leading to a potential lower willingness-to-pay.

[17] For the Fedwire analysis, we focus on maturities between one month and sox months, since these are the Libor terms most widely used for financial contracting. These maturities also form a large majority of overall Fedwire-inferred term volume, as shown in table 2.

spread is positive in only 7.8 percent of cases and > +20 basis points in only 1.3 percent of cases, statistically indistinguishable from zero.

The fraction of inferred Fedwire loans whose rate exceeds the matched Libor quote is somewhat larger (perhaps reflecting the greater noise in the Fedwire inferences, as well as the fact that these loans are unsecured). The proportion of observations where the loan rate spread to Libor exceeds +20 basis points is only 12 percent, however. The average rate spread over Libor in Fedwire is economically small and statistically insignificant up to March 2008 (2.0 basis point up to August 8 2007 and -0.4 basis points between August 9, 2007, and March 14, 2008).

In contrast, estimates for the period after the failure of Bear Stearns show a significantly higher incidence of panel-bank Libor quotes lying below our matched borrowing cost measures, at least among a subset of reporting banks. Between March 15 and September 12, 2008, the fraction of observations where the loan or bid rate exceeds the bank's Libor quote increases significantly, to 31 percent of TAF bids (from 8 percent) and 54 percent of inferred Fedwire loans (from 33 percent). In addition, the average spread-to-quote in both cases shifts upwards.

These findings are significantly magnified during the period immediately following the collapse of Lehman Brothers on September 15, 2008. During this period, 54 percent of TAF bids exceed banks' corresponding Libor quotes, as do 80 percent of inferred term loans. Despite the magnification of interbank bid-ask spreads during this period, the average spread-to-quote becomes positive, based on both sources of results (it is +31 basis points for TAF and +21 basis points for Fedwire).

4.2 Correlates of Libor - borrowing cost spread

Table 4 repeats this analysis, including two additional explanatory variables measuring banks' dollar-funding costs: (i) the bank's CDS spread; and (ii) a dummy for whether the bank parent is a non-U.S. bank. The CDS spread is a measure of the bank's credit risk. The second variable is included because non-U.S. banks experienced shortages of dollar funding during the financial crisis, particularly after the failure of Lehman Brothers, when the euro-U.S dollar implied-swap basis spread regularly exceeded 100 basis points (Goldberg, Kennedy, and Miu 2010, see also Acharya, Afonso and Kovner, 2012).

[Insert Table 4 here]

Turning to panel A of table 4, both the CDS spread and non-U.S. bank dummy are significantly associated with a higher spread of the bank's TAF bids over its matched Libor quote. The size and significance of the non-U.S. dummy are particularly elevated after the failure of Bear Stearns. The coefficient on "non-U.S. bank x post-Bear" is 40 percent in column 1 (measuring the frequency of TAF bids above Libor quotes), and 32 basis points in column 2 (measuring the spread-to-Libor itself). The spread-to-Libor quote is also larger for banks with high CDS spreads. We also note that the incidence of banks bidding above their matched Libor quote is significantly serially correlated. This suggests these differences between bank bids and matched Libor quotes are somewhat persistent, rather than representing "one-off" bidding mistakes or other random factors.

Panel B repeats this analysis for the inferred Fedwire term loans. As with the TAF results, higher CDS spreads are also correlated with a higher "spread-over-Libor", and the "spread-over-Libor" is significantly serially correlated. In general though, the results in panel B are significantly weaker than in Panel A, and generally not statistically significant. This difference may reflect additional noise in the Fedwire inferences; for example, these inferences are likely to include at least some correspondent loans, leading to attenuation bias in the table 4 coefficients. Alternatively, it may also reflect rationing of funds during the crisis. Banks with the greatest credit and liquidity problems (e.g. non-U.S. banks) may have had difficulty obtaining term dollar funding during this period (in line with the model of Heider, Hoerova and Holthausen (2009), and evidence in Afonso et al. (2011) of a narrowing of lenders' range of counterparties during the crisis period). These selection effects would not influence the TAF results, since all eligible banks could access TAF funds at the same terms.

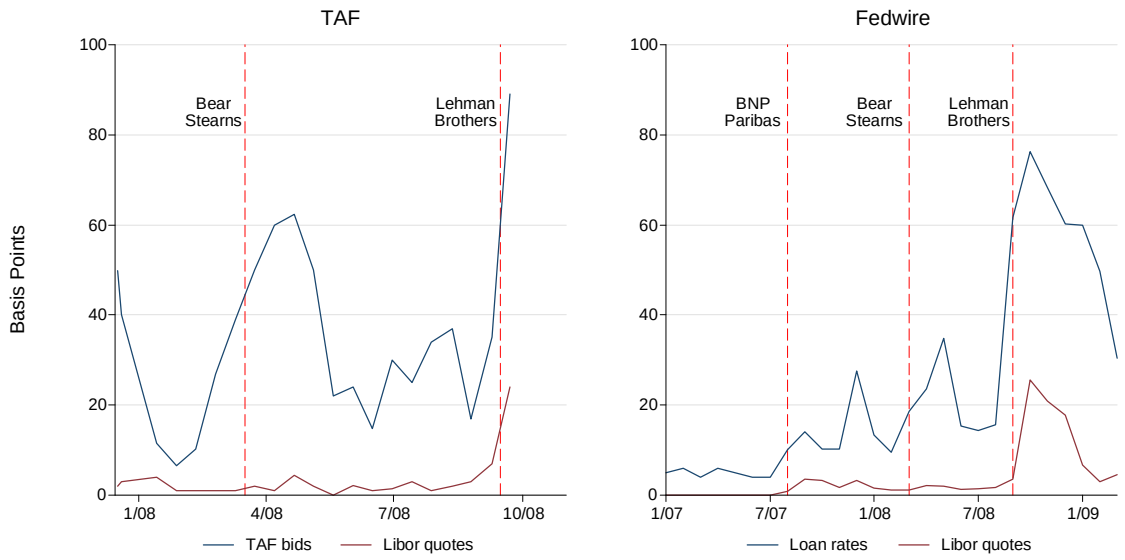
4.3 Dispersion

Figure 2 compares the dispersion of Libor survey responses to the dispersion of TAF bid rates and inferred Fedwire loan rates amongst Libor-panel banks. This figure is constructed by computing the cross-sectional interquartile range of TAF bids, inferred loan rates, and Libor quotes from the regression samples used in tables 3–5; this is done by auction in the case of TAF and by calendar month for the Fedwire inferences.[18]

[18] Specifically, for TAF, we compute the interquartile range of the bids submitted by all panel banks bidding in a given auction, as well as the interquartile range of the Libor quotes for the same set of banks (to ensure that differential trends in dispersion are not driven by selection in terms of which banks bid at the auction). For Fedwire, we do the same thing by calendar month, except that we normalize each Fedwire inferred loan rate and Libor survey

In both cases, figure 2 suggests that Libor quotes are more tightly clustered than the variation in underlying borrowing rates observed in the two microdata sources. This difference in dispersion is prevalent over the entire sample period in both datasets but is significantly magnified in the period after Lehman's failure. This could reflect the noise in these measures themselves (e.g. random variation in TAF bidding strategies by different banks), or other factors.

Figure 2: Dispersion of Libor Quotes Compared to TAF Bids and Inferred Loan Rates



5. Comparing Libor to Other Funding-Cost Indexes

As complementary evidence, in this section we compare the Libor fixing rate to other public measures of bank unsecured dollar funding costs during the financial crisis period. A natural comparison index is the New York Funding Rate, which, as discussed in section 2, was developed by ICAP partly in response to concerns about Libor's limitations. NYFR is first reported in June 2008; figure 3 plots the difference between NYFR and Libor at one-month and three-month maturities.

Figure 3 shows that NYFR deviates quite significantly from Libor at certain points in the crisis. From its introduction, NYFR slightly exceeds Libor, by between one and two basis points on average. The difference between the two series rises sharply to around 40 basis points after the Lehman collapse in

quote by the Libor fixing rate in the calendar day in question. This is done so that the dispersion index measures variation across banks, rather than movements in the general level of interest rates.

September 2008 and remains high for several weeks. The NYFR spread then diminishes and returns to a range between -5 and 15 basis points.

In general these two series move together during the financial crisis, as shown in figure 1. However, as illustrated above, NYFR is elevated relative to Libor in the period after Lehman's failure. This is directionally consistent with the regression estimates from section 4 (i.e., the period directly after Lehman's failure). There are a number of explanations for these differences, as described in section 2. For example, NYFR is measured in the New York trading session, and includes a different set of financial institutions to Libor. Furthermore, NYFR is a midmarket rate, while Libor is an offer rate.

Figure 3: Spread of NYFR over Libor

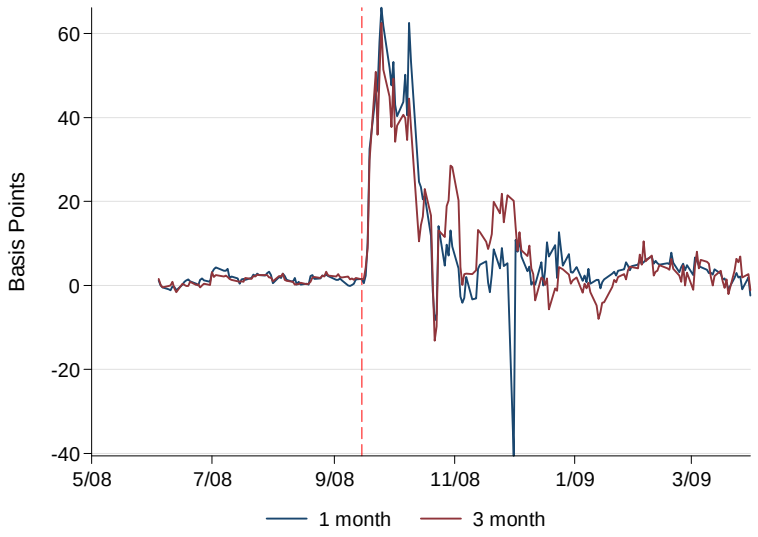
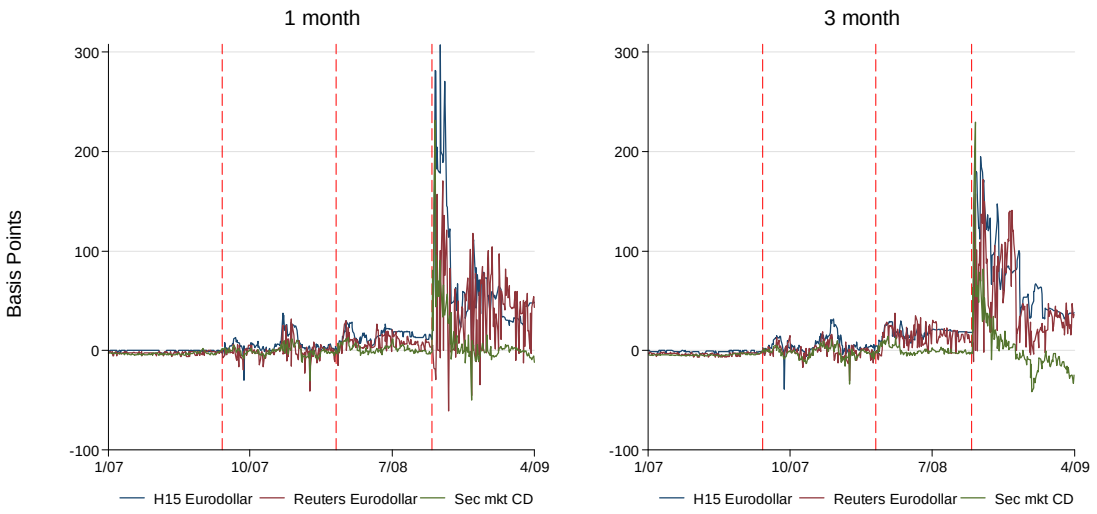


Figure 4 compares Libor to three other rates of bank unsecured funding: (i) Eurodollar borrowing rates collected by ICAP and reported weekly in the Federal Reserve's H.15 report; (ii) a second Eurodollar deposit rate series reported by Reuters; and (iii) secondary market CD yields, also as reported as part of the H.15 report.

Figure 4: Spread of Eurodollar and Secondary Market CD Rates over Libor



These three series closely track Libor through most of 2007–09, although the dispersion across them increases sharply in the period between the Bear and the Lehman failures. Like NYFR, each series spikes upward relative to Libor, after the failure of Lehman. The differential between them then declines as the crisis eases but remains elevated in the case of the two Eurodollar deposit series. The fact that the two Eurodollar series lie at the upper end of the funding-cost measures considered here appears to reflect features of the way they are collected—in particular that they reflect the upper end of rates paid by banks (Wrightson ICAP 2008).[19]

To support this graphical evidence, we also estimate regressions similar to those reported in table 3, in which the rate differential of these alternative series (NYFR, secondary CD yields, Reuters Eurodollar, and H.15 Eurodollar) over Libor is regressed on a set of time dummies. Results are presented in table 5. Before the onset of the crisis, each of these comparison series actually lay slightly *below* the Libor fixing rate at both 1 month and 3 month maturities, by 0.3 to 3.0 basis points, respectively. The difference between them then flips sign and rises to between +0 to +18 basis points (depending on the series) in the period between Bear and Lehman and increases to between +31 and +134 basis points in the two weeks after Lehman's failure. (The NYFR-Libor differential

[19] In particular, Wrightson ICAP (2008) writes: "One of the yardsticks that we and other analysts have used to evaluate LIBOR is the Eurodollar deposit rates published by the Federal Reserve on its H.15 report. Those rates are in fact produced by ICAP. They reflect the upper end of an indicative run that ICAP furnishes to data-vendors that is intended to capture the bulk of the rates paid by A1/P1 banks at any given time. With the high degree of dispersion in interbank rates at present, the bid-ask spread for that series is often set as wide as 15 or 20 basis points. The LIBOR fixings have at times appeared to be too low, but picking the upper limit of rates being paid by active participants almost by definition produces a rate that is too high."

lies at the lower end of this range; here the differential is 34 basis points at a one-month maturity and 31 basis points at a three-month maturity.) The differential then declines, although the variation across these series is strikingly large even in the "after crisis easing" period, defined as November 12, 2008, to March 31 2009.

[Insert Table 5]

Summing up, overall, this panel of rates moves quite closely over the crisis period. Observed differences between Libor and other unsecured funding indexes appear approximately consistent with our micro evidence from section 4 – namely, Libor is lower than these alternative funding measures in the period immediately following Lehman's bankruptcy. Interestingly, the spread of the secondary CD and Eurodollar rates over Libor actually flips sign (from negative to positive) between the precrisis to the crisis period. In other words, the patterns we observe are not simply a magnification of preexisting differences among these series.

5.1 Inferring bank funding costs from public data

Libor is often used by market participants and others as a public measure of bank funding costs. In this section, we compare Libor to a number of alternative publicly observable indexes, by analyzing how these different measures track movements in term funding rates inferred from Fedwire. We estimate variations of the following regression specification:

$$\text{loan rate}_{it} - \text{OIS}_t = a + b.\ [\ \text{Libor}_t - \text{OIS}_t\ ] + c.\ \text{other spreads to OIS}_t + e_{it}. \qquad (2)$$

If Libor is a sufficient statistic among public indexes, we would observe estimates of b close to unity and the elements of the vector c close or equal to zero.

For this exercise, we compare Libor to NYFR, an index of secondary market CD rates, the BBB-AAA corporate bond spread, and a weighted-average index of bank CDS spreads. Our thought experiment is to consider an observer seeking to infer information about average funding costs using only publicly observable data. We estimate what fraction of loan-rate variation is captured by these public variables and which linear combination of these public indexes is closest (in a minimum-squared-error sense) to inferred transaction-level loan rates from Fedwire.

Results are presented in table 6. Our loan sample includes all inferred loans from Fedwire (not just the subsample where the receiving bank is a Libor-panel member), since our goal is to analyze how public measures move with term funding costs more generally. We focus on one-month and three-month maturities.

[Insert Table 6 here]

Since NYFR is not available over the entire sample period, we exclude it from the first two columns of the table. Column 1 shows that wholesale loan spreads move almost one-for-one on average with the Libor-OIS spread. The Libor-OIS spread explains 61.7 percent of the spread variation at a one-month maturity and 52.1 percent at a three-month maturity. Column 2 then adds other measures of funding costs to this specification. The secondary market CD spread and bank index CDS spread have the correct sign and are statistically significant, implying that these variables contain additional data about market conditions not reflected in the Libor fixing rate. The BBB-AAA spread is statistically significant but has the wrong sign.

Columns 3 through 6 focus on the subperiod since NYFR's introduction and include the NYFR rate as one of the alternative indexes. Comparing columns 3 and 4, we find that NYFR is somewhat more correlated with movements in Fedwire-inferred funding rates than is Libor, although the difference in R^2's is slight (0.712 compared to 0.704 at a one-month maturity, and 0.533 compared to 0.525 at a three-month maturity). In addition, in examining columns 5 and 6, we see a smaller and generally statistically significant relationship between Libor and wholesale loan rates, after conditioning on NYFR (and other public data, in the case of column 6).

The set of market indexes we consider is highly correlated (e.g., in a principal-components analysis of the RHS variables from table 7, the first principal component has a weight of 97 percent at a three-month maturity). However, these findings do imply that Libor is not a sufficient statistic for bank funding costs among the set of available public indexes. These results suggest that it may be helpful for policy makers and market participants to examine a range of funding-cost measures, rather than relying only on Libor, particularly in periods where different indexes diverge. Among the alternatives, NYFR appears most closely related to our microdata-based measure of funding conditions, likely because most term dollar loans settled over Fedwire (rather than CHIPS or another

settlement system) reflect transactions from the New York session (Stigum and Crescenzi 2007), the location of trade where the NYFR survey is also conducted.

5.2 Basis risk

During a financial crisis period, the cross-sectional dispersion of funding costs across banks is likely to increase sharply, making any marketwide funding index, such as Libor or NYFR, less useful as a measure of the supply curve for short term funds facing any given bank. To examine the quantitative magnitude of this effect, in figure 5 we plot a histogram of the dispersion of inferred one-week, one-month, and three-month Fedwire loan rates, measured as a spread over the corresponding Libor fixing, during four different phases of the crisis. We do this for all banks, not just observations where the borrowing bank is a Libor panel member.

[Insert Figure 5 here]

Figure 5 documents a striking increase in the dispersion of loan rates during the crisis. Before August 9, 2007, rates are tightly clustered near the Libor fixing, with the median loan rate slightly below Libor, consistent with the definition of Libor as an offer rate. Dispersion in loan rates significantly increases in the period between August 2007 and the failure of Lehman, although a roughly bell-shaped distribution is maintained. At the crisis peak, inferred loan rates are widely dispersed and scattered. The distribution then becomes narrower and more bell shaped as the crisis eases.[20]

These facts are important, because Libor is widely used as an index for interest-rate swaps and other financial contracts because it is intended to closely track banks' cost of funds. Figure 5, however, suggests this association becomes weaker during crisis periods; in other words, basis risk increases. For example, consider a bank with a large portfolio of adjustable-rate loans indexed to Libor, which are partially funded via wholesale markets. Figure 5 suggests that, during stress periods such as 2007-09, such a bank may be exposed to significant basis risk between the Libor-indexed rate received on this loan book and the bank's cost of wholesale funding.

[20] The volume of term activity also significantly declines late in our sample period, due to the bank liquidity provided by the introduction of interest on reserves and the buildup of excess reserves that accompanies the implementation of the Federal Reserve's Large Scale Asset Purchase programs. See Kuo et al. (2012) for further evidence on these trends in interbank volume as estimated by the output of our Fedwire term algorithm.

6. Additional Analysis and Robustness Checks

Amongst our filters, in our benchmark Fedwire estimates in tables 3 and 4, we drop transaction pairs identified as Eurodollar deposits, pairs where the sender is a foreign central bank, and loans less than one month in maturity. We have also reestimated our results relaxing each of these restrictions in turn. Our main results are robust to including Eurodollar deposits or foreign central bank transaction pairs. Interestingly, however, we find less evidence of a shift towards Fedwire loan rates above Libor quotes amongst loans less than one month in maturity. In other words, the trends discussed in Section 4 appear to be most striking for "focal" maturities of 1 month, 3 months and 6 months, which are the Libor maturities most closely watched by market participants.

As a further robustness check, we have also reestimated our TAF analysis including all TAF bids, in cases where a bidder placed two bids at a given auction (rather than just retaining the upper bid). This change in specification has no effect on our main finding from Table 3 that the incidence of observing bids above the matched Libor quote increases at the peak of the crisis. The fraction of such observations declines moderately, however; for example the fraction of post-Lehman TAF observations in which bid spread-to-Libor exceeds +20 basis points falls from 0.385 to 0.278.

As a final piece of analysis, Table 7 estimates a more saturated model in which the "non-U.S. bank" dummy is interacted with each of the six crisis-phase dummies. The table presents estimates for both the interacted and the noninteracted time dummies, since both are of interest. TAF results suggest that the "spread-over Libor" is higher and more likely to be positive for non-U.S. banks in phases 3, 4, and 5, from the failure of Bear Stearns until the end of September 2008. Correspondingly, the noninteracted time dummies for phases 2, 3, and 4 (which relate to U.S. banks) are much lower than the baseline coefficients in table 3. These results effectively imply that the overall upward trend in the incidence of TAF bids exceeding Libor is effectively concentrated entirely among non-U.S. banks (i.e., there is no upward trend in the noninteracted time dummies from phase 2 to phases 3 and 4). These differences between U.S. and non-U.S. banks are not apparent for Fedwire, however, as already discussed in section 4.

[Insert Table 7 here]

7. Summary and Conclusions

According to our results, Libor tracks overall movements in other measures of bank funding costs during the 2007-09 crisis period, at least to a first-order approximation. We do find however that these measures diverge somewhat around the crisis peak. In particular we observe an increased incidence of Libor quotes that lie below matched TAF and Fedwire funding measures, particularly in the period directly after Lehman's failure in September 2008, and to a lesser extent in the six-month period between the collapse of Bear Stearns and Lehman.

As discussed in detail in section 2, there are a number of factors for why these different measures of borrowing costs could diverge. For example, the TAF provided funding to U.S. depository institutions, while the Libor survey is conducted in London, and thus likely represents the funding costs of a different legal entity to the commercial banking subsidiary bidding at the TAF. Some of these factors suggest that market segmentation and institutional frictions would lead the TAF and Fedwire rate measures to be lower than Libor quotes during heightened market stress, although others could lead to deviations in the opposite direction. Although misreporting by Libor-panel banks would generate deviations of Libor from other funding measures, our results do not speak directly to whether or not such misreporting may have occurred.

Our findings have implications for the use of Libor in financial contracting. In particular, our results indicate sharply greater basis risk between Libor and the funding costs of any individual bank at the peak of the 2007-09 financial crisis. This finding is notable because the widespread use of Libor in interest rate swaps and other contracts is motivated by the idea that it will be a good hedge for fluctuations in bank funding costs. Our results suggest this type of hedging strategy is likely to become less effective during periods of stress.

We also note that the use of market surveys similar to Libor is common in other OTC markets (e.g., consider the range of CDS indexes developed by Markit). Studying the statistical properties of such indices in these other markets would be an interesting avenue for future research.

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Appendix A: Sources of Variables Used

Data Series	Description	Source
Libor panel quotes	Individual Libor-panel bank estimates of the rate at which the panel bank would be offered unsecured funds at different maturities ranging from overnight to 1 year, based on a daily survey conducted by Reuters and the BBA.	BBA, accessed via Bloomberg
Libor fixing	Official London Interbank Offer Rate (Libor) fixing, computed by Reuters and the BBA as a trimmed mean of individual Libor quotes at maturities ranging from overnight to 1 year.	BBA, accessed via Bloomberg
NYFR fixing	The New York Funding Rate (NYFR) is calculated based on a daily survey by Wrightson ICAP during the New York trading session. Computed as a trimmed mean of individual responses (the top and bottom 25% of responses are excluded). Respondents report a mid-market rate, not their own cost of funds. See Section 2 for details.	ICAP, accessed via Bloomberg
OIS	The overnight indexed swap (OIS) rate is the fixed rate associated with an interest rate swap whose floating leg is tied to an overnight rate such as the federal funds rate compounded over the contract term.	Bloomberg
Fedwire Funds records	Interbank payment transactions log of payments sent over the Fedwire Funds settlement system.	FRBNY Wholesale Product Office
TAF bids	Characteristics (e.g. rate, quantity) of bids placed by banks at the Federal Reserve's Term Auction Facility (TAF).	Federal Reserve
Reuters Eurodollar rates	Daily snapshot of market rates from various banks through the world taken from Reuters at 15:30.	Reuters, accessed via Haver DLX
H.15 Eurodollar deposit rate	Eurodollar deposit rate (London), based on data from CTRB ICAP Fixed Income & Money Market Products.	Federal Reserve H.15 report
Secondary market CD rate	Average of dealer secondary market bid rates on nationally traded certificates of deposit (CDs).	Federal Reserve H.15 report
Bank CDS spreads	Bank CDS spreads for individual Libor-panel banks. Libor-panel index CDS spread computed as an an asset-weighted average of individual bank CDS spreads.	Markit
Corporate bond yields	Moody's market average AAA and BAA corporate bond yields, seasoned bonds.	Federal Reserve H.15 report

Figure 5: Inferred Interbank Loan rates over the Crisis

Figure presents histogram of loan interest rates over four phases of the 2007-09 financial crisis for 1week, 1 month and 3 month loan maturities. [1] Pre-crisis period (up to BNP Paribas hedge fund event), [2] BNP Paribas until Lehman bankruptcy, [3] Lehman bankruptcy until crisis easing, [4] Post crisis easing.

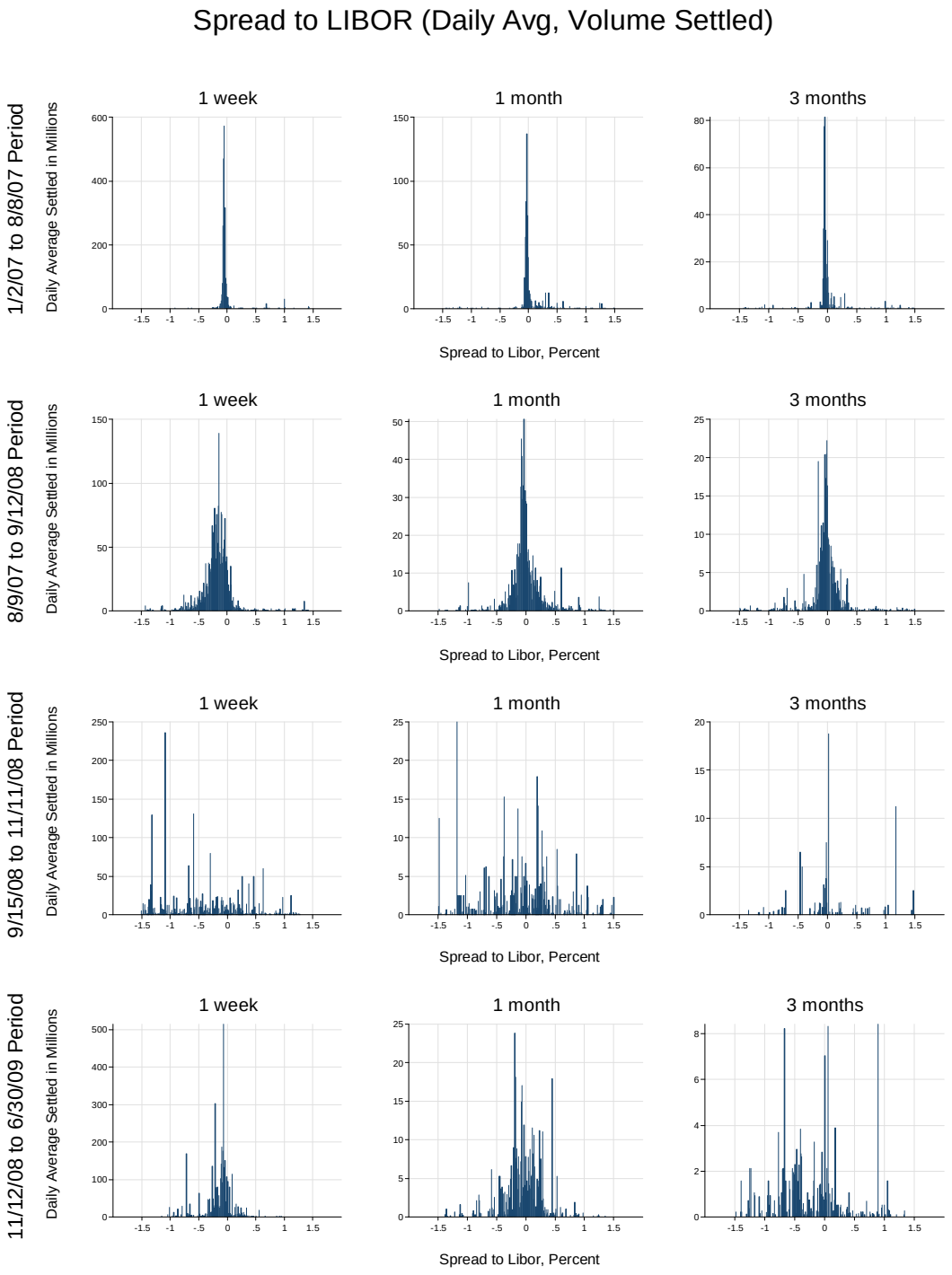

Table 1. Summary statistics: Term Auction Facility

Note: Our analysis focuses on TAF auctions conducted prior to October 2008. From this point on, each auction is undersubscribed, due to an increase in the amount of funds tendered by the Federal Reserve. Prior to this date there were 21 auctions in total for 28 day funds, and 2 auctions for 84 day funds.

	28-day auctions			84-day auctions
	Min	Average	Max	Average
All participants				
Sum of all bids ($bn)	20.0	52.9	75.0	25.0
Bid-to-cover ratio	1.1	1.7	3.1	1.7
Stop-out rate (spread to OIS, %)	2.1	2.9	4.7	2.7
Number of bidders	52.0	73.7	94.0	51.0
Number of bids	58.0	95.2	126.0	61.0
Number of firms receiving funds	24.0	45.7	72.0	25.5
Libor panel banks only				
Number of bidders	3.0	8.7	13.0	6.0
Number of bids	4.0	12.0	21.0	7.0
Sum of all bids ($bn)	4.9	19.4	35.1	11.9
Number of firms receiving funds	1.0	4.6	8.0	3.0
Dollar amount received ($bn)	1.4	10.7	19.2	7.1

Table 2. Summary statistics: Inferences from term Fedwire algorithm

Note: Maturity weighted issuance volumes are calculated as average daily loan issuance x loan maturity in days. In steady state, this will be equal to dollar volume of loans outstanding. Table includes loans with maturities of 1 week, 2 weeks, 1 month, 2 month, 3 month, and 6 months.

	Include matched pairs flagged as Eurodollar?	Time period				
		Pre-crisis before 8/9/07	BNP to Lehman 8/9/07 - 9/12/08	Crisis peak 9/15/08 - 11/11/08	Crisis easing 11/12/08 onwards	**All 1/1/07 - 31/3/09**
Number of observations						
Libor-panel banks	No	1412	2231	283	471	4397
All banks	No	2563	4645	545	1028	8781
All banks	Yes	6330	10695	1287	2490	20802
Average interest rate (% spread to OIS, 1 month)						
Libor-panel banks	No	0.1	0.53	1.95	0.61	0.48
All banks	No	0.08	0.54	2.12	0.67	0.51
All banks	Yes	0.13	0.56	2.04	0.62	0.52
Average loan size, 1 month ($m)						
Libor-panel banks	No	73.2	107.4	72.6	83.7	91.3
All banks	No	76.3	96.7	66.3	83.8	87.5
All banks	Yes	69.5	95.1	56.6	83.1	83.8
Number of observations, by maturity bucket [non-Eurodollar]						
Less than one month	No	1399	2354	333	574	4660
One month	No	693	1264	139	241	2337
Two months	No	138	358	42	83	621
Three months	No	278	543	24	116	961
Six months	No	55	126	7	14	202
Loan volume [$bn, maturity-weighted daily issuance, non-Eurodollar]						
Less than one month	No	5.09	5.99	6.31	7.29	5.99
One month	No	7.39	9.33	4.78	4.44	7.66
Two months	No	3.33	3.7	2.39	2.64	3.33
Three months	No	10.96	10.39	2.83	4.46	9.01
Six months	No	3.52	5.3	7.72	1.56	4.36

Table 3. Spread-to-Libor

Regression of transformations of (loan/bid rate$_{itj}$ - Libor quote$_{itj}$) for bank i at time t for maturity j, on a set of time dummies indicating different phases of the financial crisis. Sample period is 1/1/2007 to 3/31/2009. Standard errors are robust (TAF) or clustered by trading day (Fedwire).

	TAF: 1m loans			**Fedwire: 1m, 3m and 6m loans**		
	spread > 0	spread > 20bp	Avg spread	spread > 0	spread > 20bp	Avg spread
Phase 1: Before BNP Paribas				0.249	0.120	0.020
(1/1/2007-8/8/2007)				(0.021)***	(0.017)***	(0.016)
Phase 2: BNP Paribas to Bear	0.078	0.013	-0.236	0.329	0.116	-0.004
(8/9/2007-3/14/2008)	(0.031)**	(0.013)	(0.030)***	(0.025)***	(0.015)***	(0.015)
Phase 3: Bear to Lehman	0.308	0.121	-0.101	0.536	0.216	0.062
(3/15/2008-9/12/2008)	(0.045)***	(0.032)***	(0.025)***	(0.028)***	(0.024)***	(0.020)***
Phase 4: Two weeks after Lehman	0.538	0.385	0.314	0.800	0.400	0.207
(9/15/2008 - 9/29/2008)	(0.139)***	(0.136)***	(0.188)*	(0.113)***	(0.157)**	(0.124)*
Phase 5: Until crisis easing				0.371	0.274	-0.210
(9/30/2008-11/11/2008)				(0.067)***	(0.071)***	(0.097)**
Phase 6: After crisis easing				0.407	0.151	-0.106
(11/12/2008-3/31/2009)				(0.039)***	(0.031)***	(0.040)***
Number of observations	197	197	197	1611	1611	1611
Pseudo-R2	0.313	0.185	0.266	0.396	0.168	0.029
Tests of linear restrictions on coefficients [p-values]						
Phase 3 = Phase 2	0.00	0.00	0.00	0.00	0.00	0.01
Phase 4 = Phase 2	0.00	0.01	0.00	0.00	0.07	0.09
Phase 4 = Phase 3	0.12	0.06	0.03	0.02	0.25	0.25
Phase 3 = Phase 1				0.00	0.00	0.11
Phase 4 = Phase 1				0.00	0.08	0.14

Table 4. Determinants of spread-to-Libor

Regression of transformations of (loan/bid rate$_{itj}$ - Libor quote$_{itj}$) for bank i at time t for maturity j, on a set of time dummies indicating different phases of the financial crisis. Sample period is 1/1/2007 to 3/31/2009. Standard errors are robust (TAF) or clustered by trading day (Fedwire).

	TAF: 1m loans			
	spread > 0	Avg spread	spread > 0	Avg spread
CDS spread	0.142	0.174	0.097	0.137
	(0.078)*	(0.046)***	(0.080)	(0.043)***
Foreign bank	0.063	0.176	0.001	0.142
	(0.068)	(0.058)***	(0.071)	(0.057)**
Foreign bank * post-Bear	0.399	0.324	0.329	0.258
	(0.086)***	(0.070)***	(0.104)***	(0.072)***
Lagged Libor spread			0.378	0.261
			(0.149)**	(0.085)***
Non-participation dummy			-0.039	-0.112
			(0.078)	(0.055)**
Crisis period dummies	yes	yes	yes	yes
Number of observations	197	197	197	197
Pseudo-R2	0.433	0.510	0.457	0.536

	Fedwire: 1m, 3m, and 6m loans			
	spread > 0	Avg spread	spread > 0	Avg spread
CDS spread	0.070	0.001	0.065	-0.003
	(0.040)*	(0.025)	(0.038)*	(0.024)
Foreign bank	-0.067	-0.041	-0.028	-0.019
	(0.030)**	(0.026)	(0.032)	(0.028)
Foreign bank * post-Bear	0.015	-0.070	0.035	-0.054
	(0.074)	(0.049)	(0.072)	(0.049)
Lagged Libor spread			0.228	0.183
			(0.056)***	(0.054)***
Non-participation dummy			-0.103	-0.059
			(0.035)***	(0.033)*
Crisis period dummies	yes	yes	yes	yes
Number of observations	1611	1611	1611	1611
Pseudo-R2	0.402	0.034	0.412	0.048

Table 5. Spreads of other rates over the Libor fixing rate

Dependent variable is interest rate (e.g. NYFR, H15) relative to the Libor fixing for the same maturity and calendar date. Newey-West standard errors in parentheses.

	NYFR		H15 Eurodollar		Reuters Eurodollar		Secondary mkt CD	
	1m	3m	1m	3m	1m	3m	1m	3m
Phase 1: Before BNP Paribas			-0.003	-0.010	-0.024	-0.036	-0.030	-0.042
(1/1/2007-8/8/2007)			(0.001)***	(0.001)***	(0.002)***	(0.002)***	(0.002)***	(0.001)***
Phase 2: BNP Paribas to Bear			0.058	0.056	-0.012	-0.004	-0.010	-0.021
(8/9/2007-3/14/2008)			(0.013)***	(0.012)***	(0.008)	(0.008)	(0.006)	(0.008)***
Phase 3: Bear to Lehman	0.014	0.013	0.155	0.183	0.087	0.145	0.017	0.004
(3/15/2008-9/12/2008)	(0.003)***	(0.002)***	(0.010)***	(0.009)***	(0.009)***	(0.012)***	(0.006)***	(0.006)
Phase 4: Two weeks post-Lehman	0.343	0.310	1.337	1.045	0.096	0.420	0.724	0.685
(9/15/2008 - 9/29/2008)	(0.127)***	(0.109)***	(0.462)***	(0.348)***	(0.132)	(0.163)**	(0.212)***	(0.219)***
Phase 5: Until crisis easing	0.197	0.196	1.149	1.260	0.410	0.768	0.283	0.308
(9/30/2008-11/11/2008)	(0.072)***	(0.052)***	(0.266)***	(0.102)***	(0.123)***	(0.092)***	(0.091)***	(0.073)***
Phase 6: After crisis easing	0.034	0.042	0.487	0.532	0.415	0.403	-0.013	-0.100
(11/12/2008-3/31/2009)	(0.005)***	(0.011)***	(0.034)***	(0.037)***	(0.032)***	(0.064)***	(0.008)	(0.021)***
Number of observations	206	206	564	564	564	564	564	564
Pseudo-R2	0.52	0.58	0.71	0.87	0.50	0.63	0.50	0.53

Table 6: Informational content of wholesale funding rate indexes

Correlations between wholesale bank loan rates and five different different public proxies for bank funding rates: (i) same maturity Libor, (ii) same maturity NYFR, (iii) Secondary market wholesale CD rates, (iv) corporate bond spread, (v) an index bank CDS spread. Indexes (i) - (iii) expressed as a spread to OIS of the same maturity. Standard errors are clustered by trading day.

Dependent variable for all regressions: Loan $rate_{it}$ - OIS_t

A. One-month loans

Sample period	Full sample 1/1/2007 - 3/31/2009		Period since creation of NYFR 6/2/2008 - 3/31/2009			
	[1]	[2]	[3]	[4]	[5]	[6]
Libor - OIS	0.933	0.638	0.916		0.282	0.532
	(0.019)***	(0.093)***	(0.024)***		(0.167)*	(0.174)***
NYFR - OIS				0.837	0.584	0.335
				(0.018)***	(0.151)***	(0.189)*
Secondary mkt CD rate - OIS		0.267				0.044
		(0.080)***				(0.077)
BAA - AAA bond spread		-0.068				-0.112
		(0.022)***				(0.024)***
Bank index CDS spread		0.077				0.037
		(0.022)***				(0.028)
Constant	0.081	0.129	0.113	0.125	0.117	0.289
	(0.009)***	(0.018)***	(0.019)***	(0.019)***	(0.018)***	(0.040)***
N	4689	4689	1347	1347	1347	1347
R^2	0.620	0.627	0.707	0.714	0.715	0.723
F-tests [p-value]:						
constant = 0 & slope = 1	0.00		0.00	0.00		
LIBOR - OIS = NYFR - OIS					0.34	0.58

B. Three-month loans

Sample period	Full sample 1/1/2007 - 3/31/2009		Period since creation of NYFR 6/2/2008 - 3/31/2009			
	[1]	[2]	[3]	[4]	[5]	[6]
Libor - OIS	0.962	0.803	1.006		-0.016	0.613
	(0.030)***	(0.219)***	(0.054)***		(0.395)	(0.444)
NYFR - OIS				0.928	0.943	0.837
				(0.046)***	(0.368)**	(0.504)*
Secondary mkt CD rate - OIS		0.195				-0.337
		(0.186)				(0.148)**
BAA - AAA bond spread		-0.090				-0.221
		(0.045)**				(0.060)***
Bank index CDS spread		0.043				0.035
		(0.039)				(0.051)
Constant	0.006	0.079	-0.060	-0.012	-0.011	0.234
	(0.020)	(0.033)**	(0.062)	(0.056)	(0.059)	(0.082)***
N	2233	2233	558	558	558	558
R^2	0.527	0.533	0.535	0.545	0.545	0.565
F-tests [p-value]:						
constant = 0 & slope = 1	0.20		0.16	0.00		
LIBOR - OIS = NYFR - OIS					0.21	0.81

Table 7. Spread-to-Libor, more saturated model

Regression of transformations of (loan/bid rate$_{itj}$ - Libor quote$_{itj}$) for bank i at time t for maturity j, on a set of time dummies indicating different phases of the financial crisis. Sample period is 1/1/2007 to 3/31/2009. Standard errors are robust (TAF) or clustered by trading day (Fedwire).

	TAF: 1m loans		Fedwire: 1m, 3m, and 6m loans	
	spread > 0	Avg spread	spread > 0	Avg spread
CDS spread	0.140	0.176	0.081	0.002
	(0.078)*	(0.045)***	(0.042)*	(0.028)
Foreign bank interactions:				
Phase 1 * foreign			-0.202	-0.075
			(0.037)***	(0.030)**
Phase 2 * foreign	0.063	0.177	0.018	-0.005
	(0.068)	(0.058)***	(0.043)	(0.031)
Phase 3 * foreign	0.470	0.492	-0.065	-0.121
	(0.061)***	(0.039)***	(0.074)	(0.046)***
Phase 4 * foreign	0.395	0.579	0.292	0.161
	(0.301)	(0.232)**	(0.120)**	(0.278)
Phase 5 * foreign			0.091	-0.057
			(0.147)	(0.224)
Phase 6 * foreign			-0.018	-0.052
			(0.088)	(0.086)
Time dummies:				
Phase 1: Before BNP Paribas			0.274	0.034
			(0.025)***	(0.020)*
Phase 2: BNP Paribas to Bear	-0.061	-0.468	0.279	-0.004
	(0.082)	(0.063)***	(0.036)***	(0.024)
Phase 3: Bear to Lehman	-0.143	-0.613	0.470	0.087
	(0.081)*	(0.058)***	(0.055)***	(0.040)**
Phase 4: Period after Lehman	0.089	-0.348	0.629	0.183
	(0.294)	(0.080)***	(0.137)***	(0.145)
Phase 5: Until crisis easing			0.232	-0.197
			(0.105)**	(0.116)*
Phase 6: After crisis easing			0.256	-0.094
			(0.098)***	(0.098)
Number of observations	197	197	1611	1611
Pseudo-R2	0.434	0.511	0.406	0.035