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"Un" Networking: The Evolution of Networks in the Federal Funds Market

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Abstract

Using a network approach to characterize the evolution of the federal funds market during the recent financial crisis, we document that many federal funds small lenders began reducing their lending to larger institutions in the core of the network starting in mid-2007. But the more abrupt change occurred in the fall of 2008, when small lenders left the federal funds market en masse and those that remained lent smaller amounts, and did so less frequently. We then test whether changes in lending patterns within key components of the network were associated with increases in the counterparty risk of banks that are at the core of the network, while controlling for liquidity factors such as borrowing from the Federal Reserve's credit and lending facilities and the associated increase in the level of reserve balances. Using both aggregate and bank-level network metrics, we easily reject the null hypothesis that counterparty risk is not a significant determinant of the observed changes in lending behavior within the network.

1. Introduction

For many years, a few stylized facts regarding banking flows were pretty reliable. As far back as the mid-1800s, regional or country banks, with an excess of funds, would sell them to large banks in the cities, which usually needed them (Mitchener and Richardson 2013). This construct was even part of the reason why the Federal Reserve System was established—in order to promote and maintain an efficient transfer of funds in the banking system. Often, one large bank would buy funds from many smaller banks, and then the larger banks would connect to each other and settle transactions either through a central clearinghouse, or later, through the Federal Reserve.

Even with the consolidation of the banking industry through the 1980s and 1990s, and the innovation of interstate branching in 1995, large banks bought excess deposits held at the Federal Reserve from smaller banks. The "federal funds market," or the market for cash balances held by institutions at the Federal Reserve, was an active, unsecured overnight market (Federal Reserve Board, 2005, Stigum, 2007). In particular, through about 2007, there were many more lenders than borrowers in the federal funds market, and the lenders tended to be smaller institutions, while the borrowers were larger ones.

Everything changed with the advent of the financial crisis in mid-2007, as many of the smaller lenders reduced their lending to the larger institutions in the core of the network. Using network analysis, we find that the federal funds network began to contract rapidly and change dramatically in structure after the Lehman bankruptcy in the fall of 2008. The number of participating banks and transactions plummeted, as did overall dollar volume. This paper carefully analyzes the factors that caused this radical change in banking flows, focusing on the role of counterparty risk. Using both aggregate and bank-level network metrics, we easily reject the null hypothesis that counterparty risk is not a significant determinant of the observed changes in lending behavior within the network.

The paper proceeds as follows. Section 2 gives background and historical information on the federal funds market and payment flows. Section 3 describes the data we use and discusses our analytical framework. Section 4 reviews our aggregate results, and section 5 explores our institution-level analysis. With these results in hand, section 6 performs a series of stress tests on the network, and shows that the system is now less/more resilient to shocks, but may be less/more resilient in the future. Section 7 concludes.

2. Related literature

The literature has noted evidence of both heightened counterparty risk and increased liquidity hoarding in the federal funds market market around the time of the 2008 financial crisis. Taylor and Williams (2009) use a no-arbitrage model of the term structure to explain why the spread between interest rates on term lending and overnight federal funds lending began to grow in August 2007. Their results indicate that expectations of future interest rates and counterparty risk drove the spread, with liquidity concerns playing a negligible role.

Using Fedwire data, Ashcraft, McAndrews, and Skeie (2011) examine the behavior of the federal funds market during the 2007-2008 financial crisis, and find evidence of precautionary holdings of reserves. They distinguish large banks from small banks based on the average volume of each bank’s daily Fedwire payments. The authors find that small banks are typically net lenders who lend mostly between 3pm and 5pm when faced with unusually large intraday balances. In contrast, large banks both lend and borrow throughout the day, but are typically net borrowers. They also find that banks that had larger payment shocks (non-loan Fedwire net sends) held larger precautionary reserves, particularly those that sponsored ABCP conduits. To determine whether counterparty credit risk constrained lending during the crisis, they examine changes in the distribution in the number of banks a borrower funded itself with, and the distribution in the number of counterparties that lenders lent to. Although the distribution in the number of borrowers was little changed during the crisis, they find some evidence that banks began lending to fewer counterparties in the fall of 2008, suggesting that concerns about increased credit risk were focused on the lending side of the market.

Afonso, Kovner, and Schoar (2011) examine the behavior of the federal funds market throughout the 2007-2008 financial crisis, and the importance of liquidity hoarding and counterparty risk in the period immediately following Lehman's bankruptcy, which they interpret as a shock to the market's belief that large banks would not be allowed to fail. When they then split their sample into borrowers and lenders, they find that large banks (as measured by total assets) that borrow in the federal funds market experience a sharp increase in spreads and a drop in loan amounts on September 15, 2008, immediately following Lehman's bankruptcy, and that these effects are stronger for banks with higher levels of non-performing loans. This suggests that heightened concerns about counterparty risk reduced liquidity and increased the cost of finance for weaker banks. They do not find evidence for liquidity hoarding in the overnight federal funds market.

Bech and Garratt (2012) also discuss how the Lehman bankruptcy caused changes in Fedwire payment patterns. Their theoretical model suggests that counterparty credit risk can lead to a delay in payments, as sending institutions have lower confidence that their funds will be returned later in the day. The model also suggests that excess liquidity can cause payments to shift earlier in the day, by reducing the cost of that liquidity to market participants. Both of these characteristics were evidenced in the payment patterns that occurred right around the Lehman crisis when counterparty credit concerns spiked and also in subsequent weeks when Federal Reserve liquidity ballooned.

By looking purely at the initial stages of the crisis, however, these papers are unable to put their observations in the context of historical and post-crisis lending trends or to comment on the relative importance of counterparty risk since the crisis (post Lehman). We find that the most fundamental changes in the federal funds market occurred several months after Lehman's bankruptcy. The findings from Afonso et al. are largely based on the change in spreads observed the day after Lehman filed for bankruptcy, but it is unclear what this change is capturing because it was mostly reversed the next day with the announcement of the bailout of AIG. Furthermore, loan amounts and spreads were so volatile that any signal based on a day's worth of data is likely to be too noisy to draw reliable inferences from. In fact, "big" events like the terrorist attacks of 9-11 and Lehman's bankruptcy are barely noticeable in the daily transactions data.

Unlike previous studies which group banks as simply borrowers and lenders, our network metrics allow us to distinguish the large banks that make up the core of the market, from the smaller banks that either typically only lend to the core, or only borrow from the core. The banks in the core typically act as intermediaries and are engaged in both borrowing and lending, including to each other. These banks include the largest global banks, which were at the center of the financial crisis because of their exposures to the U.S. housing market. The network approach allows us to better evaluate the relative importance of counterparty and liquidity risk because the banks in the core were most affected by these risks. This approach also allows us to document a dramatic and persistent restructuring of borrowing and lending patterns in the market from 1998 to 2012.

3. Fedwire data

From the Volcker era through the beginning of the financial crisis, the Federal Open Market Committee (FOMC) implemented its monetary policy goals of maximum employment, stable prices, and moderate long-term interest rates primarily by affecting conditions in the federal funds market. For many years, the FOMC has employed a target for the interest rate at which depository institutions trade balances held at the Federal Reserve in the federal funds market; this rate is called the federal funds rate. The FOMC directs the Open Market Desk at the Federal Reserve Bank of New York to create conditions in the reserve market consistent with federal funds trading near the target.

Federal funds transactions are unsecured loans of balances at Federal Reserve Banks between depository institutions and certain other institutions, including government-sponsored enterprises.[1] A borrower is said to buy funds whereas a lender is said to sell funds. The vast majority of trades are spot and the duration is typically overnight, but forward trades and trades for longer terms (called term federal funds) also take place. Most of the trading in term federal funds disappeared after the start of the financial crisis; our results therefore focus on overnight trading.

In general, there are two methods for trading federal funds. Buyers and sellers can either arrange trades directly--typically using an existing relationship--or employ the services of federal funds brokers. Like other brokers, federal funds brokers do not take positions themselves. Rather, for a fee, they bring buyers and sellers together on an ex-ante anonymous basis. That is, the broker will inform the seller about the identity of

[1] More specifically federal funds are deposit liabilities exempt from the reserve requirements under the Federal Reserve's Regulation D which include deposits of a domestic office of another depository institution, agencies of the U. S. government, Federal Home Loans Banks, and Edge Act or Agreement corporations.

the buyer only after the seller's offer has been accepted. The repeated nature of the interactions ensures that a seller accepts the trade regardless of the buyer unless the seller does not have a specific credit line to the buyer or the line is already maxed out (Stigum and Crescenzi 2007). Based on summary reports from the brokers, every morning the Federal Reserve Bank of New York publishes the dollar weighted average rate of brokered trades--known as the effective federal funds rate--for the previous business day.

Trades are generally settled by the Federal Reserve's Fedwire Funds Service (Fedwire) which allows account holders to transfer funds in real time until the regular close of the system at 6:30 p.m. (6:00 p.m. for non-bank financial institutions). Unlike other parts of the money market, such as the repo market, the federal funds market tends to stay active throughout the day and according to Bartolini et al. (2010) about 40 percent of the trading occurs in the two hours before the close of Fedwire.

The federal funds market emerged in the 1920s as a method of adjusting reserve positions but over time the market acquired increased importance as an outlet for short-term investments and as a marginal source of funding. The need for adjusting reserve positions arises from a combination of Federal Reserve regulations and the redistribution of balances that result from the daily flow of payments across accounts at the Federal Reserve. The Federal Reserve imposes penalties on account holders if they end a day overdrawn. In addition, depository institutions with reserve requirements are penalized if they hold an insufficient level of balances (and vault cash) relative to their requirement at the end of each reserve maintenance period. Reserve requirements are the amount of funds that a depository institution must hold in reserve against specified deposit liabilities.

As described by Stigum and Crescenzi (2007), before the financial crisis, larger banks tended to be net buyers of federal funds, while smaller ones were often net sellers, because large corporate customers often borrowed funds from the former and individuals often deposited funds at the latter. Moreover, historically the GSEs were, because of their business models, large net sellers of funds. Fannie Mae and Freddie Mac used the market as a short-term investment vehicle for incoming mortgage payments before passing the funds on in the form of principal and interest payments to investors. After the introduction of the conservatorship and related rules, however, GSE lending in the federal funds market dropped considerably, and for Fannie Mae and Freddie Mac, fell to zero in 2011. By contrast, Federal Home Loan Bank investments in the federal funds market continued, as these institutions use the federal funds market to warehouse liquidity to meet unexpected borrowing demands from members.

For our calculations, we use proprietary transaction-level data from the Fedwire funds transfer service that has been matched to form plausible overnight funding transactions, likely related to the federal funds market. Similar data were first used by Furfine (1999) and since then by a list of other authors, most often associated with the Federal Reserve Bank of New York. The transaction data set contains basic transfer information, including the amount of the transaction, the implied interest rate of the identified transaction, and the seller and buyer in the trade. These last two pieces of information allow us to differentiate the rates earned by depository institutions and GSEs to evaluate the empirical implications described above.

The algorithm matches an outgoing Fedwire funds transfer sent from one account and received by another with a corresponding incoming transfer on the next business day sent by the previous day's receiver and received by the previous day's sender. This pair of transfers is considered a federal funds transaction if the amount of the incoming transfer is equal to the amount of the outgoing transfer plus interest at a rate consistent with the rates reported by major federal funds brokers. However, because we have no independent way to verify if these are actual federal funds transactions, our identified trades and characteristics of these trades are subject to error.[2]

While in what follows we refer to these trades as "federal funds volume," it is better characterized as "identified overnight funding volume," and so should be used as a guide, and not an absolute figure, when discussing federal funds volume. Estimates reported in Afonso et. al (2013) using Call Report and other regulatory data suggest that federal funds volume at commercial banks was over $60 billion at the end of 2012, so our estimates should be viewed in that light.

Figure 1 shows our daily estimates of the daily federal funds volume by all Fedwire participants, excluding transactions between the three large clearing banks (J.P. Morgan, Bank of New York Mellon, and State Street).[3,] Federal funds volume gradually climbed from an average of roughly $100 billion per day in 1998, to almost $300 billion in June 2007. In early July, daily federal funds volume dropped sharply -- by about 25 percent or $70 billion-- as markets began to reassess the potential for large losses on bonds backed by subprime loans, and banks' large exposures to these mortgages.[4]

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[2] One drawback of these data is that some portion of the transfers likely reflects Eurodollar transactions, which also go over Fedwire. Traditionally, Eurodollars traded at rates similar to federal funds, although there have been some periods post-crisis where the rates have diverged.

[3] We exclude these transactions from our analysis because at least a portion of them likely represent funding transactions other than for federal funds and the algorithm fails to identify them separately.

[4] On July 10, 2007, Moody's and S&P downgraded hundreds of subprime RMBS bonds (refer to Mark Pittman, "Moody's Lowers Ratings on Subprime Bonds, S&P May Cut," Bloomberg News Service, available at http://www.bloomberg.com/apps/news?pid=newsarchive&sid=akJOnhaU63wk).

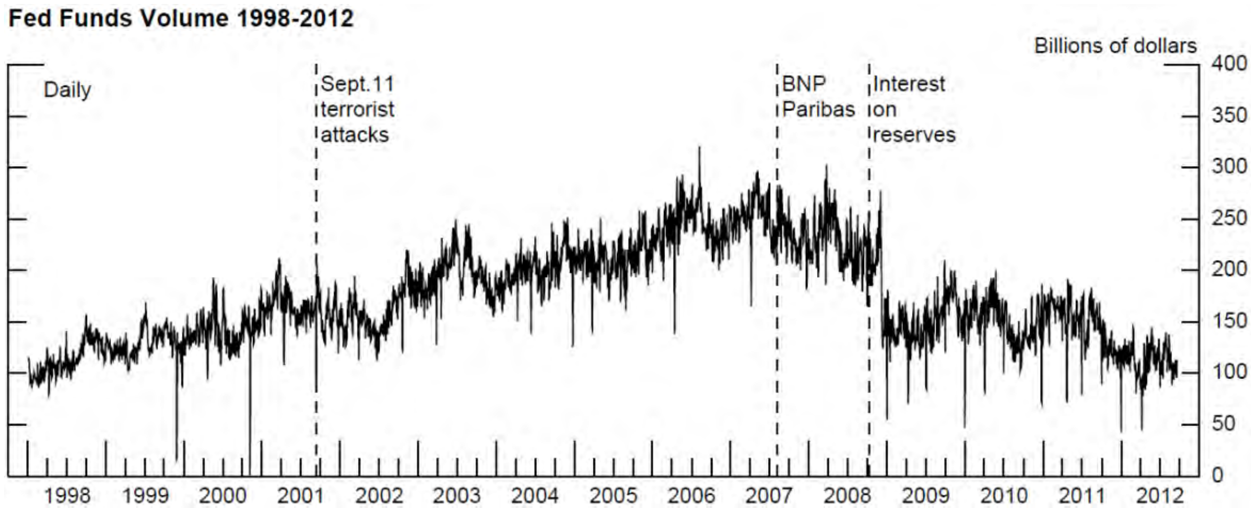

Figure 1

As shown by the shaded region in Figure 2, estimated federal funds volume was relatively stable around the $225 billion range even through the Bear Stearns (March 2008) and Lehman (September 2008) failures. Afonso, Kovner, and Schoar (2011) also find that overnight federal funds market was "remarkably stable" during this period, as the amounts transacted, number of institutions participating in the market, and weighted average interest rate remain relatively unchanged during this period. However, as we document below, our analysis using network topology metrics reveals that the federal funds market was indeed increasingly stressed during this period.

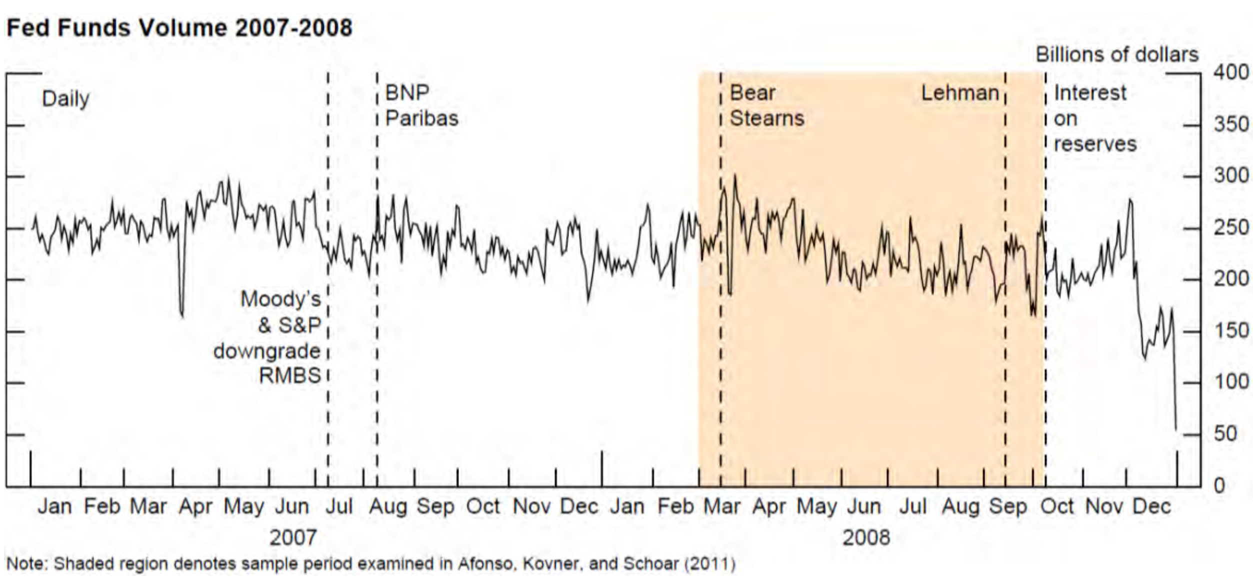

Figure 2

Federal funds volume dropped dramatically in the first week of December 2008, a few months after the Fed began to pay interest on reserves. A few factors likely explain at least some of this dramatic drop-off. First, reserve balance continued to climb through the fall of 2008 and were expected to increase even further with the announcement of the first round of large-scale asset purchases in November 2008. A system awash in liquidity likely did not need as much marginal borrowing to cover account positions. Second, on December 16, 2008, the target federal funds rate was lowered to its effective zero lower bound, decreasing the incentive to engage in reserve market arbitrage. And third, counterparty credit concerns likely soared in the wake of the Lehman episode as well as with the approaching year-end statement date, which as we explore more fully later in the paper, caused institutions to shrink both the number of and quantity lent on credit lines to individual institutions. Following the fall of 2008, federal funds volume hovered around the $150 billion range until mid 2011, after which it continued to decline, eventually stabilizing at $110 billion by year-end 2012, or 40 percent of its level in mid 2007.

4. Federal funds market from a network perspective

We rely on network theory to analyze the various patterns of connections in the federal funds market. In our context, the federal funds network describes a collection of nodes (banks), and the links (federal funds transactions) between them. We model federal funds flows as a directed network linking the sender of the payment (lender) to the receiver of the payment (borrower). For the Fedwire payments network, Soramaki et al. (2006) find that the large number of nodes and links makes it difficult to analyze using conventional network visualization tools. We find that the federal funds network is also too complex to analyze using visualization tools, and thus adopt a similar set of statistical measures of the network's topology to characterize how the network evolved on a daily basis over a 15-year period from 1998 to 2012, paying special attention to the 2007-2008 financial crisis.

Figure 3 shows that there was a sharp contraction in the number of links in the network during the last quarter of 2008, as fewer banks were transacting with each other. Also, there was a sizable increase in the average dollar volume transacted per link, which, as we demonstrate later, is largely driven by the exit of many of the smaller banks from the market.

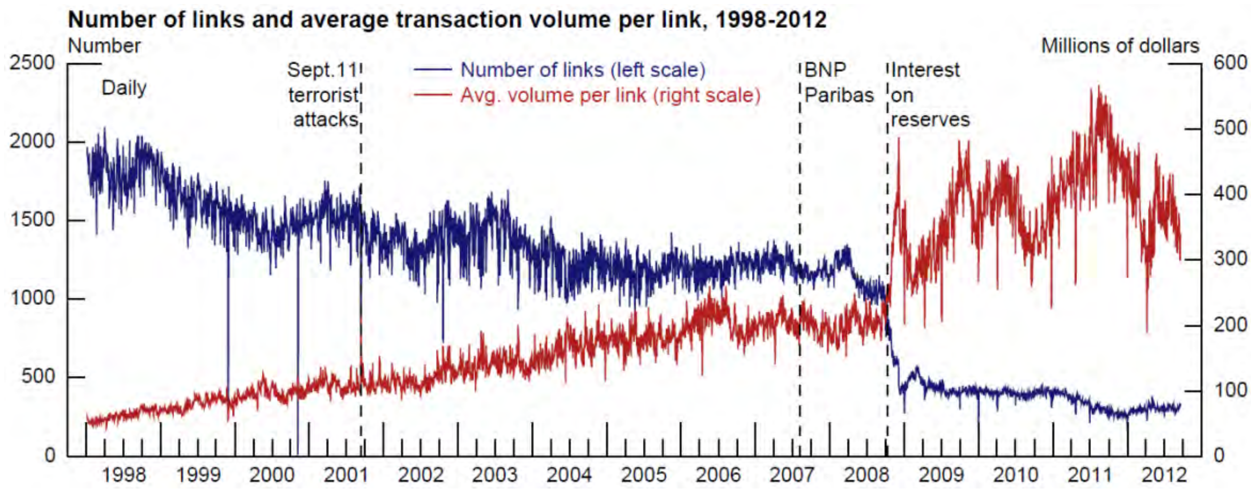

Figure 3

Figure 4 shows one measure of connectedness, the degree of completeness, defined as the number of links over the number of possible links. For a directed network, the degree of completeness is given by $\alpha = \frac{m}{n(n-1)}$, where m is the number of links and n is the number of nodes. Surprisingly, the federal funds network started becoming more complete starting in late 2008. Although the reduction in links in late 2008 would have made the network less complete, the reduction in the number of participants (nodes) in the network resulted in an even larger reduction in the number of possible links.

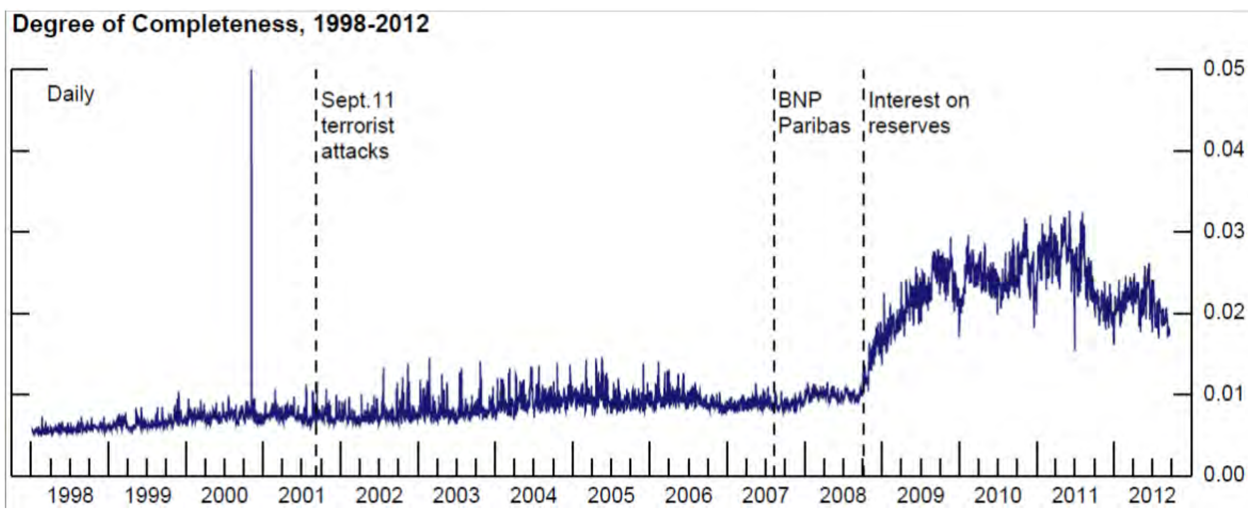

Figure 4

To understand better what factors caused these abrupt changes in the network topology, we first group the nodes into components based on how they interact with other nodes on any given day. Banks may switch groups from day to day, depending on their borrowing and lending relationships with other banks. Figure 5, taken from

Soramaki et al. (2006) illustrates the components of our network. The largest component of the network is the Giant Weakly Connected Component (GWCC) in which all nodes connect to each other via undirected paths (Jackson (2010)). Then there is a set of disconnected components (DC), whose nodes also connect with each other via undirected paths, but which have no links with nodes in the GWCC. Because the DCs (even when taken together) are several orders of magnitude smaller than the GWCC in the federal funds network, we do not include them in our analysis. The GWCC in turn comprises the Giant In-Component (GIN), Giant Strongly Connected Component (GSCC), the Giant Out-Component (GOUT), and tendrils.

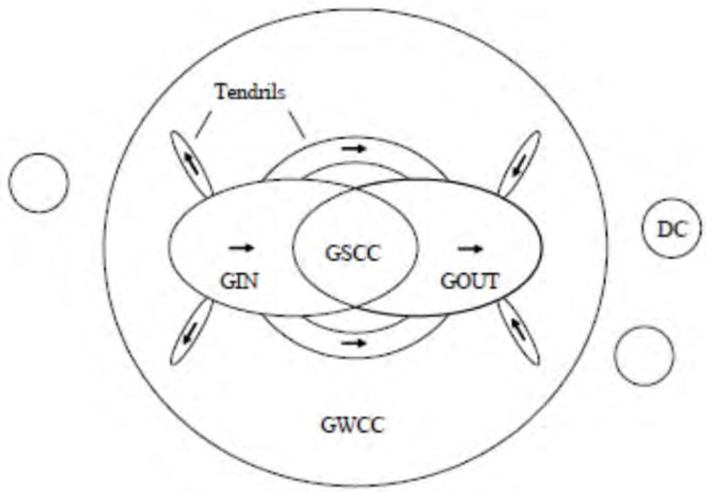

Figure 5 - Network components, from Soramaki et al. (2006)

The GSCC is the set of all nodes that can reach each other through directed paths. The banks in the GSCC are engaged in both borrowing and lending, often amongst each other, but they may also may borrow from banks in the GIN group, and lend to banks in the GOUT group. In contrast, banks (and other nonbank entities) in the GIN group have directed paths to the GSCC group but not from it. That is, they lend federal funds to the GSCC, but they do not borrow from the GSCC. The opposite is true for banks in the GOUT group: they have directed paths from the GSCC but not to it-- they borrow from the GSCC but do not lend to it. Tendrils have no directed paths to the GSCC, only to the GIN and/or GOUT groups, and also to each other. Loosely speaking, banks in the GIN group are typically “only lenders,” banks in the GOUT group are typically “only borrowers,” and banks in the GSCC group are typically “borrowers and lenders.”

For every day in our 15-year sample, we partition our network into these groups, and compute the dollar flows between them, and number of nodes inside them. Figure 6 shows the quarterly averages of the shares of daily dollar volume between the key components in the network. Between 2006 and 2011 lending among banks in the

GSCC group declined from about 30 percent of all federal funds transactions to just 5 percent. Over the same period, lending from GIN directly to GOUT (bypassing the GSCC) increased notably, and so did lending involving institutions in the tendrils of the network.

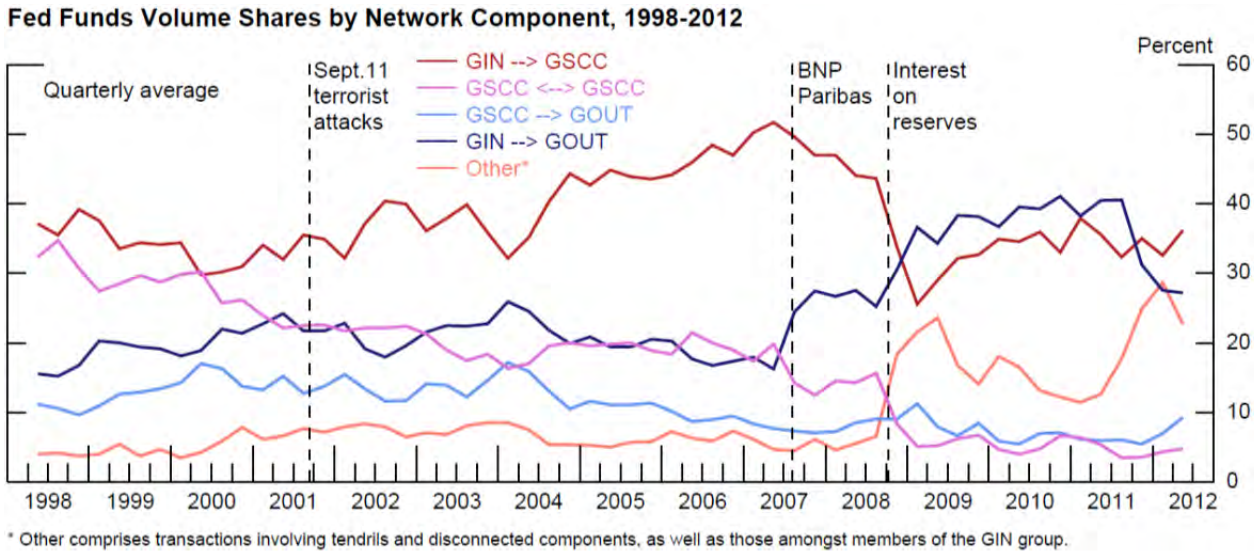

Figure 6

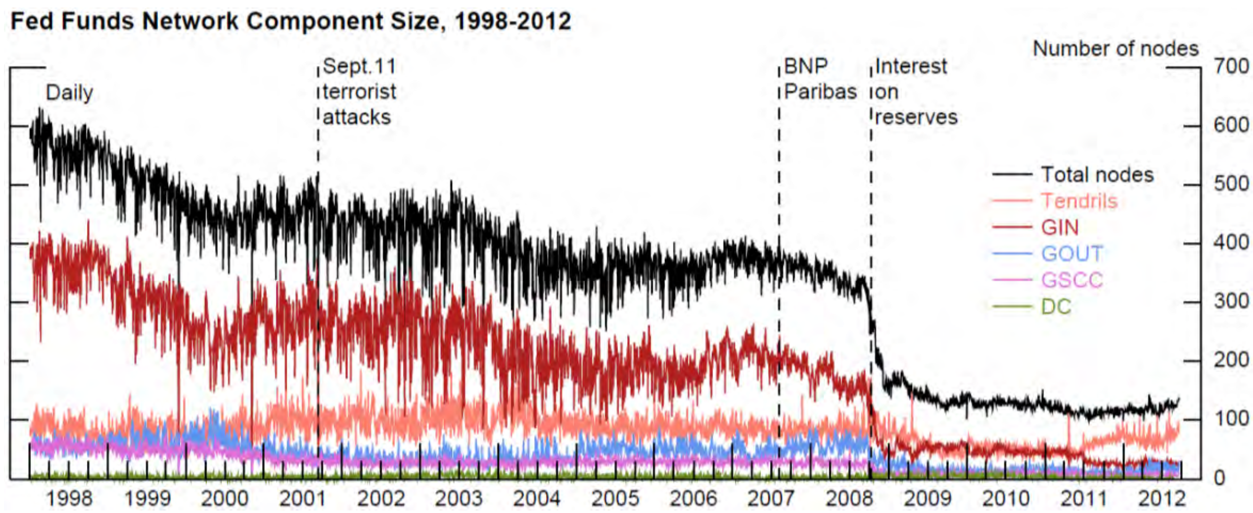

Figure 7

Figure 7 shows the evolution of the size of the federal funds network. Prior to 2007, the number of participants (nodes) in the market on any given day was quite volatile. With the consolidation of the banking industry, the number of nodes identified in the Fedwire data gradually declined from its level in early 1998 to about half that level in 2004. The largest component in terms of size is the GIN, which lends to the banks in the GSCC group.

Figure 8 zooms in on the crisis period. Between June 2007 and August 2008, the network size shrunk by 13 percent, and the size of the GIN component shrunk by 25 percent. In the last two weeks of September 2008, just after Lehman Brothers filed for bankruptcy, the GIN component contracted nearly 20 percent. The network continued to shrink throughout the fall of 2008, after reserve balances began to rise and the Fed began to pay interest on reserves. By end-2008, the GIN was roughly one fourth of its size in June 2007 and there were only 40 percent of the number of institutions participating as there were in June 2007). These dramatic changes in the network can be seen in Figure 9, which compares the structure of the network a few days before Lehman's bankruptcy (Sept. 12, 2008; left panel), and 3 months later (December 8, 2008; right panel). The GSCC component (the core) shrinks to just a handful of banks, while many of the borrowers in the GOUT group move to the tendrils, borrowing directly from banks in GIN. There are also fewer lenders, fewer borrowers, and fewer links in the network on December 8, 2008 than 3 months prior.

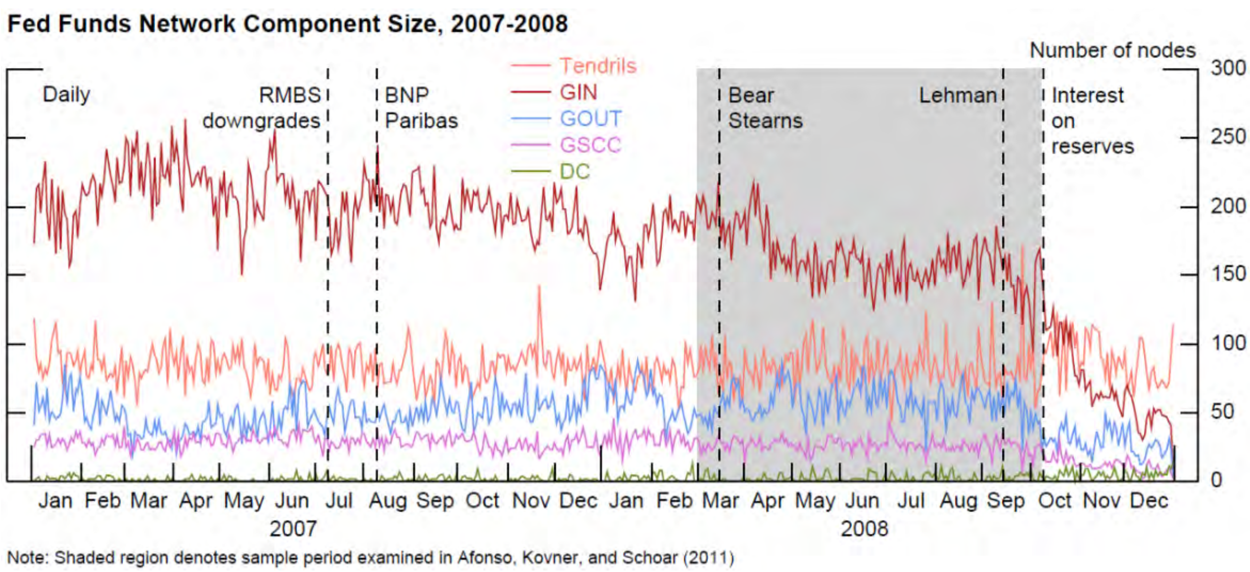

Figure 8

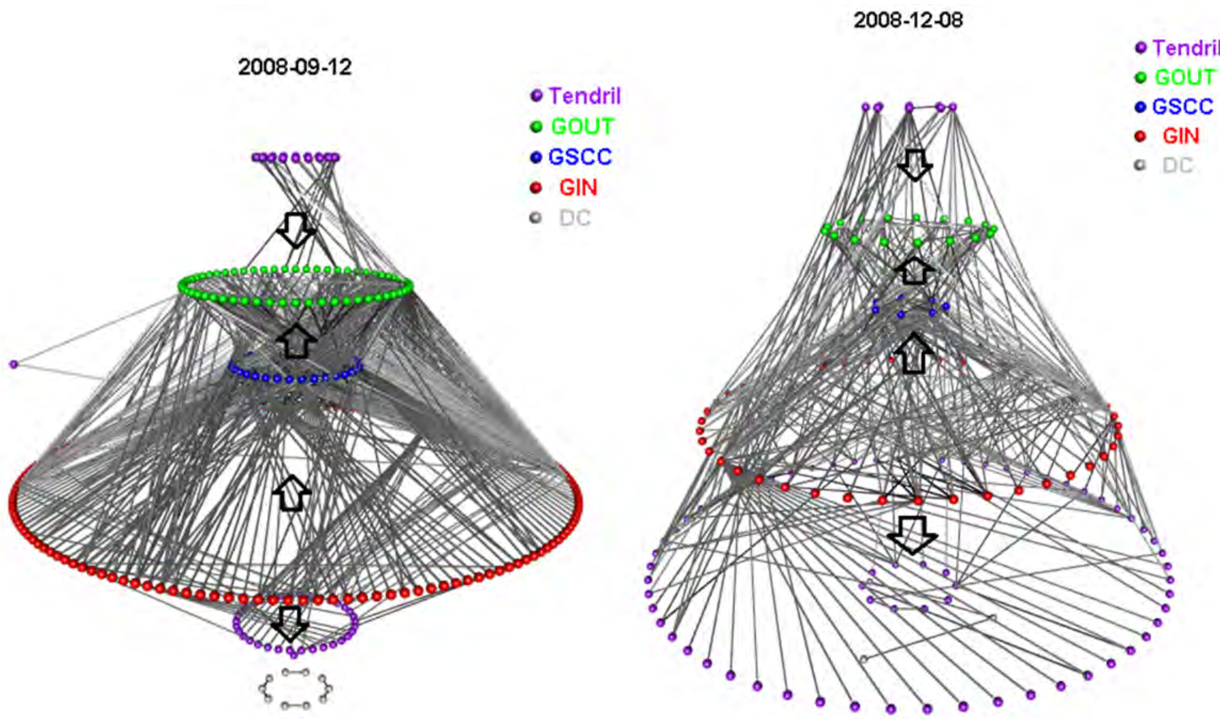

Figure 9 – Fed funds network on September 12, 2008, and on December 8, 2008. Black arrows denote direction of lending.

In order to understand the changes in the network, it is helpful to take a closer look at transitions from one component to another, as well as to a non-participant state. Figure 10 compares the number of days that banks were in the GIN component in the first quarter of 2007, before the start of the financial crisis, versus the second quarter of 2009, past the acute part of the crisis and once changes in funding patters were well underway. In the first quarter of 2007, there were 473 banks that were in the GIN group at least 1 day. Of these 473 banks which were present in the GIN component in the first quarter of 2007, nearly 60 percent of them completely left the federal funds network by the second quarter of 2009. Exit was widespread: Only the very most active institutions had a majority that stayed in the network in 2009; in all other categories, more often than not, banks exited the federal funds market, even if previously participating in more than 2/3 of the business days in the quarter.

Frequency of number of banks in GIN group by number of days in GIN in 2007q1, and Federal funds market participation in 2009q2

Frequency / *Row Percent*	Number of banks in 2009q2: Exited	Did not exit	**Total**
1-10 days in GIN	96 *57.8%*	70 *42.2%*	**166**
11-20 days in GIN	51 *67.1%*	25 *32.9%*	**76**
21-30 days in GIN	28 *62.2%*	17 *37.8%*	**45**
31-40 days in GIN	34 *65.4%*	18 *34.6%*	**52**
41-50 days in GIN	42 *56.8%*	32 *43.2%*	**74**
51-60 days in GIN	20 *33.3%*	40 *66.7%*	**60**
Total	**271**	**202**	**473**

Figure 10

Even if the banks stayed in the funding network, most of the time, their behavior changed markedly and often transitioned out of lending. As shown in Figure 11, of the banks that remained in the federal funds network in 2009q2, only 60 percent continued to lend (for at least one day) as part of the GIN component in 2009q2, while the remaining 40 percent switched to another component of the network. In addition, for those banks that continued to lend as part of the GIN component, they did so much less frequently in 2009q2.

Frequency of number of banks in GIN group by number of days in GIN in 2007q1 and 2009q2

Frequency / *Row Percent*	Number of banks in 2009q2: 0 days in GIN	1-10 days in GIN	11-20 days in GIN	21-30 days in GIN	31-40 days in GIN	41-50 days in GIN	51-60 days in GIN	**Total**
1-10 days in GIN	136 *81.9%*	20 *12.1%*	7 *4.2%*	2 *1.2%*	1 *0.6%*	0 *0.0%*	0 *0.0%*	**166**
11-20 days in GIN	65 *85.5%*	7 *9.2%*	0 *0.0%*	2 *2.6%*	1 *1.3%*	1 *1.3%*	0 *0.0%*	**76**
21-30 days in GIN	34 *75.6%*	5 *11.1%*	4 *8.9%*	1 *2.2%*	0 *0.0%*	1 *2.2%*	0 *0.0%*	**45**
31-40 days in GIN	45 *86.5%*	3 *5.8%*	0 *0.0%*	1 *1.9%*	1 *1.9%*	2 *3.9%*	0 *0.0%*	**52**
41-50 days in GIN	49 *66.2%*	10 *13.5%*	6 *8.1%*	2 *2.7%*	3 *4.1%*	2 *2.7%*	2 *2.7%*	**74**
51-60 days in GIN	27 *45.0%*	7 *11.7%*	4 *6.7%*	2 *3.3%*	6 *10.0%*	9 *15.0%*	5 *8.3%*	**60**
Total	**356**	**52**	**21**	**10**	**12**	**15**	**7**	**473**

Figure 11

The two tables discussed above focus on incidence of lending, and of activity as a node. In addition to the incidence of lending, the amount of lending also fell. As shown in Figure 12, most of the banks that remained in the GIN group from 2007q1 to 2009q2 decreased their lending. Given that the scale is in billions, the intensity of the dropoff in lending volume is notable, with next to no institutions increasing their lending over this period.

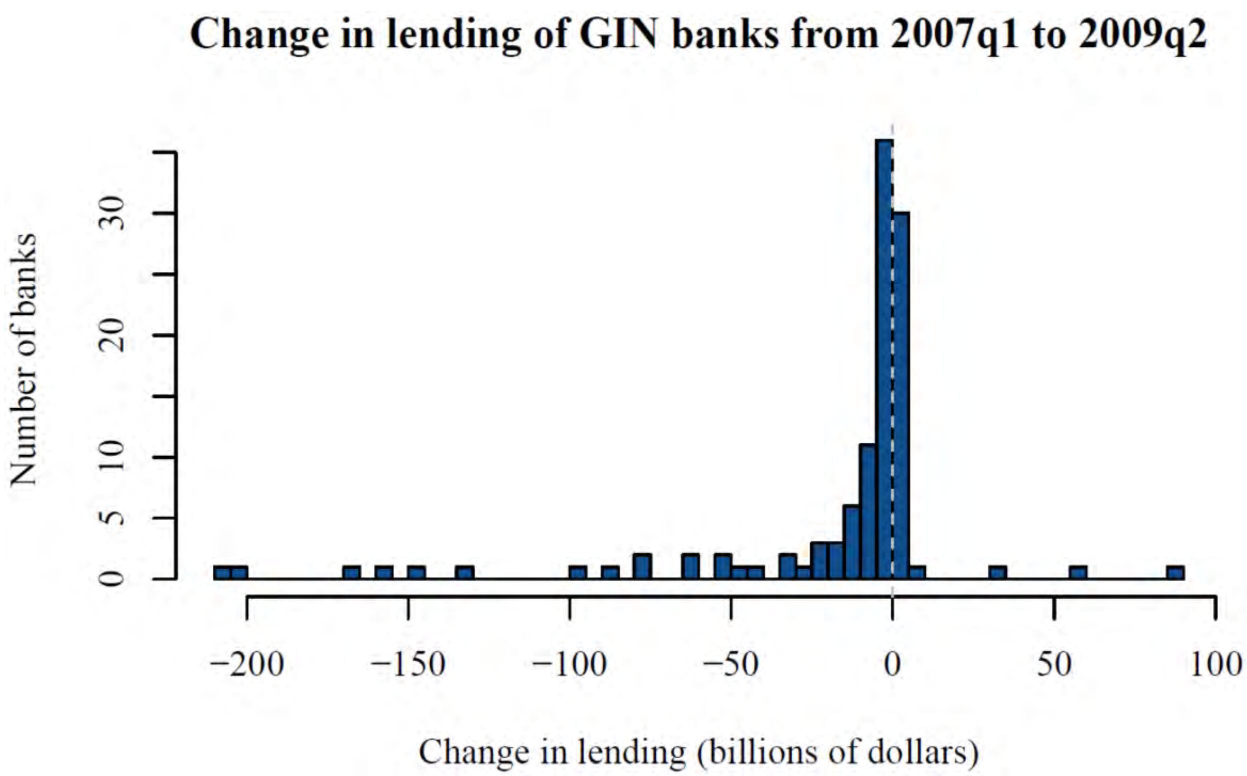

Figure 12

Looking more closely at the intensive margin, or dollars lent by institutions, the data show that institutions that lent less and to fewer institutions were the most likely to exit the market, consistent with our observation that the network became more complete as a result of the financial crisis. To this end, Figure 13 groups GIN banks which exited the market between 2007Q1 and 2009Q2 and those that did not exit the market by the dollar volumes lent in 2007Q1. The banks that exited were relatively smaller lenders: 70 percent of banks that lent less than $500 million in 2007Q1 exited, whereas "only" 38 percent of those that lent over $2 billion exited. Also, as shown in Figure 14, the banks that had fewer counterparties (small out-degrees) in 2007q1 were more likely to have exited the market. 65 percent of the banks that had an average out-degree in 2007q1 of less than 5 left the market. For banks that had an average outdegree in 2007q1 of greater than 20 (many counterparties), only 19 percent exited the market.

Frequency of number of banks in GIN group in 2007q1 that exited in 2009q2, by dollar volume lent in 2007q1

Number of banks	Frequency / *Column Percent*	Dollar volume lent in 2007q1 (billions of dollars): (0 , 0.5)	[0.5 , 1)	[1 , 1.5)	[1.5 , 2)	> 2	**Total**
	Did not exit	63 *30.4%*	16 *28.6%*	18 *51.4%*	9 *47.4%*	96 *61.5%*	**202**
	Exited	144 *69.6%*	40 *71.4%*	17 *48.6%*	10 *52.6%*	60 *38.5%*	**271**
	Total	**207**	**56**	**35**	**19**	**156**	**473**

Figure 13

Frequency of number of banks in GIN group in 2007q1 that exited in 2009q2, by average out-degree in 2007q1

Number of banks	Frequency / *Column Percent*	Average out-degree in 2007q1: (0 , 5)	[5, 10)	[10, 15)	[15, 20)	> 20	**Total**
	Did not exit	129 *35.3%*	27 *54.0%*	16 *69.6%*	13 *92.9%*	17 *81.0%*	**202**
	Exited	236 *64.7%*	23 *46.0%*	7 *30.4%*	1 *7.1%*	4 *19.1%*	**271**
	Total	**365**	**50**	**23**	**14**	**21**	**473**

Figure 14

All told, the contraction in the number of links and nodes in the federal funds network was mainly due to many small lenders in the GIN component exiting the market. At the same time, those that remained lent smaller amounts, and did so less frequently. In the next section, we explore factors that may have affected this pattern, including the role of counterparty risk and of liquidity in network dynamics.

5. Aggregate regressions and counterparty risk

Taylor and Williams (2009) find evidence that, between August 2007 and March 2008, increased counterparty risk between banks contributed to the jump in the spread between the 3-month Libor rate (the rate at which banks lend to each other on an unsecured basis for 3 months) and the overnight interest swap (OIS) rate. We examine the how counterparty risk (proxied by CDS spreads) and liquidity risk (proxied by bank borrowings from the Fed's emergency liquidity facilities) affected overall activity in the federal funds network. At a daily frequency some our variables display a fair amount of autocorrelation, so to ensure that our residuals are well behaved we use dynamic OLS regressions with 5 lags of both the dependent and explanatory variables, and then examine the coefficients of the static long-run solution. All our regressions include a constant, trend, and time dummies for maintenance period day, day before and after holiday, FOMC announcement day, and last day of each month, quarter, and year. We also control for other factors which could affect activity in the federal funds market: the level of excess reserves, the spread between the effective federal funds rate and the target federal funds rate, trading volume in the S&P500 stocks, and payments volume in the Fedwire system (excluding federal funds transactions) to capture payment shocks.

Our proxy for counterparty risk is the average of the spread on the 5-year CDS contract of 5 U.S. banks: Citibank, J.P. Morgan, Wells Fargo, Capital One, and U.S. Bancorp.[5] The CDS quotes are from Markit. To capture liquidity risk, or demand for liquidity, we use borrowings from the Federal Reserve's liquidity facilities established during the 2008 financial crisis: Term Auction Facility, Primary Dealer Credit Facility, Commercial Paper Funding Facility, Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility, and the Primary Credit Facility.[6] We use the amount of excess reserves to control for the supply of liquidity in the market. Banks began to accumulate large amounts of excess reserve balances after the Federal Reserve stopped offsetting increases in credit and lending by shedding other assets in the fall of 2008. Excess reserve balances continued to climb through a series of large-scale asset purchase programs, which prompted increases in reserve balances early in 2009 and continues to the present.

We split our sample into 3 time periods: pre-crisis (from 7/7/2004 – 6/29/2007), early crisis (7/2/2007 – 8/29/2008), and late crisis (1/2/2009 – 8/31/2012). We intentionally exclude the turbulent period around Lehman's bankruptcy— because during this period federal funds volume is plummeting and most of our network metrics appear to be transitioning to a new "steady state." Although including this period in our regressions would strengthen our results, empirical tests suggest that doing so would introduce some irregularities such as heteroscedasticity and non-normality in the residuals.

Table 1 shows the regressions for federal funds dollar volume as identified by our Fedwire series. The coefficients on the 5-year CDS spread and fed liquidity facilities—proxies for counterparty and liquidity risk—are not significant in the pre-crisis and early-

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[5] We selected these banks because their CDS contracts are liquid, and because data were available for the entire sample period.

[6] These data can be found at: http://www.federalreserve.gov/monetarypolicy/bst.htm

crisis periods. In the late-crisis period, both of these coefficients become negative and highly significant. If we include both CDS spreads and the Fed liquidity facilities together in the same regression, their coefficients become somewhat less significant because these variables are strongly correlated with each other. In principle, counterparty and liquidity risk are intertwined because losing access to liquidity (short-term funding) could have resulted in insolvency, and a higher probability of insolvency (default) likely impaired access to liquidity.

Table 1. Regressions on total dollar volume

	Pre-crisis	Early crisis		Late crisis	
	Dollar volume (1)	Dollar volume (2)	Dollar volume (3)	Dollar volume (4)	Dollar volume (5)
Excess reserve balances	145.119	322.787	327.913	29.284	31.458
	(0.10)	(0.25)	(0.23)	(1.36)	(1.56)
Effective fed funds rate minus target	-28.277	-22.510	-26.959	70.762	84.636
	(0.39)	(0.75)	(0.82)	(0.95)	(1.19)
Fedwire payments volume	19.966	27.034	53.672 *	17.354	32.628 **
	(0.94)	(1.33)	(2.42)	(1.55)	(2.84)
S&P500 trading volume	-7.558	4.409	2.115	3.524	2.151
	(1.07)	(1.62)	(0.71)	(1.77)	(1.08)
5-year CDS spread	-19.944	20.725		-19.311 ***	
	(0.32)	(1.83)		(5.29)	
Fed liquidity facilities			0.114		-0.064 ***
			(0.90)		(5.97)
Adjusted R-squared	0.71	0.50	0.49	0.70	0.70
Number of observations	752	294	294	923	923

Notes: Coefficients shown are for the solved static long-run equation for total federal funds dollar volume. T-statistics reported in parentheses. *** denotes 0.001 level of significance, ** denotes 0.01 level of significance, and * denotes 0.05 level of significance. Pre-crisis sample period is from 7/7/2004 to 6/29/2007. Early crisis period is from 7/2/2007 to 8/29/2008. Late crisis period is from 1/2/2009 to 8/31/2012. All regressions include a constant, trend, 5 lags of dependent variable, and 5 lags of each of the explanatory variables shown in the table. In addition, all specifications include time dummies for maintenance period day, day before holiday, day after holiday, last day of month, last day of quarter, last day of year, and FOMC announcement day. Fedwire payments volume excludes identified federal funds transactions. 5-year CDS spread is average of CDS spreads of Citibank, J.P. Morgan, Wells Fargo, Capital One, and U.S. Bancorp. Federal reserve liquidity facilities are the outstanding balance on the Term Auction Facility, Primary Dealer Credit Facility, Commercial Paper Funding Facility, Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility, and the Primary Credit Facility.

Table 2 shows the regressions for the dollar amount lent from the GIN component to the core of the network (GSCC component). In the pre-crisis and early crisis period, the coefficients on the 5-year CDS spread and the amount outstanding at the Fed liquidity facilities are not statistically significant. But in the late crisis period (post-Lehman), these variables are negative and significant at the 0.001 level, indicating that lending to the core decreased when both counterparty risk and demand for liquidity increased. The coefficient on Fedwire payments volume—a proxy for payment shocks— is positive and significant in specifications 2, 3, and 5, suggesting after July 2007 there was increased lending to the core on days when there were above-average payments.

Table 2. Regressions on lending from GIN component to GSCC component

	Pre-crisis	Early crisis		Late crisis	
	GIN lending to GSCC	GIN lending to GSCC	GIN lending to GSCC	GIN lending to GSCC	GIN lending to GSCC
	(1)	(2)	(3)	(4)	(5)
Excess reserve balances	805.936	-189.848	-323.306	11.816	12.235
	(0.88)	(0.22)	(0.36)	(0.99)	(1.21)
Effective fed funds rate minus target	9.967	-12.818	-15.979	55.314	54.423
	(0.21)	(0.60)	(0.73)	(1.34)	(1.52)
Fedwire payments volume	14.409	32.587 *	49.335 ***	0.855	12.138 *
	(1.07)	(2.29)	(3.36)	(0.14)	(2.10)
S&P500 trading volume	-4.716	3.718	2.859	2.042	0.844
	(1.05)	(1.90)	(1.44)	(1.85)	(0.85)
5-year CDS spread	54.303	6.269		-10.967 ***	
	(1.37)	(0.80)		(5.42)	
Fed liquidity facilities			0.069		-0.040 ***
			(0.83)		(7.44)
Adjusted R-squared	0.56	0.41	0.40	0.45	0.00
Number of observations	752	294	294	923	0

Notes: Coefficients shown are for the solved static long-run equation for dollar volume lent from GIN to GSCC. T-statistics reported in parentheses. *** denotes 0.001 level of significance, ** denotes 0.01 level of significance, and * denotes 0.05 level of significance. Pre-crisis sample period is from 7/7/2004 to 6/29/2007. Early crisis period is from 7/2/2007 to 8/29/2008. Late crisis period is from 1/2/2009 to 8/31/2012. All regressions include a constant, trend, 5 lags of dependent variable, and 5 lags of each of the explanatory variables shown in the table. In addition, all specifications include time dummies for maintenance period day, day before holiday, day after holiday, last day of month, last day of quarter, last day of year, and FOMC announcement day. Fedwire payments volume excludes identified federal funds transactions. 5-year CDS spread is average of CDS spreads of Citibank, J.P. Morgan, Wells Fargo, Capital One, and U.S. Bancorp. Federal reserve liquidity facilities are the outstanding balance on the Term Auction Facility, Primary Dealer Credit Facility, Commercial Paper Funding Facility, Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility, and the Primary Credit Facility.

Table 3 shows regressions for the size of the GIN component, that is, the number of banks that lend to the core. The coefficient on CDS spreads and Fed liquidity facilities are negative and significant only in the late crisis period, suggesting that there were fewer lenders in the market on days in which counterparty and liquidity risk were high.

In sum, the results in Tables 1-3 suggest that counterparty risk and liquidity risk only began to significantly alter the lending patterns in the federal funds market after Lehman's bankruptcy in the fall of 2008 (late crisis period). During this period, overall dollar volume transacted, lending from GIN to the core, and the number of banks lending to the core become very sensitive to CDS spreads and demand for liquidity.

Table 3. Regressions on size of GIN component

	Pre-crisis	Early crisis		Late crisis	
	Size GIN (1)	Size GIN (2)	Size GIN (3)	Size GIN (4)	Size GIN (5)
Excess reserve balances	2322.450	-1895.800	-1850.010	-8.980	-4.935
	(1.46)	(1.95)	(1.74)	(1.09)	(0.51)
Effective fed funds rate minus target	-44.579	11.796	5.142	45.572	67.514
	(0.56)	(0.49)	(0.20)	(1.59)	(1.95)
Fedwire payments volume	61.045 **	40.079 *	52.533 **	-2.970	-0.946
	(2.66)	(2.43)	(2.90)	(0.69)	(0.17)
S&P500 trading volume	6.409	-2.478	-3.118	1.205	1.257
	(0.85)	(1.14)	(1.33)	(1.57)	(1.30)
5-year CDS spread	23.664	10.638		-7.000 ***	
	(0.35)	(1.22)		(4.99)	
Fed liquidity facilities			0.040		-0.016 **
			(0.41)		(3.12)
Adjusted R-squared	0.35	0.64	0.64	0.82	0.82
Number of observations	752	294	294	923	923

Notes: Coefficients shown are for the solved static long-run equation for the size of the GIN component. T-statistics reported in parentheses. *** denotes 0.001 level of significance, ** denotes 0.01 level of significance, and * denotes 0.05 level of significance. Pre-crisis sample period is from 7/7/2004 to 6/29/2007. Early crisis period is from 7/2/2007 to 8/29/2008. Late crisis period is from 1/2/2009 to 8/31/2012. All regressions include a constant, trend, 5 lags of dependent variable, and 5 lags of each of the explanatory variables shown in the table. In addition, all specifications include time dummies for maintenance period day, day before holiday, day after holiday, last day of month, last day of quarter, last day of year, and FOMC announcement day. Fedwire payments volume excludes identified federal funds transactions. 5-year CDS spread is average of CDS spreads of Citibank, J.P. Morgan, Wells Fargo, Capital One, and U.S. Bancorp. Federal reserve liquidity facilities are the outstanding balance on the Term Auction Facility, Primary Dealer Credit Facility, Commercial Paper Funding Facility, Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility, and the Primary Credit Facility.

6. Panel regressions using bank-level data

Although the results of the previous section suggest a strong relationship between counterparty risk, liquidity risk, and lending in the federal funds market after the fall of 2008, more evidence is needed to infer any causality. In this section we perform panel regressions using the bank-level data for banks that are in the core of the network (the GSCC component) to explore how their borrowing and lending is influenced by their own credit risk.

Table 4 shows panel regression results on the following bank-specific dependent variable: dollar volume borrowed from banks in GIN (GIN to GSCC), dollar volume lent to banks in GOUT (GSCC to GOUT), total dollar volume lend and borrowed (GSCC gross flow), net dollar volume borrowed (GSCC net flow), number of banks in GIN that bank is borrowing from (GIN to GSCC nodes), number of banks in GOUT that the bank is lending to (GSSC to GOUT nodes), and total number of counterparty in GIN and

GOUT that the bank deals with (total nodes). Because of CDS price data availability, we include only 11 banks in our panel.[7]

Table 4. Fixed effects panel regression: 2009-2012

	Fixed effects panel regression				Fixed effects panel poisson regression		
Dependent variable	GIN to GSCC	GSCC to GOUT	GSCC gross flow	GSCC net flow	GIN to GSCC nodes	GSCC to GOUT nodes	Total nodes
cds5yr	-1.842**	0.058	-1.783**	-1.900**	-0.147*	0.004	-0.102
	(0.53)	(0.06)	(0.51)	(0.55)	(0.07)	(0.03)	(0.05)
Total balances	0.001	0	0.001	0.001	-0.001**	0	-0.001**
	(0.00)	0.00	(0.00)	(0.00)	0.00	0.00	0.00
Month end	-0.395	0.038	-0.357	-0.433*	0.029	-0.035	0.012
	(0.19)	(0.06)	(0.20)	(0.19)	(0.02)	(0.04)	(0.01)
Quarter end	-1.228	-0.526	-1.755	-0.702	-0.210**	-0.480**	-0.273**
	(0.66)	(0.29)	(0.91)	(0.48)	(0.07)	(0.09)	(0.06)
Constant	7.572**	0.822*	8.394**	6.751**			
	(1.49)	(0.28)	(1.61)	(1.42)			
Observations	9310	9310	9310	9310	9310	7070	9310
Number of institutions	11	11	11	11	11	8	11
R-squared	0.089	0.005	0.08	0.088			
Robust standard errors in parentheses							
* significant at 5%; ** significant at 1%							

The results suggest that increases in CDS spreads lead to decreases in dollars borrowed, but not necessarily lent, to the tune of about $2 billion per percentage point. Furthermore, the number of nodes lending to the GSCC drops with the CDS spread. The small coefficient is at least partly attributed to the fact that so many banks had already dropped out of the market before our sample period begins in 2009. Finally, increases in total balances leads to decreases in number of participants. As we would expect, the calendar effects lead to lower participation in the federal funds market, as banks generally may not want to show unsecured exposures on quarter-end balance sheet reports.

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Table 5. Fixed effects panel regression: 2007-2010, with TAF borrowings

	Fixed effects panel regression				Fixed effects panel poisson regression		
Dependent variable	GIN to GSCC	GSCC to GOUT	GSCC gross flow	GSCC net flow	GIN to GSCC nodes	GSCC to GOUT nodes	Total nodes
cds5yr	-1.001	-0.365	-1.366	-0.636	-0.100*	-0.046	-0.058*
	(0.55)	(0.18)	(0.71)	(0.42)	(0.04)	(0.04)	(0.03)
Total balances	-0.002	0	-0.002	-0.002	0	-0.001**	-0.001**
	(0.00)	0.00	(0.00)	(0.00)	0.00	0.00	0.00
TAF	-0.077*	0.02	-0.056*	-0.097*	0.009*	-0.007	-0.004
	(0.03)	(0.01)	(0.02)	(0.04)	(0.00)	(0.00)	(0.00)
Month end	0.233	-0.009	0.225	0.242	-0.017	0.049	0.034
	(0.34)	(0.16)	(0.43)	(0.30)	(0.06)	(0.04)	(0.04)
Quarter end	-1.424	-0.738	-2.162	-0.687	-0.348**	-0.209*	-0.238*
	(1.02)	(0.42)	(1.38)	(0.71)	-0.067	-0.106	-0.095
Constant	9.694**	2.106**	11.801**	7.588**			
	-0.959	-0.317	-1.147	-0.851			
Observations	4032	4032	4032	4032	4032	4032	4032
Number of institutions	7	7	7	7	7	7	7
R-squared	0.138	0.041	0.154	0.107			
Robust standard errors in parentheses							
* significant at 5%; ** significant at 1%							

Simply investigating the characteristics of the network does not allow us to discern whether changes in the network result from the demand for or supply of funds. For a slightly different sample, however, we can investigate how funds borrowed from the TAF affects the network at the same time that changes in the CDS spread affect the network. Presumably, institutions borrowing from the Fed have lower demand for funds from counterparties, damping demand, while poor credit risks are likely to have credit lines cut, trimming supply.

In that spirit, table 5 reports a similar specification to table 4, although adds the amount of funds the institution borrowed from the TAF and alters the sample slightly. In this case, we can differentiate the effect of liquidity borrowings from the Federal Reserve and changes in counterparty credit quality during the TAF borrowing period.[8] As shown in the first four columns of the table, the results suggest that flows appear to decrease with TAF borrowings – the GSCC banks borrow less, although lending is not significantly affected. The effect is less than one-for-one, consistent with TAF borrowings being used as precautionary demand for liquidity. If the coefficient were closer to -1, then the banks would have decreased their borrowings from counterparties one-for-one with TAF borrowings. Because the coefficients are significantly less than one, banks cut back on their borrowings somewhat, but still continued to demand funds from counterparties.

One caveat to this result can be seen in the last three columns of the table, which give a sense of incidence of borrowing through the number of nodes. The number of nodes available to borrow from drops with rises in CDS spreads, as lending counterparties

[8] Funds from the TAF were available to depository institutions from December 20, 2007 to April 8, 2010.

control credit risk by cutting credit lines to borrowers. This effect is slightly mitigated by TAF borrowings, although the coefficient is economically small. The overall increase in liquidity does tend to dampen borrowing and lending patterns as well. The aversion to reporting unsecured exposures on statement dates still remains, as the coefficients on quarter end remain economically and statistically significant.

7. Conclusion

The federal funds network shrank some during the early phase of the crisis (mid-2007 to mid-2008), but it contracted much more at the end of 2008. The new “steady-state” is characterized by fewer lenders, who lend smaller amounts, and do so less frequently. Lending and size of GIN component become negatively correlated with average CDS spreads, despite banks being flush with liquidity. Our aggregate and bank-level regressions suggest that counterparty risk and liquidity risk only began to significantly alter the lending patterns in the federal funds market after Lehman’s bankruptcy in the fall of 2008 (late crisis period). During this period, overall dollar volume transacted, lending from GIN to the core, and the number of banks lending to the core become very sensitive to CDS spreads and demand for liquidity.

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