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Stressed, Not Frozen: The Federal Funds Market in the Financial Crisis

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ABSTRACT

We examine the importance of liquidity hoarding and counterparty risk in the U.S. overnight interbank market during the financial crisis of 2008. Our findings suggest that counterparty risk plays a larger role than does liquidity hoarding: the day after Lehman Brothers' bankruptcy, loan terms become more sensitive to borrower characteristics. In particular, poorly performing large banks see an increase in spreads of 25 basis points, but are borrowing 1% less, on average. Worse performing banks do not hoard liquidity. While the interbank market does not freeze entirely, it does not seem to expand to meet latent demand.

THE OVERNIGHT INTERBANK MARKET, known as the federal funds market (or fed funds market) in the United States,[1] is the most immediate source of liquidity for regulated banks in the United States and thus an important indicator of the functioning of the banking and financial system. Problems in the efficiency of interbank markets can lead to inadequate allocation of capital and lack of risk sharing between banks. At the extreme, disruptions in interbank markets could even trigger bank runs. In addition, the fed funds market plays a crucial role in the implementation of monetary policy. It is therefore of particular interest to understand whether the interbank market mitigates or amplifies shocks to individual banks or the banking sector as a whole. While we find evidence of meaningful disruptions in the U.S. interbank market after the bankruptcy of Lehman Brothers, we do not observe a complete freeze in overnight interbank lending.

The theoretical literature proposes two channels by which shocks to individual banks can lead to market-wide reductions in liquidity. One set of models focuses on an increase in counterparty risk to explain a drying up of liquidity.

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[1] Fed funds are unsecured loans of reserve balances that financial institutions hold at the Federal Reserve banks. Fed funds loans are traded in an over-the-counter market, mostly overnight at a rate known as the fed funds rate. See Section II for a detailed description of the fed funds market.

For example, Flannery (1996), Freixas and Jorge (2008), and Heider, Hoerova, and Holthausen (2009) all examine adverse selection that can lead to market unraveling. In these models, information asymmetry becomes worse during a crisis when the fraction of risky banks goes up and investors are unable to differentiate among the credit risks of individual banks. As a result, lenders need to be paid more to participate in the market. If uncertainty becomes very high, the fear of adverse selection can become so great that interbank lending might stop altogether.

A different approach to modeling the role of counterparty risk assumes that lenders in the interbank market do not face information asymmetry. Instead, these papers suggest that the counterparty risk for some of the banks in the market has increased up to a point where their cost of capital prevents them from accessing the interbank market. Thus, in a crisis we should see greater divergence in the cost of borrowing and in access to liquidity between weaker and stronger banks. Examples of this view include Furfine (2001), Flannery and Sorescu (1996), or Bruche and Suarez (2010), who discuss an alternative mechanism related to deposit insurance that can lead to a freeze.

A second set of theories emphasizes the importance of liquidity hoarding in interbank lending disruptions. In these models, banks are not willing to lend even to high-quality counterparties because they prefer to keep liquidity for precautionary reasons. For example, in Allen, Carletti, and Gale (2009) and Caballero and Krishnamurthy (2008), banks hoard liquidity in anticipation of their own needs or in anticipation of high volatility in asset prices and correspondingly high aggregate demand for liquidity. Similarly, in Diamond and Rajan (2009), banks hoard liquidity, expecting high returns when banks in need of cash are forced to sell at fire sale prices. In these models, the perceived future cost of capital for banks is so high that they do not want to lend at the prevailing interest rate. This effect should be stronger for lenders that are in worse shape or those that rely more heavily on external liquidity.[2] As a result, borrowers' access to funds will be reduced regardless of borrower quality.

We study the Lehman Brothers' bankruptcy and the ensuing government interventions as an example of the market-wide shock to banks modeled in the theoretical literature. While the direct losses from Lehman's failure were not big enough to trigger the immediate bankruptcy of any of the large American banks, we interpret Lehman's bankruptcy as a shock to the market's belief that large banks would not be allowed to fail. We test for the importance of both liquidity hoarding and counterparty risk in the aftermath of this shock. Our results lend support to the interpretation that heightened concerns about counterparty risk reduced liquidity and increased the cost of finance for weaker banks. We do not find evidence for liquidity hoarding in the overnight fed funds market.

Using daily transaction-level data, we document that under "normal" or pre-crisis conditions the fed funds market functions via rationing of riskier

[2] One possible exception is the model by Diamond and Rajan (2009) in which good banks might hoard liquidity to take advantage of future fire sales.

borrowers rather than prices, for example, via adjustments of spreads.[3] However, in the days immediately after the Lehman Brothers' bankruptcy the market becomes more sensitive to bank-specific characteristics, especially in the amounts lent to borrowers but also in the cost of overnight funds. In particular, large banks with high percentages of non-performing loans (NPLs) showed drastically reduced daily borrowing amounts and borrowed from fewer counterparties in the days after Lehman's bankruptcy. However, beginning on Tuesday, September 16, 2008, once the AIG bailout was announced, the trend reversed, and spreads for the largest banks fell steeply. We interpret the return to pre-crisis spreads as the effect of the government's support for systematically important banks because the same is not true for small banks, which continued to face higher spreads. This reversal supports the idea that concerns over increased counterparty risk were at the heart of the observed tensions in the fed funds market, since rates returned to normal levels as soon as the government interventions relieved fears of counterparty risk.

Contrary to the predictions of many models of liquidity hoarding, we do not find a relationship between *lender* characteristics and amounts lent in the days after Lehman's failure for large banks. Banks that might be expected to hoard liquidity—such as worse performing banks or banks that had been more dependent on repo financing—did not lend less in the interbank market immediately after the Lehman Brothers' bankruptcy. This suggests either that these banks did not need to hoard overnight liquidity, or that they did not want to reveal weakness to this market by appearing to hoard liquidity. The fact that larger, worse performing banks disproportionately increased their number of counterparties could mean that they wanted to signal their soundness to the market. Of course, this interpretation is only suggestive; an alternative explanation could be that worse performing lenders differentially sought to diversify their exposure to any single borrower. However, regardless of the interpretation of banks' lending behavior, our results suggest that liquidity hoarding was less important than counterparty risk in explaining the difficulty many banks had in accessing the fed funds market. Our results seem consistent with models that propose increased sensitivity to counterparty risk during times of crisis (in the form of higher cost of capital and rationing of credit for weaker banks). In contrast, we do not find evidence that increased information asymmetry leads to higher risk premiums in the market overall nor do we find a total market freeze.

While these results are consistent with the hypothesis that the interbank market became more responsive to counterparty risk during the crisis, we cannot test whether the fed funds market provided an efficient level of financing since we do not observe the full distribution of latent demand and supply. We attempt to measure the extent of unmet demand by examining borrowing from

[3] For example, in the aftermath of the Bear Stearns' near-bankruptcy we do not observe that amounts borrowed or interest rate spreads become more sensitive to the underlying bank characteristics, for example, NPLs. However, in general we do see that bank characteristics predict borrowing amounts and the number of banks willing to lend to a borrower.

the Federal Reserve's discount window. Because of the higher interest rate and potential for stigma, banks usually access the discount window only if they have severe unmet liquidity needs. Thus, use of the discount window gives a lower bound for unmet demand in the fed funds market. We find that even in the days after the Lehman Brothers' bankruptcy, only poorly performing banks, that is those with low return on assets (ROA), accessed the discount window. It seems reasonable to assume that such banks were rationed by private lenders in the fed funds market. While again it is difficult to assess whether the level of funding expanded efficiently during the crisis, it is reassuring that we do not observe more profitable banks being forced to turn to the discount window. Our results further corroborate the interpretation that lenders in the fed funds market were able to screen out the worst performing borrowers.

Our results are different from the findings of Furfine's (2002) study of the U.S. interbank market around the Russian debt crisis and the collapse of Long Term Capital Management in 1998. He finds no evidence of either counterparty risk or liquidity hoarding, perhaps because that crisis was not severe enough to ignite counterparty risk concerns. Our findings are also different from those documented in the U.K. interbank market during the 2007/2008 financial crisis by Acharya and Merrouche (2010). The authors find that, in the United Kingdom, riskier banks hold more reserves relative to expected payment value and the borrowing rates of the 10 largest banks do not vary significantly with bank characteristics. They interpret these results as evidence of liquidity hoarding. The difference between their findings and ours may reflect the tiered structure of the U.K. interbank market (only 15 participants) or the different time period of their study (January 2007 to June 2008). It is worth noting that we do not find disruption in the U.S. overnight interbank market around the dates that they document.

Wetherilt, Zimmerman, and Soramäki (2009) find evidence more similar to ours in the U.K. unsecured overnight market, documenting a post-crisis reduction in the number of bilateral relationships. In addition, our findings are consistent with Angelini, Nobini, and Picillo (2009), who examine Italian banks participating in e-MID (the Italian-based electronic market for interbank deposits) and find that the importance of borrower bank characteristics to interbank lending rates increases after August 2007. They estimate that more liquid lenders charge higher rates after August 2007 (liquidity hoarding), but the economic magnitude of the estimated effect is small.[4] Finally, Kuo, Skeie, and Vickery (2010) document that while maturities seem to shorten, the U.S. term interbank market does not decline dramatically during the early financial crisis period or immediately after Lehman Brothers' bankruptcy, although they do not analyze cross-sectional variation in borrowing.

[4] Using the same data set, Brunetti, Filippo, and Harris (2009) find decreased participation in interbank lending after August 2007 and interpret the reduced participation of lenders as hoarding. But it is difficult to assess whether this evidence indicates hoarding or a reluctance to participate in the e-MID open trading platform.

I. The Federal Funds Market and Other Funding Sources

Federal funds are uncollateralized loans of reserve balances at Federal Reserve banks. On a daily basis, banks borrow and lend these balances to meet reserve requirements and to clear financial transactions. Most loans have an overnight term, although some transactions have longer maturities.[5] The weighted average rate at which banks lend in the overnight fed funds market is known as the fed funds rate. Fed funds borrowings are accounted for like deposits; however, unlike traditional bank deposits, fed funds are exempt from reserve requirements.

The fed funds market is an over-the-counter market where institutions negotiate loan terms directly with each other or indirectly through a fed funds broker. To expedite lending and reduce transaction costs, most overnight loans are booked without a contract. These verbal agreements rely on relationships and informal credit lines between borrowing and lending institutions. In addition to commercial banks, thrift institutions, and branches of foreign banks in the United States, participants include federal agencies (typically lenders in this market) and government securities dealers.

Depository institutions have several alternatives to the fed funds market to meet their overnight funding needs. First, they can borrow in the repo market. A repurchase agreement, or repo, is a financial contract that allows the use of a security as collateral for a cash loan, mostly on an overnight basis, at a rate known as the repo rate. Since repos are collateralized, the repo rate is generally lower than the fed funds rate.

The repo market is a large and opaque over-the-counter market that exceeded $10 trillion in the United States in 2008 (Hördahl and King (2008)). Gorton and Metrick (2009) find evidence for a "run on repo" in the 2 weeks following Lehman's bankruptcy. They estimate that average haircuts for non–U.S. Treasury collateral increased from approximately 25% to 43% in these 2 weeks, and argue that this pricing change was the result of concerns about the illiquidity of the assets being used as collateral.[6] While we cannot directly measure repo borrowing, we proxy for banks' pre-Lehman repo funding with the amount of repo borrowing on banks' balance sheets at the end of 2007. Given the dislocations in the repo market in 2008, we expect banks with high repo funding to need more liquidity from other markets after Lehman's bankruptcy.

A third source of overnight liquidity is the discount window.[7] Unlike fed funds loans, borrowing from the discount window is collateralized. However, the Federal Reserve accepts a broad range of assets as discount window collateral, including home mortgages and related assets, and thus collateral is

[5] The term fed funds market has been estimated to be one-tenth (Meulendyke (1998)) to one-half (Kuo, Skeie, and Vickery (2010)) of the size of the overnight market.

[6] See also Gorton and Metrick (2010) for a more detailed analysis of the impact of financial turmoil on repo haircuts.

[7] Banks can borrow from three discount window lending programs. Primary credit is extended to depository institutions with strong financial positions while secondary credit is offered to those institutions that do not qualify for primary credit. Small depository institutions in agricultural communities are the typical users of seasonal credit.

unlikely to be a limiting factor.[8] More importantly, banks have been reluctant to borrow from the discount window because of a perceived "stigma."[9] Federal Reserve banks extend primary credit at the discount window on a short-term basis to banks that are adequately or well capitalized for up to 90 days at a rate currently 25 basis points above the target federal funds rate.[10] Discount window loans are typically overnight and allow for early repayment of the loan if issued for a longer term. We expect that banks that borrow from the discount window are banks that could not meet their liquidity requirements in the fed funds market; we study these institutions to see which types of banks may have had unmet fed funds demand.

In this period, banks could also borrow from the Federal Reserve's Term Auction Facility (TAF).[11] We focus on discount window lending instead of TAF as the best substitute for overnight fed funds because TAF funding is available only on a term basis, cannot be prepaid, and can be accessed only on prespecified dates.

II. Data

Fed funds data for this analysis come from a proprietary transaction-level data set that contains all transfers sent and received by institutions through Fedwire. An institution that maintains an account at a Federal Reserve Bank can generally become a Fedwire participant and use this account to make large-value payments as well as settle interbank loans. Fed funds loans are thus a subset of all Fedwire transactions. We identify transfers as fed funds transactions using an algorithm similar to the one proposed by Furfine (1999), which is summarized in the Appendix. Similar data are used in Ashcraft and Duffie (2007), Bech and Atalay (2008), and Bartolini, Hilton, and McAndrews (2010), among others. These data include the date, amount, interest rate, time of delivery, and time of return as well as the identity of the lender and the borrower of every transaction sent over Fedwire. The borrower and lender are identified at the lead American Banking Association (ABA) level, which corresponds to a unique identifier assigned to institutions by the Federal Reserve (RSSD). We aggregate the fed funds data at the bank holding company level, dropping

[8] Acceptable collateral includes U.S. government and agency securities, certain types of foreign sovereign debt obligations, municipal or corporate obligations of investment quality, commercial paper of investment quality, bank-issued assets by an institution in "sound financial condition," and customer obligations that meet credit quality standards.

[9] Armantier et al. (2009) and Furfine (2003) find empirical evidence of discount window stigma.

[10] In March 17, 2008, the spread between the primary rate at the discount window and the federal funds target was narrowed from 50 to 25 basis points and the maximum maturity of discount window loans extended from 30 to 90 days.

[11] The TAF was created on December 12, 2007 and provides term funding at interest rates and amounts set by biweekly auctions. Armantier, Krieger, and McAndrews (2008) present a detailed analysis of the liquidity conditions in the term funding markets leading up to the introduction of the TAF as well as the structure and results of the first 10 TAF auctions. See also http://atthebank.ny.frb.org/BankBusiness/facilities.shtml#taf for more information on the facility.

transactions between entities of the same bank holding company, and aggregate loans between each borrower–lender pair on a daily basis, calculating the federal funds rate for each borrower–lender pair as a weighted average.

We augment these data with quarterly information on bank characteristics as filed in the Consolidated Financial Statements for Bank Holding Companies (FR Y-9C),[12] which provides information on credit risk variables, total assets, and financial ratios. In addition, we add information from proprietary Federal Reserve databases on reserve requirements and discount window borrowing. Data on discount window loans are available daily and include information on the borrower, amount borrowed, available collateral, and interest rate. These data are described in greater detail by Armantier, Ghysels, and Sarkar (2009) in their analysis of the interaction between TAF bidding and discount window borrowing.

III. The Federal Funds Market during the 2007–2008 Crisis

Despite theoretical predictions and public perception of a collapse in interbank lending around financial crises, the overnight federal funds market was remarkably stable through the recent period of turmoil in the financial markets. Figures 1 to 3 show the amount, participation, and interest rates in the fed funds market from March 3, 2008 to October 8, 2008. We highlight two key dates in each figure:[13] (i) March 16, 2008—JP Morgan announces that it will acquire Bear Stearns for $2 a share, and (ii) September 15, 2008—Lehman Brothers files for bankruptcy after failing to find a merger partner.

As shown in Figure 1, the daily amount of transactions is surprisingly stable over the period considered, hovering around $200 million through the summer of 2008 and even after Lehman's bankruptcy. Similarly, as shown in Figure 2, the number of borrowers remains relatively stable at 100–150 banks throughout the Lehman Brothers' episode. In contrast, the number of lenders falls from approximately 250 to 300 in the summer of 2008 to around 225 after Lehman Brothers' bankruptcy. As shown in Figure 3, the daily fed funds rate is relatively stable after the Bear Stearns' episode until Lehman Brothers' bankruptcy. The weighted average rate jumps more than 60 basis points on September 15, 2008, with substantially more widening of the distribution.

IV. Definition of Variables

To understand the impact of the financial crisis on the fed funds market, we study the period surrounding the bankruptcy of Lehman Brothers. We begin the pre-Lehman period on April 1, 2008 so as to avoid the collapse of Bear

[12] Consolidated Reports of Income and Condition (FR Y-9C) are available from the Federal Reserve online at http://chicagofed.org/webpages/banking/financial_institution_reports/bhc_data.cfm. Data are available about 2 to 3 months after the end of each quarter (e.g., data for the third quarter of 2008 became available at the beginning of December 2008).

[13] These figures are available for a longer time period in the Internet Appendix.

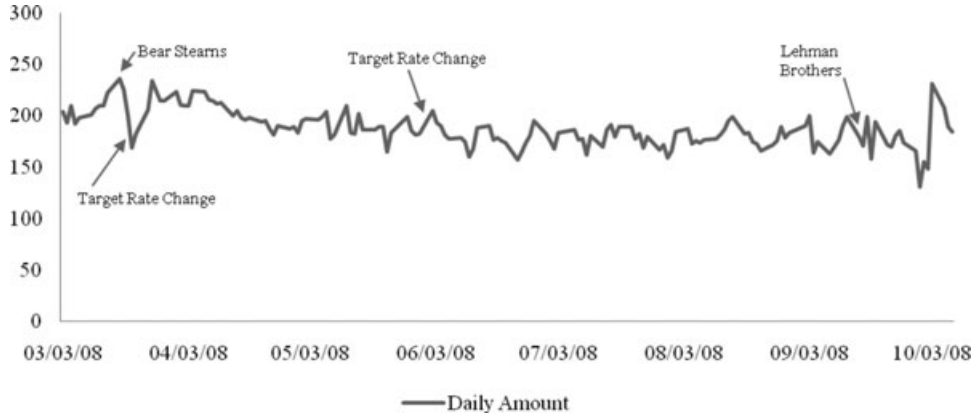

Figure 1. Daily amount of federal funds transactions ($ billions). The figure shows the aggregate daily amount borrowed in the fed funds market (in U.S. $ billions) from March 3, 2008 to October 8, 2008. The arrows indicate the following dates: (i) March 16, 2008—JP Morgan announces that it will acquire Bear Stearns for $2 a share, (ii) March 18, 2008—Federal Reserve Open Market Committee (FOMC) lowers target overnight federal funds rate 75 basis points to 2.25%, (iii) April 30, 2008—FOMC lowers target overnight federal funds rate 25 basis points to 2.00%, and (iv) September 15, 2008—Lehman Brothers files for bankruptcy after failing to find a merger partner.

Stearns and continue the sample through February 28, 2009 so that there are an equal number of days preceding and following the event.

Summary statistics for the fed funds market in this time period are presented in Table I. While the mean and median amount of daily loans do not fall, the mean spread between banks' fed funds loan rates and the target fed funds rate almost doubles in the days immediately surrounding Lehman's bankruptcy, and the volatility of spreads increases as well. It is worth noting that even in the pre-Lehman period only approximately 30% of borrowers actually borrow on any given day. This number falls to 27.4% surrounding Lehman's bankruptcy, although the decline in mean daily borrowers is significantly different from the pre-Lehman period only after the Federal Reserve begins to pay interest on excess reserves (October 2008).

Table II shows characteristics for all borrowing and lending banks in the sample. The borrower sample has only borrowers with Y-9C data so that we can measure banks' characteristics consistently. It includes loans from all lenders to these borrowers, including amounts borrowed from government-sponsored enterprises (GSEs) and U.S. subsidiaries of foreign banking organizations. As summarized in Table II, the median borrower in this market has more than $1 billion in assets (the mean is $28 billion) and NPLs of 0.8% of total loans as of December 31, 2007 (the mean level of NPLs is 1.1%). The lender sample is different from the borrower sample because it has only lenders with Y-9C data. Loans from GSEs and U.S. subsidiaries of foreign banking organizations are excluded, but we do not exclude loans to those entities. The median lender in this market has characteristics that are similar to those of the median borrower,

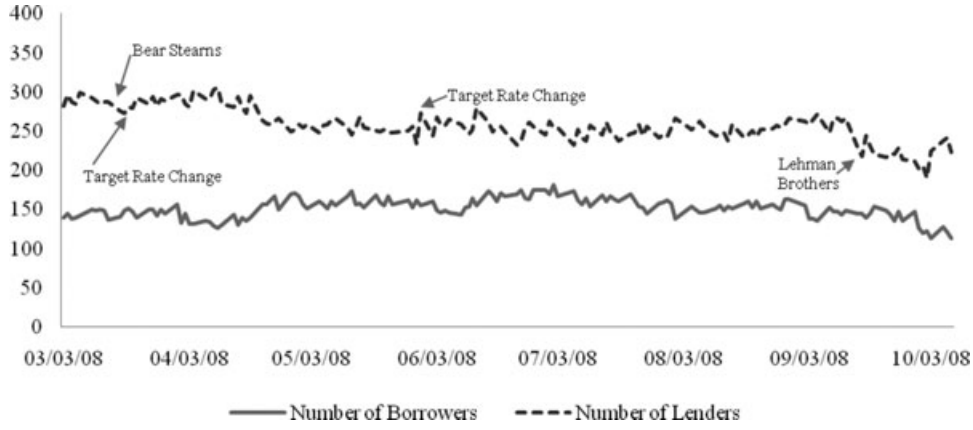

Figure 2. Daily number of borrowers and lenders. The figure shows the daily number of borrowers and lenders in the fed funds market from March 3, 2008 to October 8, 2008. The arrows indicate the following dates: (i) March 16, 2008—JP Morgan announces that it will acquire Bear Stearns for $2 a share, (ii) March 18, 2008—FOMC lowers target overnight federal funds rate 75 basis points to 2.25%, (iii) April 30, 2008—FOMC lowers target overnight federal funds rate 25 basis points to 2.00%, and (iv) September 15, 2008—Lehman Brothers files for bankruptcy after failing to find a merger partner.

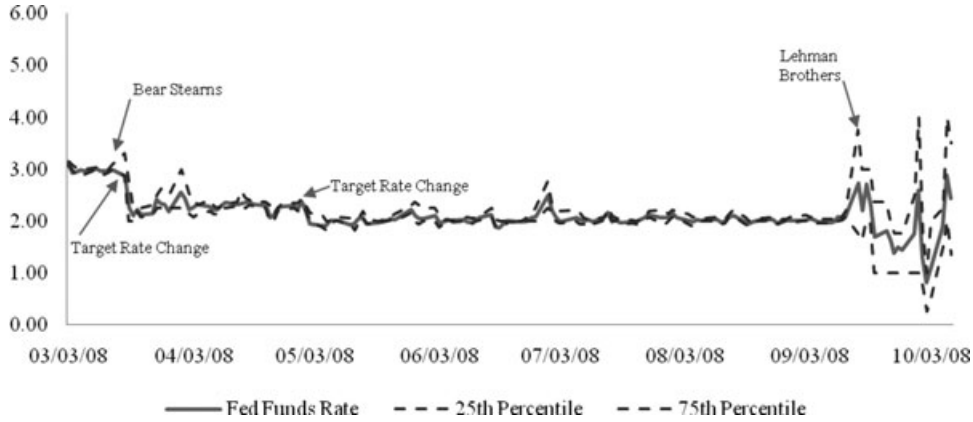

Figure 3. Daily fed funds rates. The figure shows the weighted average daily fed funds rate as well as the daily fed funds rate for the 25th and 75th percentiles of borrowers from March 3, 2008 to October 8, 2008. The arrows indicate the following dates: (i) March 16, 2008—JP Morgan announces that it will acquire Bear Stearns for $2 a share, (ii) March 18, 2008—FOMC lowers target overnight federal funds rate 75 basis points to 2.25%, (iii) April 30, 2008—FOMC lowers target overnight federal funds rate 25 basis points to 2.00%, and (iv) September 15, 2008—Lehman Brothers files for bankruptcy after failing to find a merger partner.

with close to $1 billion in assets and NPLs of 0.8% of total loans as of December 31, 2007. Again, the mean values are $26 billion and 1.3%, respectively.

For the analysis in Tables III to VII, we aggregate the data into two samples so that we can examine the importance of both borrower and lender

Table I

Fed Funds Market Summary Statistics

The sample consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The first three variables include one observation per borrower-day, and the final variable consists of one observation per day.

	Obs.	25%	Median	Mean	75%	*SD*
Pre-Lehman (4/1–9/11)						
Spread to target	12,306	0.0118	0.1025	0.1264	0.2273	0.1961
Amount ($M)	12,306	20.0	71.3	1,148.0	395.0	3,836.6
Counterparties	12,306	1.0	2.0	7.6	8.0	13.8
Borrowers/day (%)	115	27.5	30.0	29.7	31.7	2.8
Surrounding Lehman (9/12–9/16)						
Spread to target	296	0.0000	0.1875	0.2184	0.4982	0.6201
Amount ($M)	296	20.0	85.0	1,188.8	431.9	4,099.7
Counterparties	296	1.0	2.0	7.3	8.0	13.0
Borrowers/day (%)	3	26.7	27.5	27.4	28.1	0.7
Post-Lehman (9/17–2/28)						
Spread to target	8,224	−0.5000	0.0973	−0.0432	0.2863	0.5337
Amount ($M)	8,224	20.0	85.0	1,264.0	457.0	4,062.7
Counterparties	8,224	1.0	2.0	5.9	7.0	8.8
Borrowers/day (%)	111	18.1	20.3	20.6	22.8	3.1

Table II

Fed Funds Participant Summary Statistics

The sample for borrowers consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The sample for lenders consists of 26,557 observations from 373 lenders from April 1, 2008 to February 28, 2009. Note that *Nonperforming Loans (%)* and *Repurchase Agreements (%)* are in percentage format here, but are in decimal format for all specifications.

	Obs.	25%	Median	Mean	75%	Std. Dev.
Borrower Characteristics						
Nonperforming loans (%)	360	0.4148	0.8252	1.1424	1.3581	1.4801
Assets ($M)	360	487	1,403	27,832	4,684	176,337
Repurchase agreements (%)	360	0.0000	1.7068	3.1951	5.2044	3.8930
Lender Characteristics						
Nonperforming loans (%)	373	0.2395	0.7761	1.2899	1.4293	1.9402
Assets ($M)	373	324	829	26,372	3,286	173,259
Repurchase agreements (%)	373	0.0000	0.6420	2.6860	3.8724	4.1764
Fed Funds Variables						
Spread to target	20,826	−0.0094	0.1014	0.0607	0.2500	0.3844
Amount ($M)	20,826	20.0	75.1	1,194.4	422.0	3,931.4
Counterparties	20,826	1.0	2.0	6.9	8.0	12.1
Total amount ($M)	229	103,311.1	117,312.2	113,518.5	127,582.5	20,962.7
Target rate (%)	229	1.0	2.0	1.4	2.0	0.8
Fed funds rate (%)	229	0.2453	1.9472	1.3333	2.0441	0.8908

characteristics. The first sample, in which we aggregate all fed funds loans to each borrower in a day, consists of 20,826 observations from 360 borrowers. The second sample, in which we aggregate all fed funds loans from each lender in a day, consists of 26,557 observations from 373 lenders. Each analysis is conducted with one observation per borrower-day (lender-day).

We allow market conditions to vary in different windows around the bankruptcy of Lehman Brothers, selecting break points around the following events:

- September 15, 2008—Lehman Brothers files for bankruptcy (pre-market open).
- September 16, 2008—Federal Reserve loans $85 billion to AIG (after market close).
- October 9, 2008—Federal Reserve begins to pay interest on required and excess reserve balances (IOR).[14]
- October 14, 2008—Nine large banks agree to capital injection from Treasury (Capital Purchase Program (CPP)).[15]

We indicate with binary variables the following time periods: 2 weeks pre-Lehman (August 29, 2008 to September 4, 2008); 1 week pre-Lehman (September 5, 2008 to September 11, 2008); Friday, September 12, 2008; Monday, September 15, 2008; Tuesday, September 16, 2008; post-AIG and pre-IOR (September 17, 2008 to October 8, 2008); post-IOR and pre-CPP (October 9, 2008 to October 13, 2008); and monthly after CPP (October 14, 2008 to November 10, 2008 and thereafter). While controls for all time periods are included in all specifications, we present coefficients only through the post-AIG and pre-IOR period in the tables due to size limitations. Tables with all estimated coefficients are available in the Internet Appendix.[16]

We analyze three variables to assess conditions in the fed funds market: price, amount, and number of counterparties. We measure the price of fed funds with the weighted average spread between the rate for each bank and the target federal funds rate on a given day.[17] The amount of fed funds loans

[14] The Financial Services Regulatory Relief Act of 2006 authorizes the Federal Reserve to pay interest on reserve balances and on excess balances held by or on behalf of depository institutions beginning October 1, 2011. The effective date of this authority was advanced to October 1, 2008 by the Emergency Economic Stabilization Act of 2008. Beginning on October 9, 2008 the interest rate paid on required reserve balances was 10 basis points below the average target federal funds rate over a reserve maintenance period while the rate for excess balances was set at 75 basis points below the lowest target federal funds rate for a reserve maintenance period. Since December 18, 2008 the Federal Reserve has paid 25 basis points on required reserve balances and excess balances.

[15] In October 2008, Treasury created the CPP to provide capital to viable banks through the purchase of banks' preferred shares. In return for its investment, Treasury receives dividend payments and warrants.

[16] An Internet Appendix for this article is available online in the "Supplements and Datasets" section at http://www.afajof.org/supplements.asp.

[17] We measured the price of fed funds using the spread to the effective fed funds rate rather than to the target. Results for the interaction of bank characteristics were similar, although the

is calculated as the log of the total amount borrowed in $ millions plus one. We include in this analysis only banks that were observed borrowing in the market at any time from April 1, 2008 to February 28, 2009.[18] Finally, we calculate the number of counterparties as the log of the number of different lenders (borrowers) in a given day. We also tabulate the daily percentage of the number of banks borrowing, by dividing the number of unique borrowers by the 360 banks that borrowed in the sample time period (April 2008 to February 2009).

V. The Effects of Shocks to the Interbank Market

In the following analyses, we want to shed light on the functioning of the fed funds market in the aftermath of a major shock to the banking industry, namely the bankruptcy of Lehman Brothers. Our objective is to document which banks were able to access the market after the onset of the Lehman crisis and at what terms. One view is that this shock led to a market-wide collapse of the fed funds market and prevented even banks that are good credit risks from accessing the market. Accordingly, we look at different dimensions of access to credit such as the interest rate at which banks borrow, the amount of the loan, and the number of counterparties. The last two are particularly important since many participants in the fed funds market suggest that credit risk is managed via credit rationing rather than interest rates.

In Table III, we first look at the effect of Lehman's bankruptcy on the fed funds market with and without controlling for fixed bank borrower characteristics. This allows us to separate the effect of the crisis on a given bank from the composition effects of who was able to access the interbank market after the Lehman crisis. The first column is a probit estimation with a dependent variable equal to one if a bank borrows on a given day. We do not estimate a probit model with borrower fixed effects because fixed effects for the 20 banks that borrow every day (including the period around Lehman's bankruptcy) would predict access perfectly and thus be excluded from the analysis, distorting the results.[19] The dependent variable in the next two columns is the spread to target (the difference between the weighted average interest rate for a given bank and the target interest rate). Columns (4) and (5) report the effect on the logarithm of the amount borrowed and the dependent variable in columns (6) and (7) is the logarithm of the number of counterparties for a given borrower. Standard errors are clustered at the bank level. Results are robust to clustering at both the bank and time period levels.

positive coefficient on Monday September 15 was naturally reduced, since the effective rate was dramatically higher than the target rate on that day.

[18] We estimated similar results, expanding the analysis to include banks that did not borrow, filling in the amount to be the log of one, effectively creating observations for banks that did not borrow on a given day with amounts of zero.

[19] Although 360 banks borrowed in the fed funds market from April 1, 2008 to February 28, 2009, only 20 borrowed every day of this time period.

Table III
Impact of the Lehman Event on Borrowers

The sample used in column (1) consists of 79,619 observations from 360 borrowers from April 1, 2008 to February 28, 2009, where observations have been filled in with 0's on days banks do not borrow. The sample used in columns (2) to (7) consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009, where only banks that borrow are present. The dependent variables are *Access (Fed Funds), Spread to Target, Amount,* and *Counterparties*. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

	Access	Spread to Target		Amount		Counterparties	
	Probit	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1 week pre-Lehman	−0.084**	−0.021***	−0.016**	0.019	−0.028	0.049	0.003
(9/5–9/11)	(0.037)	(0.008)	(0.007)	(0.105)	(0.057)	(0.057)	(0.038)
Friday (9/12)	−0.049	0.069***	0.077***	−0.064	−0.070	0.016	−0.005
	(0.048)	(0.012)	(0.009)	(0.151)	(0.084)	(0.073)	(0.049)
Monday (9/15)	−0.066	0.235***	0.246***	−0.004	−0.193**	−0.049	−0.135**
	(0.046)	(0.087)	(0.087)	(0.150)	(0.095)	(0.075)	(0.055)
Tuesday (9/16)	−0.091*	−0.033	−0.026	0.069	−0.102	0.025	−0.076
	(0.048)	(0.053)	(0.049)	(0.142)	(0.077)	(0.075)	(0.053)
Post-AIG, pre-IOR	−0.146***	−0.227***	−0.232***	−0.053	−0.257***	0.042	−0.097**
(9/17–10/8)	(0.033)	(0.038)	(0.036)	(0.094)	(0.062)	(0.051)	(0.039)
Borrower fixed effects	No	No	Yes	No	Yes	No	Yes
N	79,619	20,826	20,826	20,826	20,826	20,826	20,826
Adjusted-R^2		0.27	0.51	0.00	0.86	0.00	0.83

In contrast to theoretical predictions of a cessation in trading, without controlling for bank fixed effects there does not seem to be much happening in the 2 days following Lehman's bankruptcy. While the probit estimation suggests that access to the interbank market decreased around Lehman's bankruptcy, the change to the market is not the abrupt cessation of activity predicted by both counterparty and liquidity hoarding theories. Rather than a sudden large negative coefficient immediately after Lehman's bankruptcy, we estimate small negative coefficients beginning in August 2008. These negative coefficients become significantly more negative after the Federal Reserve pays interest on reserves. Also, there is no statistically significant change in the amount borrowed (column (4)) or the number of counterparties (column (6)). Spreads increase on Monday, September 15, but begin falling thereafter (column (2)). Results are similar when the data are grouped by lender and we control for fixed lender characteristics, and when data are included for all borrowers and all lenders (see the Internet Appendix).

But these results hide a dramatic shift in the flow of funds and the distribution of rates across different borrowers. When we include borrower fixed effects in column (5), the coefficient on the post-Lehman dummy is negative and significant with a coefficient estimate of −0.19 on September 15. The economic effect is economically large since a point estimate of −0.19 translates

into a reduction in borrowing of 17.3%. The results suggest that while after Lehman's bankruptcy the average loan size of banks in the fed funds market did not drop (Table III, column (4)), for any given bank the amount borrowed decreased (column (5)). These two seemingly contradictory effects can only be reconciled if there is a change in the composition of banks that are borrowing in the market: larger banks or those banks that were able to borrow larger amounts must have accessed the interbank market less often after Lehman's bankruptcy. Therefore, the average loan in the sample is unchanged, while at the same time the average bank in the sample sees a decline in the amount borrowed. It seems that those banks that usually borrow a lot and often from the market were the ones facing very different borrowing terms or even losing access, while banks that use the market less seem to have increased their borrowing.

Similarly, column (7) shows that there is a reduction in the number of counterparties a bank borrows from post-Lehman only after including borrower fixed effects. The coefficient on the post-Lehman dummy is negative in the cross-section but not significant. This suggests that a given borrower in the sample borrows from fewer counterparties post-Lehman. Even those banks that are able to access the fed funds market after Lehman's bankruptcy borrow from a smaller number of counterparties.

It is important to note that when including borrower fixed effects in Table III the adjusted-R^2 jumps dramatically. So, clearly, bank characteristics are an important determinant of banks' borrowing in the fed funds market. In fact, including only borrower characteristics such as assets, ROA, NPL levels, and risk ratios instead of bank fixed effects, we can explain about 70% of the cross-sectional variation of bank borrowing.

In Tables IV–VII we begin to disentangle the impact of the Lehman Brothers' bankruptcy on banks of different size and performance metrics. If lenders respond to the crisis by hoarding liquidity, we would expect to find an aggregate decrease in amounts lent as well as worse performing banks lending less. In contrast, if uncertainty about counterparty risk increases but banks can still distinguish among risks, we would expect to find worse performing banks borrowing less and/or paying higher prices.

We first estimate a probit specification where the dependent variable is a binary variable, $Access_{b,t}$, equal to one when banks borrow (lend):

$$Access_{b,t} = \beta(Date) + \delta(Date \times X_{b,2007}) + \gamma(Date \times Assets_{b,2007}) + \varepsilon_{b,t}. \quad (1)$$

Then, for each of the fed funds terms $F_{b,t}$ (spread to target, log amount, and log number of counterparties), we estimate

$$F_{b,t} = \beta(Date) + \delta(Date \times X_{b,2007}) + \gamma(Date \times Assets_{b,2007}) + \theta\left(\frac{Amount_{b,t}}{Assets_{b,2007}}\right) + \alpha_b + \varepsilon_{b,t}, \quad (2)$$

where b indexes bank borrowers or lenders, t indexes time in days, *Date* is a vector of dummy variables equal to one in the time period of interest and

Table IV
Impact of the Lehman Event on Participation in the Fed Funds Market

The sample for borrowers consists of 79,619 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The sample for lenders consists of 83,255 observations from 373 lenders from April 1, 2008 to February 28, 2009. We divide the samples into terciles, where *Large* is the top tercile of assets and *Small* is the bottom tercile of assets. The dependent variable is *Access (Federal Funds)*. All specifications include controls for the interaction of *Assets* and the time period dummies. Bank characteristics are measured as of the Call Report as of December 2007. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. a, b, and c indicate the difference between the coefficients of the *Large* and *Small* banks is statistically significant at the 1%, 5%, and 10% level, respectively.

	Borrowers		Lenders	
	Large (1)	Small (2)	Large (3)	Small (4)
1 week pre-Lehman (9/5–9/11)	−4.015***c	−1.183c	−1.775***	−0.225
	(0.970)	(1.244)	(0.620)	(0.829)
Friday (9/12)	−3.782***	−2.334	−1.731**b	0.566b
	(1.093)	(2.245)	(0.749)	(0.890)
Monday (9/15)	−5.921***c	−1.197c	−2.348***b	0.347b
	(1.693)	(1.895)	(0.735)	(0.900)
Tuesday (9/16)	−5.011***b	0.415b	−2.952***a	0.386a
	(1.315)	(1.767)	(0.750)	(0.888)
Post-AIG, pre-IOR (9/17–10/8)	−4.735***	−3.268***	−1.995***b	0.290b
	(0.917)	(1.095)	(0.560)	(0.793)
1 week pre-Lehman × %NPL	−48.753***a	11.398a	23.736**	4.118
	(17.947)	(10.042)	(10.802)	(5.250)
Friday × %NPL	−40.423**	−16.019	20.563*	6.436
	(19.612)	(20.130)	(11.047)	(5.892)
Monday × %NPL	−69.910***a	10.163a	36.339***b	−0.194b
	(23.243)	(14.231)	(13.018)	(5.949)
Tuesday × %NPL	−50.656**a	11.769a	27.381**c	2.237c
	(20.015)	(12.184)	(11.478)	(5.776)
Post-AIG, pre-IOR × %NPL	−53.455***a	19.100**a	14.182	0.831
	(17.638)	(8.052)	(9.325)	(4.675)
Bank fixed effects	No	No	No	No
N	22,866	31,103	26,705	28,197

zero otherwise, $X_{b,2007}$ is the bank characteristic of interest such as % NPLs measured as of December 31, 2007, $Assets_{b,2007}$ are bank borrower or lender assets as of December 31, 2007, $Amount_{b,t}$ *is* the amount borrowed or lent in the fed funds market (not included when the dependent variable is *Amount*), and $\varepsilon_{b,t}$ is an error term. The fed funds terms specifications include α_b fixed effects for bank borrowers (lenders).

We consider characteristics of borrowing (lending) banks in two ways. First, we split the sample into three equally sized bins by asset size. The smallest banks are those with less than $690 million in assets, and the largest have more than $2.6 billion. In the fed funds terms specifications (Tables IV to VII), there are fewer observations in the smaller bank group because smaller

Table V
Impact of the Lehman Event on Spreads

The sample for borrowers consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The sample for lenders consists of 26,557 observations from 373 lenders from April 1, 2008 to February 28, 2009. We divide the samples into terciles, where *Large* is the top tercile of assets and *Small* is the bottom tercile of assets. The dependent variable is *Spread to Target*. All specifications control for amount borrowed (lent) as a percent of bank assets. Specifications (3), (4), (7), and (8) include controls for the interaction of *Assets* and the time periods. Bank characteristics are measured as of the Call Report as of December 2007. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. a, b, and c indicate the difference between the coefficients of the *Large* and *Small* banks is statistically significant at the 1%, 5%, and 10% level, respectively.

	Borrowers				Lenders			
	Large (1)	Small (2)	Large (3)	Small (4)	Large (5)	Small (6)	Large (7)	Small (8)
1 week pre-Lehman	−0.017**	−0.012	0.019	0.039	−0.023**	−0.014*	−0.028	−0.052
(9/5–9/11)	(0.007)	(0.024)	(0.040)	(0.515)	(0.010)	(0.008)	(0.050)	(0.050)
Friday (9/12)	0.081***	0.111***	−0.021	0.293	0.073***	0.062***	0.081	0.022
	(0.011)	(0.037)	(0.074)	(0.221)	(0.013)	(0.012)	(0.068)	(0.080)
Monday (9/15)	0.143[a]	0.950***[a]	0.823	0.016	0.093	0.322***	−0.168	0.431
	(0.115)	(0.243)	(0.752)	(2.336)	(0.121)	(0.119)	(0.568)	(0.833)
Tuesday (9/16)	−0.103*[c]	0.289[c]	0.232	0.756	−0.248***	−0.297***	−1.475***[a]	0.400[a]
	(0.058)	(0.215)	(0.488)	(1.317)	(0.089)	(0.066)	(0.441)	(0.381)
Post-AIG, pre-IOR	−0.328***[a]	0.192**[a]	0.299	1.146	−0.444***	−0.501***	−1.256***[a]	0.043[a]
(9/17–10/8)	(0.044)	(0.091)	(0.328)	(0.870)	(0.044)	(0.068)	(0.173)	(0.392)
1 week pre-Lehman			0.523	−0.606			−0.673	−0.017
× %NPL			(1.526)	(0.863)			(0.659)	(0.230)
Friday × %NPL			2.203	−4.297			−0.868	−0.050
			(3.650)	(2.835)			(0.624)	(0.410)
Monday × %NPL			33.260*	2.980			−4.296	2.554
			(18.493)	(7.350)			(5.976)	(5.378)
Tuesday × %NPL			−18.086*	−16.963**			5.027	0.371
			(10.342)	(7.915)			(4.020)	(2.538)
Post-AIG, pre-IOR			12.169*[a]	−12.499***[a]			−0.899	−3.714
× %NPL			(7.153)	(3.369)			(1.933)	(2.910)
Fixed effects	Borrower	Borrower	Borrower	Borrower	Lender	Lender	Lender	Lender
N	13,860	1,805	13,860	1,805	10,438	9,213	10,438	9,213
Adjusted-R^2	0.50	0.51	0.52	0.54	0.40	0.51	0.42	0.52

banks are less frequent borrowers (both in the pre- and post-crisis periods). We estimate the same specifications separately for each size group, allowing all of the coefficients to vary with bank size. We present the coefficients for the largest and smallest banks to show how pricing changes differently for large and small banks. When the difference in coefficients between columns is statistically significant, the coefficients are labeled a, b, or c, if the difference is statistically significant at the 1%, 5%, and 10% level, respectively. This format was selected for expositional clarity. Results were qualitatively similar when estimated with different size breakpoints and using an interaction between assets and the explanatory variables. It is worth emphasizing that the fed funds terms regressions include borrower (lender) fixed effects. Our identification therefore is only driven by changes in the sensitivity of fed funds terms to banks' pre-crisis characteristics. That means we estimate a change in the slope

Table VI

Impact of the Lehman Event on Amount Borrowed/Lent

The sample for borrowers consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The sample for lenders consists of 26,557 observations from 373 lenders from April 1, 2008 to February 28, 2009. We divide the samples into terciles, where *Large* is the top tercile of assets and *Small* is the bottom tercile of assets. The dependent variable is *Amount*. Specifications (3), (4), (7), and (8) include controls for the interaction of *Assets* and the time periods. Bank characteristics are measured as of the Call Report as of December 2007. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. a, b, and c indicate the difference between the coefficients of the *Large* and *Small* banks is statistically significant at the 1%, 5%, and 10% level, respectively.

	Borrowers				Lenders			
	Large (1)	Small (2)	Large (3)	Small (4)	Large (5)	Small (6)	Large (7)	Small (8)
1 week pre-Lehman	−0.036	0.032	0.246	−0.190	0.082	−0.028	0.478[b]	−0.666*[b]
(9/5–9/11)	(0.076)	(0.062)	(0.313)	(0.521)	(0.074)	(0.055)	(0.352)	(0.382)
Friday (9/12)	−0.069	0.091	−0.269	−1.089***	0.141	−0.006	0.346	−0.364
	(0.102)	(0.078)	(0.508)	(0.398)	(0.120)	(0.073)	(0.526)	(0.589)
Monday (9/15)	−0.288**	−0.089	−0.639	−0.942**	−0.021	−0.194**	0.500	−0.339
	(0.120)	(0.122)	(0.591)	(0.436)	(0.107)	(0.080)	(0.523)	(0.519)
Tuesday (9/16)	−0.100	−0.118	0.135	0.230	−0.108	−0.199**	0.329	−0.507
	(0.096)	(0.122)	(0.428)	(0.643)	(0.106)	(0.082)	(0.549)	(0.550)
Post-AIG, pre-IOR	−0.274***	−0.113	0.005	1.046	−0.077	−0.177***	0.082	−0.468
(9/17–10/8)	(0.082)	(0.097)	(0.441)	(1.183)	(0.074)	(0.062)	(0.380)	(0.395)
1 week pre-Lehman			−49.493***[a]	−6.605[a]			5.150[c]	−2.307[c]
× %NPL			(15.396)	(4.774)			(3.999)	(1.647)
Friday × %NPL			−33.714	−6.258*			5.577	−4.328
			(22.999)	(3.246)			(6.609)	(2.683)
Monday × %NPL			−53.533***[b]	−10.841***[b]			−1.827	−5.779*
			(19.520)	(2.723)			(4.910)	(3.172)
Tuesday × %NPL			−28.184	−8.363			−0.427	−4.511
			(24.606)	(11.607)			(7.189)	(2.946)
Post-AIG, pre-IOR			−33.826*[c]	−0.198[c]			−1.788	−4.041
× %NPL			(17.701)	(7.064)			(4.022)	(2.777)
Fixed effects	Borrower	Borrower	Borrower	Borrower	Lender	Lender	Lender	Lender
N	13,860	1,805	13,860	1,805	10,438	9,213	10,438	9,213
Adjusted-R^2	0.80	0.83	0.81	0.84	0.82	0.94	0.83	0.94

of the relationship between bank characteristics and fed funds' loan amounts and pricing.

Since the fed funds terms specifications already include controls for bank fixed effects, splitting the sample by asset size also allows us to see if the time period effect is different for banks of different sizes. We also control for the interaction of asset size and the date dummies in each specification shown in Tables IV to VII, although these coefficients are not presented in the tables due to size limitations (results are available in the Internet Appendix). In specifications with spread or counterparties as the dependent variable, we control for the interaction of amount borrowed divided by asset size and the date dummies in each specification, although these coefficients are not presented in the tables. We next add the interaction of bank characteristics such as the percentage of NPLs with time period dummies to the specifications sorted by bank size. The

Table VII

Impact of the Lehman Event on Number of Counterparties

The sample for borrowers consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The sample for lenders consists of 26,557 observations from 373 lenders from April 1, 2008 to February 28, 2009. We divide the samples into terciles, where *Large* is the top tercile of assets and *Small* is the bottom tercile of assets. The dependent variable is *Counterparties*. All specifications control for amount borrowed (lent) as a percent of bank assets. Specifications (3), (4), (7), and (8) include controls for the interaction of *Assets* and the time periods. Bank characteristics are measured as of the Call Report as of December 2007. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. a, b, and c indicate the difference between the coefficients of the *Large* and *Small* banks is statistically significant at the 1%, 5%, and 10% level, respectively.

	Borrowers				Lenders			
	Large (1)	Small (2)	Large (3)	Small (4)	Large (5)	Small (6)	Large (7)	Small (8)
1 week pre-Lehman	−0.015	0.025	0.142	−0.098	0.014	0.005	0.079	−0.229
(9/5–9/11)	(0.038)	(0.021)	(0.207)	(0.226)	(0.039)	(0.032)	(0.198)	(0.321)
Friday (9/12)	−0.030	0.029	0.117	−0.129	0.067	0.032	−0.058	−0.130
	(0.054)	(0.031)	(0.251)	(0.160)	(0.058)	(0.028)	(0.302)	(0.211)
Monday (9/15)	−0.151***[a]	0.033[a]	0.329	−0.107	−0.027	−0.042	0.298	−0.159
	(0.054)	(0.028)	(0.276)	(0.226)	(0.057)	(0.041)	(0.254)	(0.230)
Tuesday (9/16)	−0.103*[a]	0.164**[a]	0.787**[a]	−0.485[a]	−0.036	−0.051	−0.092	−0.222
	(0.055)	(0.082)	(0.323)	(0.312)	(0.071)	(0.042)	(0.385)	(0.355)
Post-AIG, pre-IOR	−0.063[c]	0.077[c]	0.640***[a]	−0.873[a]	−0.132***[c]	−0.035[c]	−0.137	−0.295
(9/17–10/8)	(0.039)	(0.062)	(0.178)	(0.543)	(0.040)	(0.041)	(0.204)	(0.372)
1 week pre-Lehman			−13.457**[b]	−0.393[b]			4.299**[c]	−0.007[c]
× %NPL			(6.164)	(1.131)			(2.189)	(0.780)
Friday × %NPL			−6.141	−3.837*			5.374[c]	−0.504[c]
			(10.550)	(2.296)			(3.423)	(0.724)
Monday × %NPL			−19.363**[b]	0.292[b]			6.014**[b]	−0.688[b]
			(9.241)	(1.657)			(2.654)	(1.586)
Tuesday × %NPL			−16.105	−3.579			2.831	−1.099
			(12.891)	(4.409)			(3.951)	(1.856)
Post-AIG, pre-IOR			−20.218**[b]	0.686[b]			0.950	−0.088
× %NPL			(9.658)	(2.182)			(2.331)	(0.974)
Fixed effects	Borrower	Borrower	Borrower	Borrower	Lender	Lender	Lender	Lender
N	13,860	1,805	13,860	1,805	10,438	9,213	10,438	9,213
Adjusted-R^2	0.88	0.65	0.90	0.65	0.85	0.92	0.85	0.92

end result is effectively a triple difference-in-difference estimation, testing to see if the market becomes more sensitive to these underlying characteristics in the post-Lehman period, and if the borrowing of small and large banks in the fed funds market is differentially sensitive to these characteristics.

We first test to see if borrowing (lending) is associated with borrower (lender) characteristics (Table IV). We find that large borrowers and lenders access the fed funds market less after Lehman's bankruptcy. Furthermore, it is the worst performing large banks that access the market least to borrow—the coefficient on *%NPL* is negative and statistically significant for large borrowers. Surprisingly, this pattern is reversed for lenders—the worst performing large lenders are actually more likely to lend on the Monday and Tuesday following Lehman's bankruptcy.

Table V examines how interbank lending rates for large and small banks changed after the Lehman Brothers' bankruptcy. While smaller borrowers see an increase in spreads of over 95 basis points on Monday, larger borrowers observe no significant increase in their spreads. Post-Lehman spread changes are similar for small and large lenders. In columns (3), (4), (7), and (8), we add interactions of the post-Lehman dummies with NPLs as a proxy for borrower and lender quality.[20] Immediately after Lehman's bankruptcy, the relationship between spreads and quality is no different from that for the pre-crisis period.

These results underscore again that interest rates in the fed funds markets did not become increasingly sensitive to bank performance metrics in a consistent manner. Yet, this does not necessarily mean that lenders are not concerned about the counterparty risk of banks. Rather, the results suggest that lenders seem to be more likely to manage their risk exposure by the amount they lend to a particular bank or even whether they lend to the bank at all. The fact that interest rates go up for the smaller banks but not for the larger banks does not necessarily constitute a flight to size. In contrast, these trends could be driven by rationing in the market. If only smaller banks are able to access the fed funds market after the Lehman Brothers shock but at higher rates, we could find higher rates for smaller banks. But in this case the higher rate is an indication that only smaller banks are able to access the market, while large banks are not. The results of the next two tables provide additional evidence that corroborates this interpretation.

We next describe, in Table VI, the daily amount borrowed and lent by banks in the fed funds market. Interestingly, we see a difference in the effect on larger versus smaller banks that comes through differences in bank quality. The decline in borrowing on September 15 is largest for large banks with high amounts of NPLs (−53.5). This means that the reduction in loan amounts after Lehman for large banks is concentrated in banks with more NPLs (Table VI, column (3)).

Borrowers with higher quality metrics are able to access larger loans in the fed funds market on September 15. The negative coefficient on the interaction between NPLs and the Monday dummy shows that banks with higher NPLs are associated with lower borrowing post-Lehman.[21] The relationship is also economically large. For example, a bank with one standard deviation higher NPLs will borrow approximately $1.61 million less (1.5% of median large bank borrowing of $209 million) on September 15. These results underscore that banks manage their risk exposure in the interbank market via rationing of loan amounts rather than interest rates. Large banks with high percentages of NPLs continue to borrow less even after the Federal Reserve's investment in AIG was announced after the market closed on September 16. We found similar results when we estimated similar specifications looking only at a binary measure of

[20] Surprisingly, we do not consistently see a statistically significant flight to quality as measured by ROA or the risk ratio.

[21] Similarly, lower ROAs and lower risk ratios are associated with lower borrowing post-Lehman.

whether a bank accessed the market. The importance of bank characteristics to their fed funds borrowing is evidence for the role of counterparty risk in this market. However, lenders discriminate among quantities offered to banks rather than withdrawing from the market completely.

In contrast, lender characteristics such as NPLs are not associated with changes in the amount lent immediately after Lehman Brothers' bankruptcy for large borrowers. This means that even riskier banks did not hoard funds on the Monday and Tuesday after Lehman's failure. It is impossible to know if these lenders were trying to send a positive signal to the interbank market or simply did not want to hoard cash. Whatever the reason, our findings are not consistent with liquidity hoarding.

Finally, in Table VII we look at the number of counterparties. We again begin by splitting the specification between the smallest and largest banks. Controlling for amount borrowed, we see a sharp difference in the number of counterparties for small versus large borrowers. The direct effect of the Monday (September 15) dummy now turns positive for smaller borrowers while the coefficient for large borrowers is negative and highly significant; the point estimate is −0.151. Large banks see a statistically significant reduction in counterparties they borrow from while smaller banks have more counterparties immediately post-Lehman. Smaller banks do not seem to be as strongly affected by the Lehman shock. In fact, the market was functioning well enough that small banks were able to add more counterparties in order to maintain their level of borrowing from the market. The reduction in counterparties for larger banks appears to be driven by larger banks with worse performance (as measured by NPLs). In contrast, smaller banks' number of counterparties does not appear to be associated with performance.

We find an interesting relationship between lender characteristics and counterparties. For every additional 1% in NPLs, larger lenders increase their counterparties by 6% on September 15. Effectively, worse performing larger banks are distributing the same amount of money to more counterparties—spreading the signal that they are lending to even more banks. We do not see a similar increase in counterparties for small lenders, perhaps because it is more difficult for them to quickly increase counterparties.

Overall, we show that large banks that borrow in the fed funds market see a sharp increase in spreads and a drop in loan amounts immediately following Lehman's bankruptcy. These effects are particularly strong for large banks with high NPL levels. In contrast, small banks do not experience the same decline in loan amounts. However, immediately before the Federal Reserve's $85 billion loan to AIG is announced we see that spreads for large banks return to pre-crisis levels or below. These results suggest that Lehman's bankruptcy led to a change in beliefs in the interbank market about whether the authorities would let big banks fail. In response, we see that lenders in the fed funds market started to both price the credit risk of and reduce exposure to poorly performing large banks (rather than a complete freeze of the market). However, as soon as the AIG loan is announced the fear of counterparty risk for large banks is alleviated and loan amounts and spreads go back to pre-crisis levels.

In contrast, we do not see any significant changes in worse performing banks' average lending amounts in response to the crisis. There is some evidence that larger banks lend to more counterparties. These results do not seem consistent with liquidity hoarding by banks in the overnight interbank market.

VI. Discount Window Analysis

One concern with the preceding analysis is that observed transactions are the result of the intersection of supply and demand for funds. To cleanly differentiate between supply and demand effects, we would need to observe the levels of and changes in banks' (unmet) liquidity demand and supply. Such observations are very difficult to obtain since they entail knowing the amount and interest rate schedule at which each bank would have liked to borrow.

The overnight interbank market provides a rare opportunity to observe latent demand. In particular, we obtain daily data on the amount of loans that banks draw from the discount window. Borrowing from the discount window is a near perfect proxy for latent or unmet demand for fed funds: discount window loans are provided by the Federal Reserve at the same periodicity as fed funds, that is, as daily overnight loans. While discount window loans are collateralized, collateral is unlikely to be a limiting factor for discount window access. Further, the discount window can be accessed at the end of the day, allowing banks first to transact in the fed funds market. The discount window rate is higher, however, than the target fed funds rate (the rate has been 25 basis points higher than the target rate since March 17, 2008 and was 50 basis points higher prior to that date). In addition, accessing the discount window is associated with a stigma. Banks thus resort to this form of liquidity only if they are shut out from other forms of funding.

We first analyze whether the level of borrowing from the discount window increased dramatically after Lehman's bankruptcy. Similar to the analysis in Table IV, we include in the sample all banks that borrowed from the fed funds market from April 2008 to February 2009, and indicate with a binary variable equal to one if they accessed the discount window.[22] If the main predictor of accessing the discount window is poor past performance, we infer that the fed funds market is allocating funds to better banks, which would be consistent with the predicted demand shortfalls of weaker banks. However, if we instead see that even banks with good past performance have to go to the discount window to meet their liquidity needs in the post-Lehman period, this would be a sign of dysfunction in the fed funds market.

In column (1) of Table VIII, we use a probit estimator of the likelihood that a bank goes to the discount window pre- and post-Lehman controlling for the interest rate and lending amount this bank had in its last transaction on the fed funds market. There is a clear increase in the likelihood of accessing

[22] We include as controls the amount borrowed on the most recent previous day. As a result, we exclude observations for which banks have not yet borrowed, resulting in a lower number of observations compared to the fed funds access analysis (Table IV).

Table VIII
Discount Window Borrowing

The sample consists of 64,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. The dependent variable is *Access (Discount Window)*. Specifications (2) through (5) include controls for the interaction of *Assets* and the time period dummies. Bank characteristics are measured as of the Call Report as of December 2007. %NPL is the percentage of nonperforming loans; ROA is return on assets. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

	Percent Borrowers	(1)	%NPL (2)	%NPL (3)	ROA (4)	ROA (5)
1 week pre-Lehman	1.6	0.244**	−1.017***	−0.795*	−0.980***	−0.758*
(9/5–9/11)		(0.116)	(0.290)	(0.439)	(0.284)	(0.423)
Friday (9/12)	1.7	0.256	−1.223***	−1.036*	−1.095***	−0.912*
		(0.163)	(0.383)	(0.532)	(0.330)	(0.481)
Monday (9/15)	3.9	0.630***	−0.187	0.090	−0.167	0.100
		(0.139)	(0.337)	(0.509)	(0.333)	(0.493)
Tuesday (9/16)	1.7	0.255	−0.737***	−0.535	−0.607*	−0.412
		(0.179)	(0.286)	(0.451)	(0.334)	(0.477)
Post-AIG, pre-IOR	2.3	0.377***	−0.130	0.137	−0.096	0.146
(9/17–10/8)		(0.096)	(0.371)	(0.530)	(0.322)	(0.461)
1 week pre-Lehman × characteristic			−3.022	−2.671	−25.432	−27.172*
			(7.916)	(7.865)	(16.788)	(16.435)
Friday × characteristic			3.462	3.845	−34.131	−34.372
			(5.297)	(5.229)	(24.813)	(24.591)
Monday × characteristic			−4.406	−4.570	−50.992**	−53.181**
			(9.877)	(10.027)	(24.562)	(23.669)
Tuesday × characteristic			7.766*	8.028*	−75.230***	−75.908***
			(4.315)	(4.326)	(27.705)	(26.914)
Post-AIG, pre-IOR × characteristic			1.519	1.544	−43.785**	−45.580***
			(3.783)	(3.850)	(17.304)	(16.704)
Previous fed funds Amount				0.128**		0.127**
				(0.054)		(0.054)
Previous fed funds Spread				0.067		0.095
				(0.212)		(0.214)
Same day fed funds Amount				−0.117**		−0.117**
				(0.051)		(0.053)
Same day fed funds Access dummy				0.316		0.326*
				(0.196)		(0.197)
Borrower fixed effects		No	No	No	No	No
N		64,826	64,826	64,826	64,826	64,826

the discount window, especially on Monday, September 15, when 14 of the 360 fed funds borrowers borrowed from the discount window. Of the 14 discount window borrowers, only 5 also borrowed in the fed funds market on September 15. In specifications (2)–(5), we explore the likelihood that a bank accesses the discount window as a function of bank characteristics and its past borrowing behavior in the fed funds market. We find a very strong and economically large correlation between ROA and the likelihood of accessing the discount window. Only banks that have very poor performance as measured by ROA turn to the

discount window. We find similar results with NPL on Tuesday, September 16, but the NPL results are not statistically significant in every time period, perhaps because the number of banks accessing the window is quite small.

In summary, while we cannot rule out that some banks were screened out of the market, it appears that the turmoil in the interbank market could not have been so great that solvent banks in sound condition had to turn to the discount window for liquidity. This provides evidence that the interbank market was not completely frozen during the crisis.

VII. Shocks to Other Funding Sources of Banks

To proxy for changing demand for fed funds, we exploit disruptions in other overnight funding markets to identify banks that might have increased demand for overnight fed funds. According to market participants, in normal times banks seek liquidity in both fed funds and repo markets and substitute between these markets depending on pricing (subject to collateral availability). As Gorton and Metrick (2009) show, the repo market was severely disrupted after Lehman's failure, with dramatically increased haircuts and pricing. Therefore, to the extent that these two markets are substitutes, post-Lehman fed funds borrowing demand should increase for banks that historically funded a larger percentage of their assets with repo borrowing. We examine the relationship between bank borrowing (lending) and changes in access to the overnight repo markets in Tables IX and X.

In Tables IX and X, we divide the sample into terciles based on the level of repos sold under agreement to repurchase divided by assets as of December 31, 2007 (*%Repo*). Banks in the bottom tercile have *%Repo* less than 0.00176 and banks in the top tercile have *%Repo* greater than or equal to 0.03721. Comparing the estimated coefficients from the bottom and top terciles allows us to see if results from our previous estimations are different for banks with high and low values of repo financing. As before, the dependent variable in the first two columns is spread to target, in the next two columns, the logarithm of amount, and in the final two columns the logarithm of the number of counterparties.

Table IX examines the impact of increased liquidity demand for borrowers while Table X summarizes the identical analysis for lenders. Controlling for *%NPL*, the coefficients in column (4) are higher than those in column (3) of Table IX (although the difference is not statistically significant) in the three days immediately surrounding Lehman's bankruptcy (second to fourth rows), indicating that banks that should have higher demand for fed funds loans are not increasing their borrowing more than banks that do not have reduced access to an important source of overnight funding. If pre-crisis reliance on repo funding is an indicator of increased liquidity demand post-Lehman, our results suggest that lending in the fed funds market did not expand in response to increased demand, not even for the best of these borrowers (those with low NPL levels).

Just as borrowers that relied on the repo market for overnight financing should have higher demand for fed funds, lenders that relied on the repo

Table IX
Impact of Lehman Event on Spread, Amount, and Counterparties for Borrowers, Split by Demand Proxies

The sample consists of 20,826 observations from 360 borrowers from April 1, 2008 to February 28, 2009. We divide the samples into terciles where banks in the bottom tercile have *%Repo* of less than 0.00176 and banks in the top tercile have *%Repo* greater than or equal to 0.03721. The dependent variables are *Spread to Target, Amount,* and *Counterparties*. All specifications include controls for the interaction of *Assets* and the time period dummies. Specifications (1), (2), (5), and (6) include controls for amount borrowed as a percent of bank assets. Bank characteristics are measured as of the Call Report as of December 2007. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. a, b, and c indicate the difference between the coefficients of the *Large* and *Small* banks is statistically significant at the 1%, 5%, and 10% level, respectively.

	Spread to Target		Amount		Counterparties	
	<0.0 (1)	≥0.04 (2)	<0.0 (3)	≥0.04 (4)	<0.0 (5)	≥0.04 (6)
1 week pre-Lehman (9/5–9/11)	0.023 (0.132)	−0.012 (0.032)	−0.990***b (0.377)	0.092b (0.254)	−0.318***a (0.078)	0.236a (0.170)
Friday (9/12)	0.133 (0.115)	0.004 (0.067)	−0.560 (0.369)	−0.508 (0.489)	−0.226*b (0.125)	0.240b (0.150)
Monday (9/15)	−0.499 (1.145)	0.334 (0.564)	−1.012** (0.470)	−0.363 (0.551)	−0.569**a (0.257)	0.384*a (0.216)
Tuesday (9/16)	1.231*c (0.650)	−0.028c (0.352)	−0.383 (0.524)	0.259 (0.399)	0.249 (0.275)	0.742*** (0.263)
Post-AIG, pre-IOR (9/17–10/ 8)	1.296***a (0.174)	0.118a (0.265)	−1.017** (0.420)	−0.391 (0.305)	−0.197a (0.172)	0.635***a (0.160)
1 week pre-Lehman × %NPL	−0.095 (1.416)	1.029 (1.091)	−4.081c (6.214)	−31.095**c (13.914)	−0.903 (1.556)	−6.068 (6.381)
Friday × %NPL	−4.312* (2.380)	1.273 (4.526)	−23.646* (12.315)	−55.412* (31.507)	−6.980** (3.448)	−8.009 (9.469)
Monday × %NPL	1.219c (9.541)	56.380**c (26.724)	−27.760* (14.319)	−23.842 (27.141)	0.690 (2.528)	−6.192 (17.141)
Tuesday × %NPL	−15.990** (7.589)	−5.655 (6.742)	−18.360 (17.183)	−31.293** (13.922)	−10.831** (5.121)	−2.305 (12.209)
Post-AIG, pre-IOR × %NPL	−8.110*b (4.753)	9.511b (7.342)	3.214 (5.424)	−15.591 (14.475)	−1.826 (1.648)	−9.332 (11.039)
Borrower fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	2,794	9,912	2,794	9,912	2,794	9,912
Adjusted-R^2	0.58	0.50	0.86	0.87	0.89	0.93

market for overnight financing might reduce their supply of fed funds when the repo market dried up. We see that, in many cases, the coefficients in column (4) of Table X are lower than the coefficients in column (3) (second to fourth rows) after Monday, September 15, although the difference is not statistically significant. Again, this effect is reversed for lenders with higher NPLs. Lenders with high NPLs and high repos actually lend more than do lenders with high NPLs and low repos, although the difference is statistically significant only in some time periods.

Table X

Impact of Lehman Event on Spread, Amount, and Counterparties for Lenders, Split by Demand Proxies

The sample consists of 26,557 observations from 373 lenders from April 1, 2008 to February 28, 2009. We divide the sample into terciles, where banks in the bottom tercile have *%Repo* equal to zero and banks in the top tercile have *%Repo* greater than or equal to 0.02502. The dependent variables are *Spread to Target*, *Amount,* and *Counterparties*. All specifications include controls for the interaction of *Assets* and the time period dummies. Specifications (1), (2), (5), and (6) include controls for amount lent as a percent of bank assets. Bank characteristics are measured as of the Call Report as of December 2007. Standard errors are clustered at the bank level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. a, b, and c indicate the difference between the coefficients of the *Large* and *Small* banks is statistically significant at the 1%, 5%, and 10% level, respectively.

	Spread to Target		Amount		Counterparties	
	≤0.0 (1)	≥0.03 (2)	≤0.0 (3)	≥0.03 (4)	≤0.0 (5)	≥0.03 (6)
1 week pre-Lehman	0.003	0.027	−0.293	0.217	−0.090	0.004
(9/5–9/11)	(0.029)	(0.042)	(0.218)	(0.276)	(0.144)	(0.152)
Friday (9/12)	0.072**	0.081*	−0.121	0.109	−0.104	−0.046
	(0.036)	(0.049)	(0.307)	(0.337)	(0.143)	(0.177)
Monday (9/15)	1.064***[a]	−0.425[a]	−0.010	−0.115	0.093	0.092
	(0.359)	(0.448)	(0.287)	(0.385)	(0.120)	(0.166)
Tuesday (9/16)	0.225[a]	−1.216***[a]	−0.120	−0.109	0.049	−0.097
	(0.207)	(0.373)	(0.378)	(0.415)	(0.212)	(0.279)
Post-AIG, pre-IOR	−0.081[a]	−1.279***[a]	−0.174	−0.240	0.077	−0.040
(9/17–10/8)	(0.210)	(0.136)	(0.263)	(0.342)	(0.204)	(0.171)
1 week pre-Lehman	0.068	−1.556	−3.618**[a]	14.658**[a]	−0.129[b]	8.938**[b]
× %NPL	(0.148)	(1.119)	(1.569)	(6.658)	(0.494)	(3.920)
Friday × %NPL	−0.254	−0.497	−3.826*	10.287	−0.555	6.535
	(0.310)	(0.895)	(2.202)	(8.324)	(0.651)	(4.567)
Monday × %NPL	−1.814	0.624	−2.914	11.478	−0.102[b]	10.793**[b]
	(2.971)	(9.439)	(2.904)	(10.342)	(0.824)	(4.368)
Tuesday × %NPL	−2.435[c]	9.079[c]	−3.409**[b]	16.119*[b]	−0.501	3.883
	(1.858)	(5.668)	(1.511)	(8.903)	(0.745)	(6.582)
Post-AIG, pre-IOR	−3.007**[c]	3.094[c]	−4.957***	6.042	−0.752	−1.173
× %NPL	(1.235)	(2.926)	(1.490)	(7.121)	(0.689)	(3.954)
Lender fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	12,205	8,841	12,205	8,841	12,205	8,841
Adjusted-R^2	0.51	0.48	0.91	0.87	0.90	0.86

Finally, we attempt to estimate fed funds market demand by estimating the pre-crisis relationship between fed funds borrowing, borrower characteristics, and macroeconomic variables.[23] We use the estimates from the pre-crisis

[23] We estimate an OLS model of the pre-crisis relationship (January 1, 2007 to August 29, 2008) between the logarithm of amount borrowed and the following bank characteristics: daily: logarithm of average amount borrowed in the previous month, logarithm of customer funds sent, logarithm of customer funds received, and difference between reserve balance without fed funds transactions and required reserves (all from Federal Reserve databases); and quarterly: assets, ROA, risk ratio,

specification to predict post-crisis demand and calculate the difference between predicted demand and actual borrowing. Of course, this methodology assumes that the estimated pre-crisis relationships are similar to post-crisis relationships. While this may not be the case, predicted demand based on pre-crisis correlations remains an interesting counterfactual.

We create a variable "forecast error" as the difference between actual borrowing and predicted borrowing and then see if bank characteristics are associated with actual borrowing being significantly below predicted borrowing. When forecast error is high, predicted borrowing is higher than actual borrowing, suggesting the possibility of unmet demand. As expected, predicted borrowing is much higher than actual borrowing immediately following Lehman's bankruptcy. Post-crisis borrowing shortfalls are associated with low-quality banks (high NPLs) experiencing higher shortfalls, although the difference is not always statistically significant.[24]

Further evidence that the overnight fed funds market may not have expanded to meet increased demand comes from the U.S. term fed funds market. Kuo, Skeie, and Vickery (2010) find that the average term amount outstanding after Lehman Brothers' bankruptcy (from September 15, 2008 to November 11, 2008) was $26 billion lower than the previous average amount outstanding (from August 9, 2007 to September 12, 2008), although the decrease in amounts does not seem to happen immediately after September 15. This reduction in term funding was not accompanied by an increase in aggregate overnight fed funds outstanding.

VIII. Conclusions

This research presents a first detailed look at the events in the fed funds market during the 2008 financial crisis. We find evidence of the importance of counterparty risk in the overnight fed funds market, but we do not find evidence that riskier lenders were more likely to hoard liquidity at the height of the crisis. In the immediate aftermath of Lehman Brothers' bankruptcy, we see that the overnight interbank market becomes sensitive to bank-specific characteristics, not only in the amounts lent to borrowers but even in the cost of funds. We find sharp differences between large and small banks in their access to credit: large banks show reduced amounts of daily borrowing after Lehman's bankruptcy and borrow from fewer counterparties. Assuming that in the very short run banks do not change their demand for liquidity, this is likely to be an effect of credit rationing. In contrast, smaller banks were able to

%NPL, *%MBS*, *%Repo* (from the Y-9C). We include the following daily macroeconomic variables: target fed funds rate; 1-month term rates on AA asset-backed commercial paper, certificates of deposit, financial commercial paper, LIBOR, and OIS; and overnight rates on Treasury repos and MBS repos. We allow fixed effects for end-of-maintenance period days, calendar months, and quarter-end dates, and estimate the model separately for small and large banks. We explain more than 60% of the variation in the amount borrowed with these variables. The results of the first-stage regression are shown in the Internet Appendix.

[24] See the Internet Appendix.

increase the amount borrowed from the interbank market and even managed to add lending counterparties during the crisis. Moreover, we do not observe the complete cessation of lending predicted by some theoretical models.

We also document that only the worst performing banks in terms of ROA accessed the Federal Reserve's discount window after Lehman's bankruptcy. It seems reasonable to assume that these are banks that were rationed by the fed funds market since private banks were not willing to lend to them. While, again, it is difficult to assess whether this means that interbank markets operated efficiently during the crisis, it is reassuring that we do not observe well-performing banks having to turn to the discount window. Such a finding would have been a very alarming indication of dysfunction in the fed funds market.

This research is only a first step in understanding how the fed funds market was affected by the financial crisis and how robust this market is against financial contagion. Future research should investigate more directly how lenders in the market react to changes in the perception of risk. For instance, we need to better understand how fed funds loans are priced and how they are affected by expectations about government and central bank interventions. The same is true for the decision of whether to add or drop counterparties. Finally, we believe that it would be useful to investigate the role that banking relationships and repeated interactions in the fed funds market can play in the monitoring of counterparty risks or in the coinsurance of liquidity needs.

Appendix: The Furfine Algorithm

We identify fed funds loans using an algorithm similar to the one proposed by Furfine (1999). This technique has been used to identify uncollateralized loans in the U.S. Fedwire Funds Service (Fedwire) in Furfine (2001, 2002), Demiralp, Preslopsky, and Whitesell (2004), Ashcraft and Bleakley (2006), Ashcraft and Duffie (2007), Bech and Atalay (2008), and Bartolini, Hilton, and McAndrews (2010), among others. Modified versions of this methodology are also employed by Millard and Polenghi (2004) and Acharya and Merrouche (2010) to identify overnight lending activity by the U.K. Clearing House Automated Payment System (CHAPS) and by Hendry and Kamhi (2007) in Canada's Large Value Transfer System (LVTS).

The algorithm identifies fed funds loans from payments as follows:

- Step 1: Screen out settlement institutions from pool of transactions transferred over Fedwire.
  - The algorithm excludes transactions for which the sending institution is not involved in fed funds activity such as transfers originating from the Clearing House Interbank Payments System (CHIPS, a private and large-value U.S. dollar payments system owned and operated by the Clearing House Payments Company), the Continuous Linked Settlement (CLS, a payment-versus-payment settlement system that settles foreign exchange transactions), or the Depository Trust Company (DTC, a securities settlement system).

- Step 2: Identify overnight loans.
  - We identify all transfers from one institution to another in amounts equal to or greater than $1 million and ending in five zeros when there is a payment of a slightly higher amount in the opposite direction on the following day. The difference between the two payments is interpreted as the interest rate on the loan. These transfers are selected because federal funds loans are usually made in round lots of over $1 million (Furfine (1999), Stigum and Crescenzi (2007)).
  - Next, we refine this set of potential fed funds loans by limiting the range of possible loan rates. "Reasonable" interest rates for uncollateralized loans may vary daily depending on market conditions. To take the variation in rates into account, we narrow the pool of overnight loans to include only loans with (positive) rates within a window of 50 basis points below the minimum brokered fed funds rate (low) and 50 basis points above the maximum brokered fed funds rate (high) published by the Markets Group of the Federal Reserve Bank of New York from a daily survey of the four largest federal funds brokers.[25]
- Step 3: Identify a unique rate per fed funds loan.
  - When on the following day multiple repayments match one outgoing payment, the algorithm identifies the median rate as the rate of the loan.
- Step 4: Separate fed funds from Euro activity.
  - The U.S. market for unsecured loans consists of federal funds and Euro[26] trades. An important difference between these two types of trades is that while fed funds can be settled directly between borrower and lender, Euros require an intermediary or correspondent bank to complete the transfer (McAndrews (2009)). Step 4 incorporates the customer code that a sending bank enters on the payment message indicating the payment is made on behalf of a customer as a proxy for a Euro loan to distinguish whether an overnight loan is fed funds or Euro.[27]

As noted by Furfine (1999) and Bech and Atalay (2008), among others, this methodology presents some weaknesses. First, only fed funds loans settled through Fedwire are identified. However, fed funds loans settle almost exclusively on Fedwire (McAndrews (2009)). Second, term fed funds loans are not included. The term funds market is considerably smaller than the overnight market and the amount of term fed funds outstanding is probably on the order of one-tenth (Meulendyke (1998)) to one-half (Kuo, Skeie, and Vickery (2010))

[25] Data are available at http://www.newyorkfed.org/markets/omo/dmm/fedfundsdata.cfm.

[26] Loosely speaking, Eurodollars are dollar-denominated deposits held outside the United States. For a more precise definition and discussion of the fed funds and Eurodollar markets, see Bartolini, Hilton, and Prati (2008).

[27] McAndrews (2009) tests the predictive power of the customer code as a proxy for a Eurodollar loan by matching brokered trades provided by BGC Brokers with Fedwire settlement data. By using the absence of a customer code as a proxy for fed funds, the probability of correctly identifying fed funds loans is 89%, with an 11% chance of counting Eurodollars as fed funds (type I error) and a 4% chance of incorrectly excluding fed funds (type II error).

of the amount of overnight funds arranged on a given day. Third, loans made on behalf of client nonfinancial firms and client banks may be misattributed to the correspondent bank.[28] Similarly, transfers between banks that pay an opportunity cost of capital for specific purposes such as settlement will be included as fed funds loans. However, as Furfine (1999) pointed out, correspondent lending mainly represents loans made by very small institutions with little or no direct contact with major financial markets. Fourth, rates outside the specified window are missed. Increasing the size of the window is unlikely to add additional fed funds transactions (Furfine (1999)). Fifth, other overnight loans settled through Fedwire, such as Euros or tri-party repos, could be misidentified as fed funds. Refinements of the algorithm, such as the use of the customer code as a proxy for Euro loans, lessen the relevance of this concern.

When comparing the loans calculated from the Furfine algorithm to quarter end overnight fed funds loans outstanding reported on Y-9C filings, there are significant differences in levels between the algorithm-estimated amount and the actual balance on the Y-9C. On average, the algorithm underestimates outstanding loans for borrowers, which is consistent with the existence of loans made with correspondent banks (which do not go through Fedwire and thus are not measured). We do not find systematic biases between fed funds loans measured by the algorithm and those reported on banks' Y-9C based on bank characteristics such as assets, the percentage of NPLs, or the percentage of repo financing.

Of particular relevance to the findings in this paper, the difference between fed funds loans measured by the algorithm and those reported on banks' Y-9C calculated as of the second quarter of 2008 and the third quarter of 2008 is also not statistically significantly associated with bank characteristics such as assets, the percentage of NPLs, or the percentage of repo financing. In sum, while the algorithm seems to miss some fed funds loans, especially those that do not go through Fedwire, we do not find any systematic bias between banks or over time from missing observations (or transactions misclassified as fed funds) that would bias the results in the paper.

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[28] Small banks and institutions that do not have a reserve account at the Federal Reserve can settle fed funds transactions through the account of correspondent banks. They can also lend to correspondent banks using correspondent rebooking. Deposits these institutions hold at correspondent banks can be reclassified as overnight federal funds loans. The next day, the correspondent bank credits the account of the lending institution with the nominal of the loan plus the negotiated interest. Rebooking does not require transfers between reserve accounts at the Federal Reserve and hence these uncollateralized interbank loans would not be identified as fed funds by the algorithm.

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