Emergency Liquidity Facilities, Signalling and Funding Costs*

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Abstract

We provide a new theoretical explanation and empirical support for the Federal Reserve offering two different liquidity facilities in periods of high asymmetric information and financial distress. In our model, illiquid yet solvent banks choose to pay a high cost to access liquidity from the Term Auction Facility (TAF) as a way to signal their quality, in exchange for more favourable funding from external markets in the future. Less solvent banks access the less costly and more flexible discount window (DW) in case they experience an unexpected run, paying a higher future funding cost. Because the TAF had worse and less flexible lending terms in all dimensions, banks could signal their level of solvency, which helped to decrease asymmetric information during the crisis. Using disclosed data on access to these facilities, we provide evidence consistent with these results. Banks that accessed TAF in 2008 paid approximately 31 basis points less in the interbank lending market in 2010 and were perceived as less risky than banks that accessed the DW. Our results can contribute to a better design of liquidity facilities during a financial crisis.

JEL classification: G21, G28, G01.

Keywords: Discount window, liquidity auction, funding cost, signaling, lender of last resort.

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1 Introduction

The role of central banks as liquidity providers has been a controversial topic since Bagehot (1878). During the recent financial crisis, many solvent banks that experienced a liquidity crunch shied away from using the discount window (DW), the main liquidity facility set by the Federal Reserve to help banks in that very situation. Instead, at the height of the crisis (the failure of Lehman Brothers), some banks were willing to pay up to 150 basis points more (equivalent to $172.6 million in additional costs in just one auction[1]) in an alternative facility, the Term Auction Facility (TAF), which had more stringent and less-flexible lending terms in all dimensions (e.g., loan maturity or the availability of funds) than the DW. In this paper, we provide a new theoretical explanation and empirical support for the Federal Reserve offering two different liquidity facilities in periods of high asymmetric information and financial distress. The existence of two liquidity facilities with different characteristics allowed banks to signal their level of solvency, which helped to decrease asymmetric information, potentially preventing the failure of financial markets. In consequence, solvent banks bid aggressively in the TAF, which resulted in lower post-crisis funding costs as they were perceived by funding markets as more solvent.[2]

We first propose a signalling model to explain the incentives of banks to use these two facilities. The lower flexibility of the TAF compared with the DW makes the TAF more costly and hence allows banks to send a credible signal to the market. These different levels of flexibility that create different costs in heterogeneous participants is key for a separating equilibrium to exist in our model. Specifically, we assume that banks need to access a liquidity facility because of a foreseeable liquidity shock or because of an unforeseeable "run" caused by concerns about their solvency. Banks can anticipate whether they will be hit by a liquidity shock and borrow when the TAF is available, but runs are unexpected and banks' only option for liquidity on short notice is the DW. While good banks experience only the former, bad banks can be hit by both types of funding shocks. In the separating equilibrium, good banks that expect a liquidity shock will pay the higher rate to access

[1] See Bernanke (2009). The largest difference between the TAF auctions and the DW was 150 basis points, which corresponds to the TAF auction of September 22, 2008. Given that the amount offered in the auction was $150 billion of loans with 28-day terms, this represents approximately a difference of $172.6 million in funding costs compared with the DW.

[2] We estimate annual savings of between $122.4 million, when considering interbank borrowing, and $1,323 million, when considering funding costs for total liabilities.

the less-flexible TAF facility to signal that they do not need the flexibility of the DW to respond to sudden runs. To sustain this separating equilibrium, it must be optimal for bad banks not to deviate by borrowing from the TAF on a precautionary basis. If the TAF rate is high enough, as we could observe during the peak of the crisis, bad banks will find it optimal to borrow from the discount window in the case of a run even if that reveals their type. Stigma from accessing the DW is thus endogenously created in this equilibrium.

Our empirical analysis tests the predictions of this model. We compare funding costs for different sources before and after the height of the financial crisis for banks that used the DW or the TAF. We find that banks that used the TAF to borrow funds at the height of the crisis have lower post-crisis total funding costs (in 2010) than banks that drew from the DW. This difference is about 7 basis points in total funding costs, and 31 basis points for rates paid in the interbank lending market. Additionally, this difference in funding costs is larger for banks that had a more intense usage of the TAF (relative to their size), and for banks that were substantially more risky than other banks.

Our model predicts that TAF banks are more solvent, and therefore markets are able to price funding accordingly. Consistent with these predictions, the majority of U.S. banks that failed during the crisis were mainly borrowing from the DW during the pre-Lehman period and only a few of them used the TAF as their main source of liquidity from the Fed. As far as we know, this is the first paper that empirically shows a clear link between access to emergency liquidity facilities and funding cost ex-post.[3]

These predictions are also consistent with an extended signalling model where banks strategically use the TAF to increase their opacity in the market. While a bank's borrowings from the DW could be inferred from public data, this inference problem was purposefully made more difficult in the TAF. Therefore, it could be argued that the TAF was an opaque liquidity facility and banks were intentionally accessing the TAF to be more opaque. We show that there is a signalling equilibrium that separates DW banks from the rest of the banks. Since markets cannot differentiate between TAF and the banks that do not access the DW, TAF banks pay lower subsequent prices

[3] Armantier *et al.* (2011) document a short term effect in the interbank market that reverses three days after banks access the DW. Our paper documents a long term effect on overall funding costs.

at the funding markets and need to bid a higher rate in the TAF for the signalling equilibrium to exist.

We also study how the use of DW or TAF affects the structure of funding. We observe that TAF banks rely more on savings and insured deposits, but they do not pay significantly different rates than DW banks on these deposit accounts. Depositors seem to be less price elastic, which is particularly true for insured deposits, which are less sensitive to the solvency of the bank. However, deposits tend to be cheaper than other sources of funding. The freeze of alternative funding markets led to an increase in the use of deposits as a source of funding, which has been well documented in the literature (Gatev and Strahan, 2006; Cornett *et al.*, 2011). Compared with DW banks, TAF banks were able to attract more deposits without significantly changing the rates paid.

Our results have relevant implications for the design of liquidity facilities because it gives a rationale for providing two facilities with distinct features. The reduced flexibility of the TAF is less costly for good banks than for bad banks and can therefore serve as a credible signal for good banks to show their quality to the market. During the peak of the crisis, as signalling became more important, good quality banks were willing to pay a much higher rate for more stringent lending terms to signal their quality. This may have helped to decrease the level of uncertainty and asymmetric information during the crisis, and may have prevented the failure of financial markets.[4]

Our findings contribute to the extensive literature on the lender-of-last resort (LOLR) role that central banks can play in times of systemic distress. In his classic paper, Bagehot (1878) argued that central banks should provide liquidity support to any institution willing to offer good collateral but at a penalty rate. Rochet and Vives (2004) and Diamond and Rajan (2005) provide a theoretical foundation for Bagehot's classical doctrine, suggesting that in times of financial stress, it is hard to distinguish between insolvent, and solvent but illiquid banks, and so the access to LOLR facilities needs to be unconditional on any criteria regarding a bank's solvency. More recently, other papers have analyzed some unintended consequences of access to LOLR, such as moral hazard leading to excess illiquid leverage (Acharya and Tuckman, 2014) or the risks of unconditional access to LOLR

[4]Signalling does not necessarily have to be welfare increasing. In times of a financial crisis, however, increased information on banks' types can prevent market failure. Bouvard *et al.* (2015) and Goldstein and Leitner (2015) document how increased regulatory disclosure can be beneficial in adverse economic conditions. While we abstract from the optimality of the disclosure decision, we analyze one specific mechanism created by the regulator to allow signalling by banks to the market.

facilities that can create the "zombie banks" phenomenon (Acharya and Backus, 2009). In this paper, we contribute to the debate on how to design LOLR facilities. We argue that a "one size fits all" approach with respect to LOLR policy will force banks into a pooling equilibrium, while the simultaneous offering of several liquidity facilities with different characteristics allows banks to signal their type (i.e., illiquid versus insolvent), which helps ensure the efficient dissemination of liquidity provisions.

Our paper is also related to the theoretical research on effects associated with DW borrowing. In a recent paper, Ennis and Weinberg (2013) propose a model to endogenize the stigma effect in which banks with heterogeneous asset quality choose between the interbank market and the discount window. In their model asset quality is observable in the interbank market, causing low quality banks to be excluded from the interbank market and forcing them to borrow at a premium from the discount window. The lower quality of the pool accessing the discount window generates the stigma. In our paper asset quality of banks is unobservable and banks are eligible to access both liquidity facilities. Separation in our model arises endogenously because of heterogeneity in the liquidity facilities' flexibility, as low quality banks value flexibility more than high quality banks.[5] Klee (2011) analyzes the interaction between discount rate and federal funds rate when banks face exogenous non-pecuniary costs (stigma) on top of monetary costs to access the DW. The focus of our model is to explain the choice between TAF and DW and to endogenously derive the stigma effect.

On the empirical front, evidence has accumulated on the presence of DW stigma effects (Peristiani, 1998; Furfine, 2001, 2005), and on how LOLR facilities alleviate banks' funding strains and enhance market liquidity (Fleming, 2011). Armantier *et al.* (2015) document stigma costs by analyzing banks' bidding behavior in TAF auctions relative to the DW rate. Since TAF-funds are obtainable only under more restrictive conditions than DW-funds, any TAF-bids above the DW-rate are driven by stigma costs. We extend their analysis in two ways: first we provide a simple model to provide an economic rationale why the DW creates stigma and the TAF does not that is consistent with the observed bidding behavior. Second we document that the stigma effect has long

[5] See also Philippon and Skreta (2012), who develop a more general framework of adverse selection in lending markets with government intervention. In their model, participation in government programs can generate some stigma in participating firms.

term implications for banks' funding costs that provide a rationale for the upfront signaling costs. In a recent paper, Berger *et al.* (2017) analyze the banks that participated in the DW and TAF facilities and their aggregate lending behaviour during the recent financial crisis. They find that bank size matters: small banks receiving funds from the DW and TAF were weak banks, whereas large banks generally were not. Also, Puddu and Wälchli (2012) find that banks that borrowed TAF funds exhibit ex-ante higher levels of maturity mismatch and have more illiquid collateral.[6] In this paper, we shed new light on the incentive to participate in different LOLR facilities. In particular, we study how banks' access to DW and TAF facilities during the crisis affected market perceptions ex-post.

The rest of the paper is organized as follows: Section 2 explains the institutional features of recent central bank liquidity facilities. We develop the theoretical model in Section 3 and present the interesting stylized facts and main empirical results in Section 4. Section 5 extends our empirical analysis and Section 6 concludes.

2 Central Bank Liquidity Facilities

During the recent financial crisis, the Fed undertook a series of unusual policy actions in order to alleviate the strain on bank funding markets.[7] In addition to easing the terms of the DW, the Fed created a number of unconventional programs, including the TAF, a new facility for auctioning short-term credit. These were the two main Fed facilities[8] used by depository institutions (DIs) at the height of the crisis.[9] In this section, we provide a brief perspective of the key features of the DW and TAF (see also Armantier *et al.* (2015) for an excellent comparison between the two programs).

[6] See also other papers, such as Wu (2008), Gilbert *et al.* (2012) and Drechsler *et al.* (2016) for the European case.

[7] See, for example, Afonso *et al.* (2011), who document the stressed interbank lending market during the crisis.

[8] In the outset of the liquidity crisis (second half of 2007) the Federal Home Loan Bank System provided significant early liquidity support to their members. However, liquidity support from the Fed grew significantly in 2008 and it became the main government-sponsored liquidity provider in the period of highest market turbulence and asymmetric information (Ashcraft *et al.*, 2010).

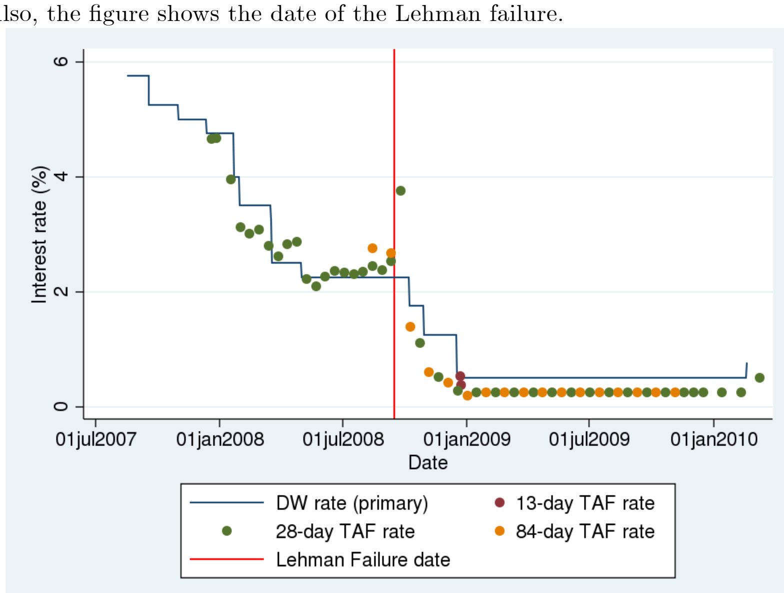
[9] There were other facilities provided by the Fed, such as the Term Securities Lending Facility (TSLF), the Primary Dealer Credit Facility (PDCF), the Commercial Paper Funding Facility (CPFF) and Term Asset-Backed Securities Loan Facility (TALF), but they were either designed for non-depository institutions, or their dimensions were significantly smaller than the DW or TAF.

2.1 Discount window lending

The Federal Reserve Act requires discount window credit to be made on a non-discriminatory basis to all institutions that are eligible to borrow. In August 2007, as a response to the incipient financial crisis, the Fed narrowed the spread in the DW rate over the FOMC's target federal funds rate and increased the allowable term for primary[10] credit borrowing to 30 days from overnight. A few months later (on March 16, 2008), in the wake of the takeover of Bear Stearns by JP Morgan Chase, the Fed further narrowed the spread to 25 basis points and extended the maximum maturity of term primary credit loans to 90 days (see Figure 1). Nevertheless, as shown in Figure 2a, total borrowing from the DW remained low, with primary credit loans peaking in late 2008 at just over $100 billion, and secondary loans at only about $1 billion in late 2009 (see Figure 2b). See the Appendix A for further details about the DW before the recent financial crisis.

Figure 1: Borrowing costs of DW and TAF

This figure displays weekly DW primary rates and stop-out rates for TAF auctions with maturities of 13 days, 28 days, and 84 days. Also, the figure shows the date of the Lehman failure.



[10] The discount window offers three types of lending programs. The "Primary Credit" program is the principal safety valve for ensuring adequate liquidity in the banking system for sound depository institutions (DIs). Primary credit is priced at a rate above the FOMC's target for the federal funds rate and is normally granted on a "no-questions-asked" basis. There are no restrictions on borrowers' use of primary credit. Priced slightly higher, "Secondary Credit" is available to DIs not eligible for primary credit. Finally, under the "Seasonal Credit" program, a DI may qualify for funding to meet seasonal borrowing needs due to fluctuations related with construction, college, farming and other sectors.

2.2 The Term Auction Facility (TAF)

In response to concerns about the reluctance of banks to use the DW, the Fed introduced the TAF on December 12, 2007. The TAF was a series of biweekly auctions for preset amounts of funding available to DIs eligible for primary credit at the DW, including U.S. branches and agencies of foreign banks.

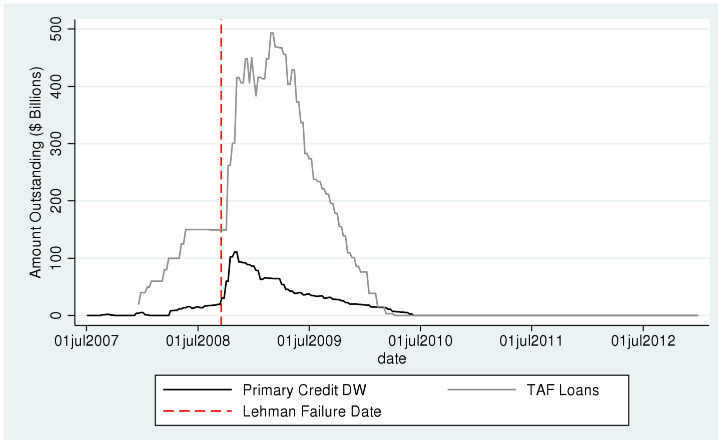
The TAF is a single-price auction whereby all successful bidders pay the stop-out rate, the interest rate of the last accepted bid that all awarded institutions pay upon maturity. TAF loans, which were offered with a maturity of 28 days and, beginning in August 2008, 84 days, were fully collateralized. Collateral eligibility and valuation procedures were the same as for the DW.

Clearly, the lending terms of the TAF were in all aspects more stringent than the DW. Whereas an unlimited amount of money is available on demand through the DW, under the TAF, banks needed to wait for three days to access the funds, funds were auctioned on a biweekly basis, there was a cap on individual bids, loans could not be prepaid, loan maturity was limited, and the collateral requirements were the same as under the DW. Absent any stigma effect, banks should be more willing to pay for funds under the DW than under the TAF. Yet during a substantial period of time, banks were willing to pay a premium over the DW rate to access TAF funds (see Figure 1). As the financial crisis ebbed, DW lending rates started to exceed TAF rates, in line with what we would expect given the funding terms.

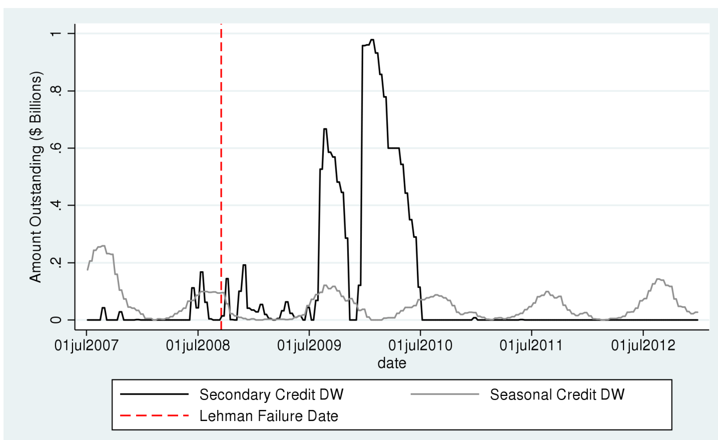
From its creation, TAF borrowing was in high demand. As shown in Figure 3, auctions were highly competitive prior to the bankruptcy of Lehman Brothers. Total bids were more than 50% larger, on average, than total offered funds over the pre-Lehman period. Demand for TAF funds continued to rise after the collapse of Lehman, exceeding $800 billion in 2009Q1; however, competition among bidders decreased after the Fed doubled the amounts supplied. In response to continued improvements in financial market conditions, the Fed reduced both the amount and maturity of new TAF auctions, until March 8, 2010 when the final auction was held.

Figure 2: Total borrowing from TAF, and from primary, secondary and seasonal DW

The figure plots weekly outstanding Federal Reserve credit for the primary DW and TAF programs (panel (a)), and for the secondary DW and seasonal DW programs (panel (b)). The figure is generated using data on DW loans to depository institutions that were released by the Fed in March 2011 in response to a Freedom of Information Act request and subsequent court ruling. The data include loans to individual institutions made between August 20, 2007 and March 1, 2010.



(a) **Primary credit in DW and TAF loans**



(b) **Secondary and seasonal loans in DW**

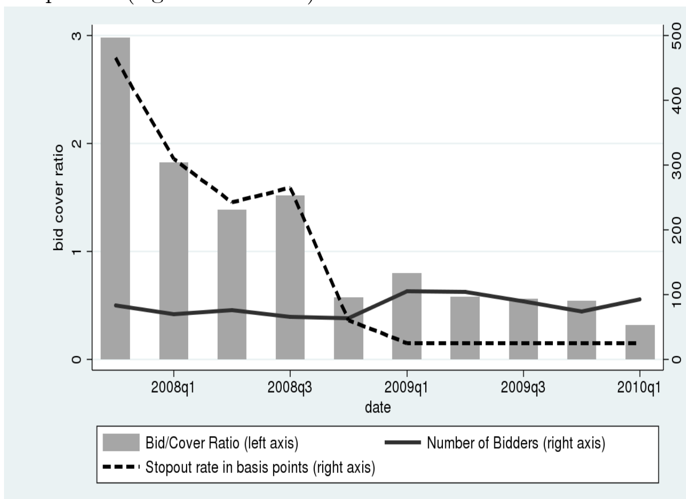
2.3 Eligibility for DW and TAF

The TAF was a liquidity facility with virtually the same eligibility and collateral criteria as the primary DW. Therefore, both liquidity facilities could be accessed by the same DIs that were in sound financial condition, including branches and agencies of foreign banks. These branches had to meet the same soundness criteria as U.S. commercial banks.[11]

[11] Foreign banks were active users of the TAF. Benmelech (2012) argues that many of these foreign banks issued liabilities in U.S. money markets that were denominated in dollars. Thus, foreign banks were subject to a roll-over risk and had to rely on special facilities such as the TAF.

Figure 3: Outcome of TAF auctions

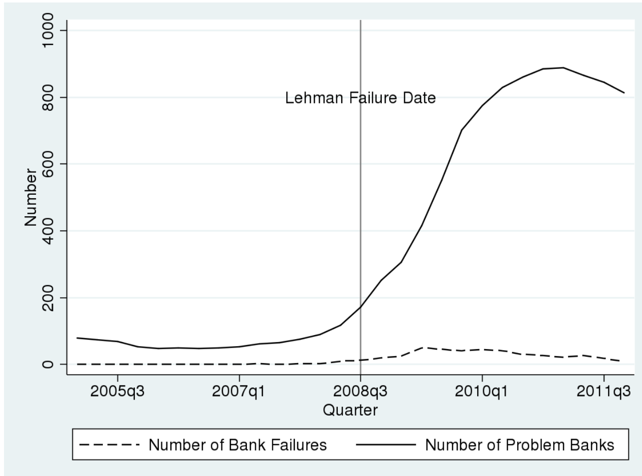
The average bid-to-cover ratio is computed as the ratio of total submitted bids to total offered TAF funds. The stop-out rate in excess of the minimum bid rate (dashed line) is the difference between the stop-out rate and the minimum accepted bid rate as set by the Fed. Number of bidders (solid line) is the average number of bidders in auctions held during a given quarter (right-hand scale).



Although available data on DW usage do not reveal whether borrowing banks were primary or not, we have some evidence that, prior to the failure of Lehman, most institutions that borrowed from the DW were considered as primary by the Fed. The amount of borrowing from the secondary window in the DW was significantly lower than from the primary window (about 100 times less, see Figures 2a and 2b), and these differences were especially significant in the pre-Lehman period. Also, in that period, the number of problem banks that could be considered as non-primary was very low (see Figure 4). Hence, it is reasonable to assume that most of the banks that borrowed from the DW in the pre-Lehman period were primary, and therefore, they had the ability to borrow from either the DW or the TAF.

Note that it could be argued that the access to TAF could be constrained by some size or scale effects. In particular, the minimum amount that could be borrowed ($10 million) may have been too high for some small institutions. However, we document that the smallest bank that borrowed from the TAF in the pre-Lehman period had $146 million in total average assets during 2008, and the 5th percentile was $244 million. This suggests that even relatively small banks were able to win some of the TAF auctions. Therefore, bank size does not seem to have been a constraint and almost all borrowing institutions had the scale to access the TAF if needed.

Figure 4: Number of bank failures and problem banks in the United States



2.4 Data

Data on DW usage were released following Freedom of Information Act requests by Bloomberg News and Fox Business Network on March 31, 2011. They include the user's name, Federal Reserve District, amount obtained, origination date and maturity date. The Fed made public the information on banks that borrowed TAF loans on December 1, 2010 as mandated by the Dodd-Frank Act. Data are available from December 12, 2007 to March 8, 2010 (i.e., the lifespan of the program) and include the auction date, the borrower's name and location, the interest rate and the type of collateral used, among other variables.

This dataset covers all borrowing institutions, including U.S. depository institutions, U.S. chartered, subsidiary banks (FSUBs), and U.S. branches and agencies of foreign banks (FBAs). Because of the unavailability of bank-level data, the latter were dropped from our sample. In the pre-Lehman period, FBAs borrowed heavily from the TAF, as did other types of institutions, despite the fact that they were also eligible to borrow from the primary DW facility. Interestingly, borrowing in the TAF by foreign institutions was not the highest at the height of the crisis. It was the highest in May and June 2008, months before the collapse of Lehman, and borrowing decreased relative to domestic banks during the collapse of Lehman, when the TAF premium over the DW rate was the highest.[12]

[12] Unlike U.S. depository institutions and other FSUBs, FBAs are integral parts of their parent banks. They are not required to meet specific risk-based capital standards, but in turn, are not permitted to accept domestic retail deposits. Therefore, they are not covered by the Federal Deposit Insurance Corporation (FDIC) and are not required

Call Reports provide quarterly financial data for all member banks. We combine this database with the DW and TAF databases using the key attributes (name and Fed region) of all financial institutions that borrowed from the DW and TAF, and manually match these attributes with those available in the Call Reports to identify the certificate number of each bank. We could match with very high certainty over 95% of the names, and discarded institutions that had an ambiguous name.

Following Acharya and Mora (2015), we use Call Reports to calculate implicit rates for funding cost by type of instrument, i.e., we divide quarterly interest expenses by the quarterly average of the respective instrument and express it in basis points. As in Acharya and Mora (2015), we eliminate outliers which are less than 0.5% of the sample size.

We use a single macro index ("State Coincident Index") from the Federal Reserve Bank of Philadelphia to summarize the macroeconomic conditions of each state where banks are located. For multi-state banks, we combine branch-level data from the Summary of Deposits (SOD) database from the FDIC to calculate the average exposure of multi-state banks to state macro conditions.

3 A Simple Model

Banks have access to a two-period investment project that requires an investment normalized to \$1 and pays either R or zero at the end of the second period. Banks can be classified as "good" or "bad". Good banks realize the positive payoff with certainty, while bad banks obtain R only with probability $1 - \theta$. A bank's type is private information for each bank and denote the ex-ante probability of a bank being good as α. The project is financed through two consecutive periods of short-term borrowing. In the second period, we assume that markets are frictionless and that banks can borrow from a competitive financial market at the fair market rate, given the market's belief about their type. In the first period we assume that banks face a distressed market and are potentially in need of a central bank facility to refinance the project. Specifically, we assume that the bank does not have access to market funding sources should a refinancing need arise.[13]

We model two possible refinancing needs reflecting the idea that banks can either be illiquid

to report bank-level financial information on a stand-alone basis (Goulding and Nolle, 2012).

[13] Our modeling approach can be seen as a simplification of Ennis and Weinberg (2013). They assume that banks need access to the liquidity facility when they do not find a matching partner in the OTC market.

owing to the general closure of the market for refinancing, which we refer to as a liquidity shock, or owing to the unwillingness of counterparties to extend financing because of concerns about the bank's asset quality, which we refer to as a run. Banks receive a liquidity shock with probability λ independent of their type, in which case they need to refinance their project.[14] We think of liquidity shocks as the inability of a bank to roll over its financing owing to adverse market conditions specific to its funding structure. Since banks know their funding structure and can observe market conditions, we assume for simplicity that banks knows at the beginning of the first period whether they will receive a liquidity shock or not.

The second possible reason for banks to need refinancing is based on adverse information about the bank's credit quality, which does not allow them to roll over very short-term funding, or causes a sudden withdrawal of callable interbank or retail deposits. We refer to the case of information-driven refinancing needs as a "run", and to simplify the exposition we assume that only bad banks that did not experience a liquidity shock can be subject to a run with probability ρ, while good banks will never experience a run. Runs occur in the middle of the first period (after the liquidity shock is revealed). Since runs can be based on informational cascades and rumours we assume for simplicity that the bad bank has no advance information about runs.

Consistent with the liquidity facilities provided by the Fed to commercial banks during the recent crisis, we assume that the central bank provides two funding facilities that banks can access to refinance their projects, the term auction facility (TAF) and the discount window (DW).[15] We capture two stylized facts about these facilities in our model: first, they offer funds at different rates – specifically, banks can borrow funds at rates r_T and r_D for the TAF and DW, respectively. Second, the TAF facility is less flexible than the DW. TAF funds cannot be accessed instantly; in the recent crisis the the Fed required three business days to transfer funds to successful bidders and TAF auctions were not held on a daily basis. We capture this institutional feature by assuming that TAF funds are only available at the beginning of the period.

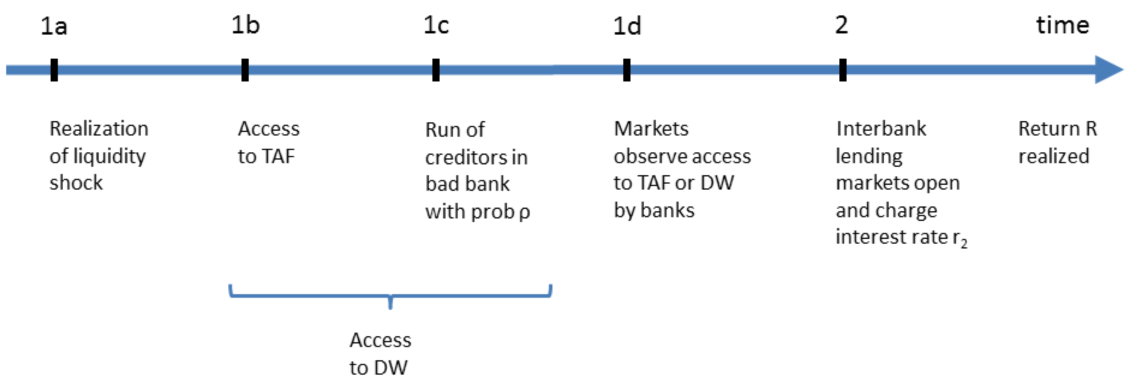
We assume the following timeline (see Figure 5). In period 1a, the bank observes whether it

[14] To simplify the exposition of the paper, we assume that the bank needs to refinance the whole project.

[15] Note that in this model we assume that all banks are qualified access both facilities. This is consistent with the facts observed previously about the low use of the secondary DW and the low number of troubled banks before the failure of Lehman (see Figures 2a, 2b and 4).

will receive a liquidity shock or not. In period 1b, the Fed offers access to TAF funding. Banks can also access the DW in that period. After banks decide whether to use the TAF/DW or not, bank runs are realized (period 1c). A bank experiencing a bank run that has not secured TAF or DW funding in period 1b is forced to refinance through the DW in period 1c. In period 1d, the market can observe whether a bank has accessed the TAF, the DW, or did not use a liquidity facility, and updates their belief about the bank's type based on that information. In period 2, markets are open and banks can borrow in the market at a rate that depends on their perceived type. At the end of period 2, the project return is realized, the bank repays its obligations if possible and closes. Note that after period 1a, there are four types of banks: good banks with or without a liquidity shock, and bad banks with or without a liquidity shock. In addition, in period 1c, the bad bank without a liquidity shock can experience a run (with probability ρ).

Figure 5: Timeline of the model



3.1 Separating equilibrium

We solve for the pure-strategy Perfect Bayesian Equilibrium (PBE) in this economy where actions of banks are a) choosing to use the DW, TAF (or none of them), and b) choosing the interest rate r_T if TAF is chosen. TAF rates are generated through an auction and therefore are endogenously set by the participant banks. We abstract from modelling this complex auction process, and examine which TAF interest rates r_T are consistent with the separating equilibrium. The DW interest rate, r_D, is in practice exogenously set by the Fed, so we take it as given.

We propose that banks use the TAF as a signalling device and, hence, conjecture a separating equilibrium in which: (i) banks that learn that they will be hit by a liquidity shock access the TAF, (ii) bad banks that experience a run access the DW, and (iii) banks that experience neither a run nor a liquidity shock do not access a liquidity facility. We solve the model by backward induction.

Banks that do not access the liquidity facility are either good banks that did not receive a liquidity shock or bad banks that received neither a liquidity shock nor a run. Denote by ξ_0 the probability that a bank is good, given that it has not accessed any facility, which is

$$\xi_0 = \frac{\alpha(1-\lambda)}{\alpha(1-\lambda)+(1-\alpha)(1-\rho)(1-\lambda)} = \frac{\alpha}{\alpha+(1-\alpha)(1-\rho)}. \tag{1}$$

Since both types of banks access the TAF upon receiving a liquidity shock, the market cannot learn from observing a bank accessing the TAF and thus sets the probability of being a good bank upon accessing TAF equal to the unconditional probability, $\xi_T = \alpha$. Since we assume that only bad banks are subject to runs, accessing the DW fully reveals the bank's type and thus $\xi_D = 0$. The market's belief in the bank being of the good type depends on the bank's actions as follows.

Lemma 1. *The market's belief that a bank is of the good type is highest for banks that do not access any liquidity facility and lowest for banks that access the discount window, i.e., $\xi_D \leq \xi_T \leq \xi_0$.*

The finding in Lemma 1 is consistent with the widely cited stigma effect that banks face when accessing the discount window. In the second period, the market will set the competitive interest rate to break even, given a belief ξ that the bank is good. Good banks always repay and bad banks default with probability θ. The interest rate r_2 for the second period will be set for investors to break even on average and thus solve the equation

$$1 = (1-\xi)(1-\theta)(1+r_2)+\xi(1+r_2), \tag{2}$$

or

$$r_2 = \frac{\theta(1-\xi)}{\theta\xi-\theta+1}, \tag{3}$$

where – because of the separating equilibrium – ξ is either zero, if the bank has accessed the DW, α in the case that the bank has accessed TAF, or ξ_0 if the bank did not access a liquidity facility.

The following lemma shows with detail the effect of the parameters on r_2 and ξ_0 (see the Appendix B for proofs of all theoretical results).

Lemma 2. *The second-period interest rate r_2 is increasing in the probability of default of the bad bank θ, and decreasing in the market's belief that the bank is good ξ. The second-period interest rate for banks that do not access a liquidity facility, $r_2(\xi_0)$, is decreasing in the fraction of good banks α, and the probability of a run, ρ. The market's belief of a bank being of the good type, given that it has not accessed any Fed funding, ξ_0, is increasing in α and ρ.*

Most comparative statics in Lemma 2 are intuitive. The set of banks that do not access a liquidity facility is composed of good banks without liquidity shocks and bad banks that have experienced neither a liquidity shock nor a run. The quality of this pool increases with the ex-ante number of good banks α and the probability of a run, ρ, as more runs reduce the number of bad banks in the pool. As the pool quality improves, the second-period interest rate decreases.

From Lemmas 1 and 2, we can rank the second-period interest rates as a function of the banks' first-period financing needs:

$$r_2(\xi_D = 0) = \frac{\theta}{1-\theta} \geq r_2(\xi_T = \alpha) \geq r_2(\xi_0) \geq r_2(\xi = 1) = 0. \tag{4}$$

Banks that access the DW are assessed as being in a worse financial condition by the market and pay higher financing rates in the second period. Nevertheless, the DW can be attractive for the bad bank due to its flexibility. If the bad bank has no liquidity shock, it can speculate that it will not experience a run, pool with the good banks that do not need to access funding from the Fed, and thus receive a favourable interest rate in the second period as $r_2(\xi_0)$. In the case of a run, the bad bank's type is revealed, and it has to pay a higher second-period rate. If the probability of a run is not too high, the opportunity to pool with the good banks in the absence of a run can create enough value for the bad bank to prefer the flexible DW over the more rigid TAF. The flexibility of the DW is of little value for the good bank as it is not subject to runs. The institutional design differences of the two liquidity facilities are thus key to the existence of the separating equilibrium.

The good bank's profit function is then as follows: if it experiences a liquidity shock, then it will access the TAF at cost r_T, it will be revealed to the market that it is a good bank with probability $\xi_T = \alpha$, and the funding cost for the second period is $r_2(\alpha)$. Therefore, the good bank that receives a liquidity shock obtains a profit of

$$\pi_{g,l} = R - (r_T + r_2(\alpha)). \tag{5}$$

If the good bank is not hit by a liquidity shock, then it does not need any funding in the first period but needs access to funding at $r_2(\xi_0)$ in the second period. The profit of the good bank without a liquidity shock is then

$$\pi_{g,n} = R - r_2(\xi_0). \tag{6}$$

The bad bank, which will realize the payoff of R only with probability $(1 - \theta)$, can also learn that it will realize a liquidity shock, in which case it would access the TAF and face the same funding costs as the good bank.

$$\pi_{b,l} = (1 - \theta)(R - (r_T + r_2(\alpha))). \tag{7}$$

Otherwise, it can experience a run, in which case it has to access the DW at cost r_D and is identified as a bad bank, resulting in a funding cost of $r_2(0)$ in the second period. Or it can have no run, in which case it will pay $r_2(\xi_0)$ in the second period. Its expected profit is then

$$\pi_{b,n} = (1 - \theta)(R - \rho(r_D + r_2(0)) - (1 - \rho)r_2(\xi_0)). \tag{8}$$

We propose the following separating equilibrium.

Separating Equilibrium. *In the separating equilibrium, the good bank with a liquidity shock, and the bad bank with a liquidity shock go to the TAF and set a rate r_T. Also, the bad bank without a liquidity shock goes to the DW if it does experience a run. Finally, the good bank without a liquidity* *shock and the bad bank without a liquidity shock and without a run do not use any liquidity facility.*

3.2 Characterization of separating equilibrium

For this equilibrium to be stable, both types of banks must not have an incentive to deviate from the conjectured strategies. First, neither the good nor the bad bank should find it profitable to access the DW rather than the TAF when receiving a liquidity shock. By accessing the DW instead of the TAF, banks could profit from lower funding costs if $r_D < r_T$, but suffer from being identified as bad banks by the market and thus pay a higher interest rate in the second period. The corresponding conditions are

$$R - (r_T + r_2(\alpha)) \geq R - (r_D + r_2(0)) \Leftrightarrow \tag{9}$$

$$r_D + r_2(0) - r_2(\alpha) \geq r_T \tag{10}$$

for the good bank and

$$(1-\theta)(R - (r_T + r_2(\alpha))) \geq (1-\theta)(R - (r_D + r_2(0))), \tag{11}$$

which is identical for the bad bank.

Second, if the good bank does not receive a liquidity shock, it could still access the TAF and invest the proceeds in a riskless storage technology, for which we assume a normalized return of zero. The corresponding incentive compatibility constraint is

$$R - r_2(\xi_0) \geq R - (r_T + r_2(\alpha)) \Leftrightarrow \tag{12}$$

$$r_2(\xi_0) - r_2(\alpha) \leq r_T. \tag{13}$$

Third, the bad bank could access the TAF even if it has had no liquidity shock and store the proceeds. The bank could then avoid accessing the DW and avoid being identified as a bad bank if there is a run. The corresponding incentive compatibility constraint is

$$(1-\theta)(R-\rho(r_D+r_2(0))-(1-\rho)r_2(\xi_0)) \geq (1-\theta)(R-(r_T+r_2(\alpha))) \Leftrightarrow \tag{14}$$

$$\rho r_D+\rho r_2(0)+(1-\rho)r_2(\xi_0)-r_2(\alpha) \leq r_T. \tag{15}$$

Note that equations (10) and (11) are identical, so we can discard one of them. Also, because we assume that $r_D \geq 0$ and $r_T \geq 0$, and $r_2(0) \geq r_2(\alpha) \geq r_2(\xi_0)$, equation (13) can be discarded. Therefore, a separating equilibrium is defined by (10) and (15), which leads to Proposition 1.

Proposition 1. *The separating equilibrium is fully characterized by equations (10) and (15).*

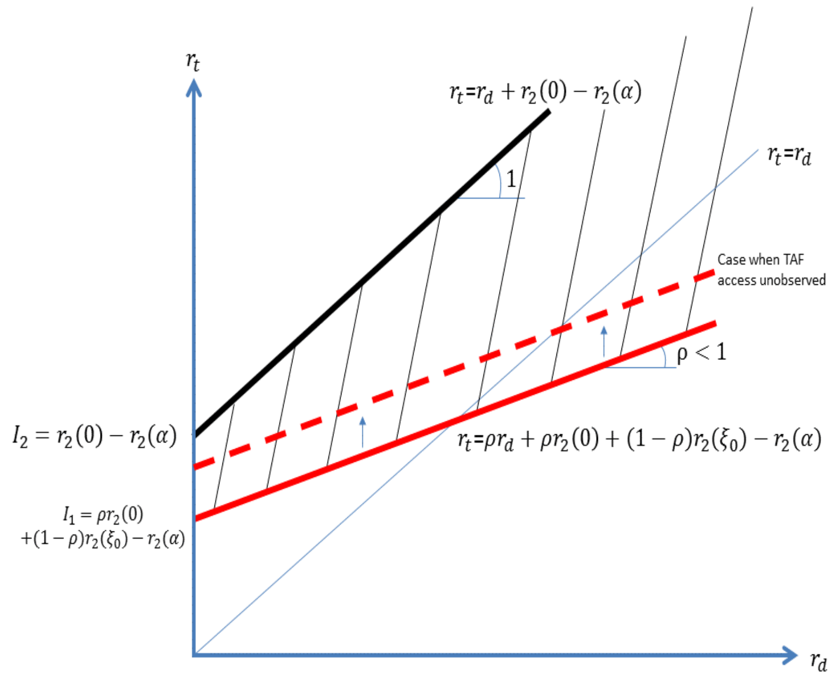
The interest rates for the liquidity facilities r_D and r_T that support the separating equilibrium are illustrated in the striped region between the solid red and black lines in Figure 6. In the equilibrium region we have that $r_T > r_D$ as long as r_D is small enough (which is a reasonable assumption during the recent financial crisis). Because $\rho \leq 1$ and $r_2(0) \geq r_2(\xi_0)$ from equation (4), it is easy to show that the line corresponding to constraint (10) is above that of constraint (15), thus opening up the equilibrium region between them.

We can observe that the equilibrium TAF rate r_T exceeds the exogenous DW rate as long as the latter is not too high, which is consistent with the DW rates set by the Fed during the recent financial crisis. Banks are willing to pay a premium to access the TAF rather than the discount window because of the associated signalling benefits.

For given exogenous DW rate, there is a multiplicity separating equilibria, i.e. there are many TAF rates, r_T, that are consistent with the equilibrium. We can easily use standard refinements used in signalling games that impose restrictions in out-of-equilibrium beliefs such as the "intuitive criterion" from Cho and Kreps (1987). Using this criterion, the separating equilibrium would be unique and characterized by Eq. (15) (the red line in Figure 6).

The equilibrium has some interesting properties. It is straightforward to show that the equilibrium region is shrinking in the probability of an information-driven run ρ such that it collapses to a single line when $\rho = 1$. As the bad banks are more likely to be caught in the market through a run, the opportunity of pooling with the good banks that have no liquidity shock and enjoying a

Figure 6: Separating equilibrium (r_T) for given discount window rate (r_D)



low second-period rate vanishes, which makes the DW less attractive. The rate differential between r_T and r_D then merely mirrors the rate differential of TAF and DW banks for the second period. Also, in this case, the two incentive constraints (10) and (15) are satisfied with equality. Additional properties of the equilibrium are shown in the Appendix.

3.3 Extension: Demand for opacity

We extend the model to consider an alternative explanation for the use of the TAF. As we discussed previously, the design of the TAF was motivated by the desire to reduce the stigma associated with the DW. While a bank's borrowings from the DW could be sometimes inferred from public data, this inference problem was purposefully made more difficult in TAF. Banks were forced to collectively bid for funds at pre-specified times, and a reduced number of banks would obtain funds in any given auction, making it much harder for markets to identify a single recipient. Also, in 2007 there was little expectation that TAF borrowings would be made public under Freedom of Information Requests. Therefore, the relatively higher opacity of TAF suggests that there could be an alternative explanation to the use of the TAF as a signalling instrument for good banks.

The institutional features of TAF and the Fed discussions suggest that the higher demand for TAF could have reflected not so much the desire of banks to pay a costly signal to demonstrate solvency, but the demand for higher opacity during a financial crisis. A collective periodic auction such as TAF makes it harder to identify a specific bank and it also removes the discretion from the timing, adding to opacity and limiting the potential for runs. The willingness for opacity in the financial industry has been broadly discussed in the literature. Gorton (2013) uses historical data to argue that bank opacity is an optimum equilibrium outcome in the U.S. banking industry, and that some of the recent financial innovations in the money markets may be designed to satisfy this demand for opacity. Dang *et al.* (2013) and Dang *et al.* (2017) provide other theoretical explanations for the desire of financial institutions to reduce transparency in the financial industry.

The model presented in the previous section is extended by assuming that access to the TAF is not observed and therefore banks that access the TAF are indistinguishable from banks that do not access any facility. As before, we abstract from modelling the complex TAF auction process, and examine which TAF interest rates (r_T) are consistent with a separating equilibrium.

We propose that banks use the DW as a signalling device and conjecture a separating equilibrium in which: (i) banks that learn that they will be hit by a liquidity shock access the TAF, (ii) bad banks that experience a run access the DW, and (iii) banks that experience neither a run nor a liquidity shock do not access a liquidity facility. Note that this is the same separating equilibrium as in the original model. Contrary to the previous model, we denote by ξ_{0T} the probability that a bank is good, given that it has not accessed the DW (therefore it has accessed TAF or no facility at all), which is equal to

$$\begin{aligned}\xi_{0T} &= \frac{\alpha(1-\lambda)+\lambda\alpha}{\alpha(1-\lambda)+(1-\alpha)(1-\rho)(1-\lambda)+\lambda(\alpha+1-\alpha)} = \frac{\alpha}{\alpha+(1-\alpha)(1-\rho)+\lambda} \\ &= \frac{\alpha}{\alpha+(1-\alpha)(1-(1-\lambda)\rho)} \leq \xi_0. \end{aligned} \tag{16}$$

Also, it can be easily shown that

$$\xi_D = 0 \leq \xi_T = \alpha \leq \xi_{0T} \leq \xi_0. \tag{17}$$

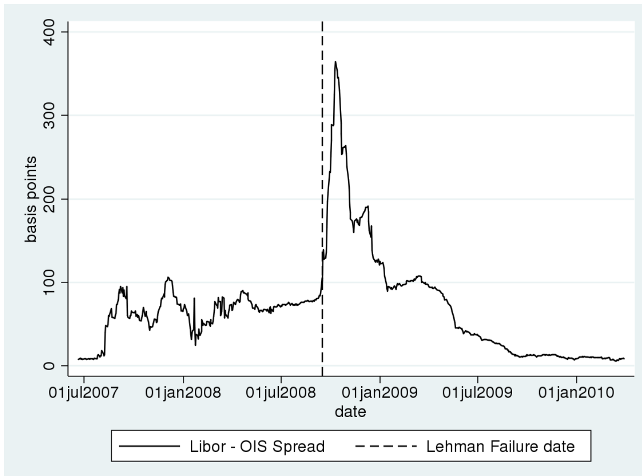
Note that $\xi_{0T} \leq \xi_0$, where ξ_0 is the probability that a bank is good in the baseline model. An implication of Eq. (17) is that $r_2(\xi_D = 0) \geq r_2(\xi_T = \alpha) \geq r_2(\xi_{0T}) \geq r_2(\xi_0)$. Since markets cannot differentiate between banks that access the TAF or no facility, we have that $r_2(\xi_T = \alpha) \geq r_2(\xi_{0T})$. We can obtain conditions that are necessary for this separating equilibrum to exist. Appendix provides details of these conditions. When access to TAF is opaque, we still obtain an equilibrium region such that $r_T > r_D$ as long as r_D is small enough. Therefore, the equilibrium implications when TAF is opaque are similar to the case when TAF can be observed. The equilibrium region is located in between the black and dashed red line in Figure 6. Note that when access to TAF is opaque, the equilibrium region is smaller compared to the region obtained in the original model, and the TAF rate necessary to sustain this equilibrium is higher than when we consider that access to TAF is not opaque. Since markets cannot differentiate between TAF and the rest of the banks that do not access the DW, it is the case that $r_2(\xi_T = \alpha) \geq r_2(\xi_{0T})$ and the TAF rate must be even higher than in the original model for the equilibrium to exist.

4 Main Empirical Results

4.1 Access and rates in the DW and TAF

The theoretical model considers two periods, with the first being one of heightened uncertainty and high financial stress. To provide empirical evidence of the model's predictions, we consider 2007 as the first period (pre-Lehman period). The second period is assumed to be the year 2010 (post-Lehman period), when turbulence scaled down significantly, and markets reacted to the observed access of banks to the different facilities in the first period. This temporal division can be seen in Figure 7, which shows the LIBOR-OIS spread in the 2007-2010 period. The figure illustrates first a progressive increase, and then an abrupt increase of the LIBOR-OIS spread around the failure of Lehman and, subsequently, a progressive decrease of the spread in 2009 and 2010. This spread has been widely used as an indicator of financial stress in the interbank lending markets during the recent crisis (Taylor and Williams, 2009; Sengupta and Tam, 2008).

Figure 7: LIBOR-OIS Spread



The model makes predictions about the banks that access the DW or the TAF. Table A.1 in the appendix reports descriptive statistics on banks' usage of the DW and TAF facilities before and after the collapse of Lehman. Banks that raised more than 95% of their Fed funds from the DW (as a percentage of total funds from TAF+DW) are called "DW main banks". Similarly, "TAF main banks" obtained more than 95% of their Fed funds from the TAF (as a percentage of total funds from TAF+DW). We observe some banks that accessed both the DW and TAF but do not fall in neither of the two previous categories and are called "BOTH banks". Finally, banks that do not fall in any of the previous categories are classified as "Rest". These are banks that did not use these facilities at all in the pre-Lehman period. Table 1 shows the number of banks that fall in each category. A relatively small number of banks accessed these facilities. The great majority of U.S. commercial banks are classified as "Rest".

4.1.1 Characteristics of banks accessing liquidity facilities

The model predicts that, in a separating equilibrium, banks access liquidity facilities depending on their level of liquidity and solvency in the pre-Lehman period. Table C.1 in the appendix shows statistics for key balance-sheet variables in 2007 for banks that mainly used the DW and the TAF, as well as for banks that used both facilities and the rest of the banks in this period. Variable

Table 1: Banks that accessed DW and TAF before Lehman and failed after Lehman

This table shows statistics about bank failures after the failure of Lehman Brothers and access to TAF and DW before the failure of Lehman Brothers. DW main= Indicator variable equal to 1 if bank was DW mainly in the pre-Lehman period. TAF main= Indicator variable equal to 1 if bank was TAF mainly in the pre-Lehman period. Both= Indicator variable equal to 1 if bank used both the DW and TAF in the pre-Lehman period (but it was not classified as DW main or TAF main). Rest= Rest of the banks that do not enter in any of the previous categories.

	Total number banks	Banks that fail	% fail
DW main	382	50	13.1%
TAF main	46	3	6.5%
Both	37	6	14.0%
Rest (no access)	9,183	367	4.0%

definitions are provided in the Appendix C.1. In the right side of the table, we test for differences in means of key balance-sheet variables for every type of bank. The t-statistics show that the rest of the banks have a much larger level of liquidity than DW or TAF banks. This is consistent with the idea in our model that if a bank does not have a liquidity shock, it will not use the DW or TAF.

Also, the model predicts which banks access liquidity facilities, depending on the level of solvency. The separating equilibrium implies that if a bank uses the DW, it is necessarily a bad bank. In contrast, the usage of the TAF or the lack of use of any liquidity facility does not have a clear implication in terms of the low solvency of the bank. Related to this prediction, we find that DW banks have lower Tier 1 capital ratios than TAF banks or the rest of the banks. We also find that DW banks tend to have lower return on assets (ROA) or return on equity (ROE), and higher ROA volatility than TAF banks. DW banks have also a lower z-score than TAF banks (marginally significant).

Table 1 documents that a great majority of the banks that failed after the collapse of Lehman accessed the DW rather than the TAF before the Lehman's collapse. Following Figure 4, most of these defaults happened after late 2009. Only 3 banks that accessed the TAF failed in the post-Lehman period, whereas 50 banks that accessed the DW failed in the post-Lehman period. In relative terms, a larger proportion of DW main banks or BOTH banks failed in the post-Lehman period. (13.1% for DW main banks, 14.0% for BOTH banks, 6.5% for TAF banks). When we consider the rest of the banks, the proportion that failed in the post-Lehman was significantly lower than the other three categories considered (4.0%).[16]

All these results suggest that banks that mainly used the DW were less solvent than TAF main banks and the rest of the banks. The differences in Tier 1 capital ratios, ROA volatility and failure rates also suggest BOTH banks are less solvent than TAF banks and therefore could be considered in the same group as the DW main banks. In our model, banks that access the DW have experienced a run because it is the most flexible facility. Therefore, banks that access both facilities could be identified as insolvent by the market.

4.1.2 TAF and DW rates

Another prediction of the model for the signalling period is a relationship between TAF and DW rates such that $r_T > r_D$ (see Proposition 2). In Figure 1, we compare TAF stop-out rates and DW rates. TAF rates are consistently higher than DW rates in the months before the failure of Lehman (with a peak difference of 150 basis points in the auction of September 22, 2008). Moreover, the term of TAF loans does not seem to play an important role in determining rates, since we do not observe a differential effect across the 28-day and 84-day terms. It cannot be that banks overbid in the TAF auction just to secure an allocation of funds. Banks had an outside option with an unlimited supply of funds (DW), so if a bank was in need of cash it could still go to the DW after being unsuccessful in the TAF auction and secure funds at a lower rate. Banks needed to have an important reason to overpay in the TAF auction, which we believe is signalling. After the failure of Lehman, the relationship between DW and TAF rates is just reversed, with rates being approximately flat for about one year (TAF rates stabilized at 25 basis points and the DW rate was equal to 50 basis points).

These empirical facts have already been studied with more detail than in our paper by Armantier *et al.* (2015) for the year 2008. These authors had access to the confidential bids submitted by the TAF participants and not only the stop-out rate. The bids submitted by participants were accepted in descending order of rates until the amount of funds supplied by the Fed was exhausted (which

[16] FBAs borrowed heavily from the TAF, as did other types of institutions, despite the fact that they were also eligible to borrow from the primary DW facility. These FBAs were typically very large multinational banks that were in general considered to be solvent, and none of them failed. Therefore, their behaviour is also consistent with the predictions of our model.

determines the stop-out rate). Note that our simple theory model abstracts from any complex auction bidding behaviour and only considers a unique equilibrium rate, r_T, that is generated in the TAF auction (the stop-out rate) and is consistent with the separating equilibrium. Since the bids submitted by TAF participants represent participants' willingness to pay for the TAF funds, and therefore represent the willingness to separate from the DW, not observing the TAF bids raises concerns about how the bidding behaviour of TAF participants is described by our model. However, we believe that the empirical facts support our model. First, TAF participants that won the TAF auctions had to bid more than the stop-out rate. Second, Armantier *et al.* (2015) show that the percentage of bids that were above the DW rate was increasing as the auction date was getting close to the failure of Lehman. In addition, in the two months before the failure of Lehman, more than 80% of the bids were above the DW rate, and in the first auction after the failure of Lehman (when the TAF premium with respect to the DW was the highest), this percentage was close to 100%. Therefore, most banks that bid in the TAF auction and did not win, were willing to bid above the DW rate. Hence, most bids submitted by banks that participated in the TAF were well above the DW rate.

Another possible concern is the role played by the FBAs in determining TAF rates, since they accounted for about 60% of the borrowing in the TAF in the pre-Lehman period. As outlined above, because FBAs were also eligible for the DW, they also took into account the stigma effect of the DW, as did other institutions. Also, the stop-out rate in the TAF auctions could be the result of the bids by the FBAs, and not those by the rest of the U.S. banks. However, the U.S. banks that won the auction had to bid above the stop-out rate and most banks submitted a bid above the DW rate. Another argument is the fact that borrowing in the TAF by foreign institutions was specially high in April, May and June 2008, months before the collapse of Lehman, and it decreased in August and September, when the TAF premium over the DW rate was the highest. For all these reasons, we believe that the role played by FBAs in determining the high observed TAF rates was limited, specially during the period immediately before the failure of Lehman (see Figure 1).

4.2 Funding cost

We next show empirical evidence that is consistent with the model's key predictions for the second period. In the first set of results, we provide evidence that banks' future funding costs are correlated with their decisions to borrow from the DW or TAF in the first period. The model assumes that the funding cost of a bank in the second period reflects market perceptions of its riskiness, based on its actions in the first period (the "signalling effect"), and is not simply determined by the rate paid to access the liquidity facilities from the Fed, which are just other sources of funding for banks. These perceptions are based on the assumption that markets are able to identify banks that have access to these facilities, even if this is usually confidential information. In our paper we assume that, in practice, markets are able to identify these banks owing to the interconnected nature of financial markets and the existence of informal information flows such as rumours regarding the identity of these banks. This is also the standard assumption in the literature.[17]

To identify this effect, we build a panel data set with quarterly bank-level information for the years 2007 and 2010. Since the amount borrowed from the TAF and DW could affect the overall funding costs of banks if it represents a large share of their liabilities, we consider the year 2010, when access to the DW and TAF was significantly reduced compared with previous years (Figure 2a). In practice, this is not problematic because the share of DW and TAF loans in banks' total liabilities was very small for all years, and for 2010 in particular.

4.2.1 Baseline evidence

For our empirical analysis we examine banks' funding costs and their funding sources. We control for their key variables, including bank-specific variables and macroeconomic indicators. All variables are defined in Appendix C.1.

[17] Courtois and Ennis (2010) argue that, because of the interconnected bilateral nature of the interbank lending market, it would not be hard for other banks to infer the identity of institutions that borrow from the DW. Furfine (2005) finds evidence on DW stigma using data from before the recent crisis.

We consider the following econometric model:

$$\begin{aligned}\text{FundingCost}_{i,t} &= \alpha_{TAF} TAF_{i,pre} \times Post_t + \alpha_{DW} DW_{i,pre} \times Post_t \\ &\quad + \alpha_T TAF_{i,pre} + \alpha_D DW_{i,pre} + \alpha_O Post_t + \alpha_X X_{i,t} + c_t + \mu_i + \varepsilon_{i,t}, \qquad (18)\end{aligned}$$

where $\text{FundingCost}_{i,t}$ is the cost of funding (implicit rate) reported by bank i in quarter t, $X_{i,t}$ are bank-specific variables, c_t are quarterly fixed effects and μ_i are bank fixed effects. We use the year 2010 as the post-Lehman period, and the year 2007 as the pre-Lehman period. $TAF_{i,pre}$ ($DW_{i,pre}$) is an indicator variable equal to one if bank i mainly accessed the TAF (DW) in 2008. $Post_t$ is an indicator variable equal to one for the quarters corresponding to the post-Lehman period. To study the cost of funding, we use total interest expense as a percentage of total liabilities. We also show disaggregated results using the cost of funding for domestic deposits, transaction accounts, savings accounts, insured and uninsured time deposits, foreign deposits, interbank borrowing, subordinated debt and other types of borrowing. The coefficients corresponding to the interaction terms $TAF_{i,pre} \times Post_t$ and $DW_{i,pre} \times Post_t$ represent the change in funding cost for TAF and DW banks (compared to "OTHER" banks) in the post Lehman period, respectively. The coefficients α_{TAF} and α_{DW} are the main variables of interest.

In this analysis we assume all commercial banks are divided in three categories: Banks that mainly used the DW, banks that mainly used the TAF, and the rest of the banks (that includes BOTH and REST categories from Table 1). As we discussed before, BOTH banks could also be considered to be similar to DW main banks because they have a lower level of solvency than TAF banks. For robustness, we have repeated our econometric analysis by considering that DW main and BOTH banks are in the same category, and our main conclusions do not change.

The fixed-effects specification considered in Eq. (18) allows us to to control for possible omitted variable bias that could arise from the correlation between unobserved time-invariant bank fixed effects and our two main variables of interest. In the next sections, we extend the model to verify the robustness of our empirical results.

Table 2: Fixed effects regression for funding cost for years 2010 and 2007 (total and by type of funding source).

This table shows results of fixed-effects regressions of funding cost by type of funding source. We show the results of total interest expense (as a % of total liabilities) in (1); interest expense for domestic deposits (as % of domestic deposits) in (2); interest expense for transaction accounts (as % of transaction accounts) in (3); interest expense for savings accounts (as % of savings accounts) in (4); interest expense for time deposits of less than 100,000 USD (as %) in (5); interest expense for time deposits of more than 100,000 USD (as %) in (6); interest expense for foreign deposits (as %) in (7); interest expense for interbank borrowing (as % of interbank borrowing) in (8); interest expense for subordinated debt (as % of subordinated debt) in (9); and interest expense for other borrowing (as % of other borrowing) in (10). All regressions use quarterly data for banks in 2010 (post-Lehman period) and 2007 (pre-Lehman period). DW= Indicator variable equal to 1 if bank was DW mainly in the pre-Lehman period. TAF= Indicator variable equal to 1 if bank was TAF mainly in the pre-Lehman period. Post= Indicator variable equal to 1 for the post-Lehman period (2010), and equal to zero for 2007. Standard errors clustered at bank-level.

	Total	Domestic deposits					Foreign	Interbank	Subordin.	Other
	funding cost	All deposits	Transaction accounts	Saving accounts	Time depos. (<100)	Time depos. (>100)	deposits	borrowing	debt	borrowing
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$DW_{pre} \times Post$	-0.0308***	-0.0220***	-0.0185	-0.0151	0.0129	-0.0768***	-0.161	-0.0272	0.0465	-0.0265
	(0.00817)	(0.00800)	(0.0143)	(0.0131)	(0.0166)	(0.0218)	(0.0987)	(0.0378)	(0.158)	(0.0276)
$TAF_{pre} \times Post$	-0.101***	-0.0461	0.0186	-0.0249	-0.0220	-0.0902	-0.313*	-0.330***	0.0530	-0.142
	(0.0321)	(0.0382)	(0.0442)	(0.0461)	(0.0485)	(0.0736)	(0.158)	(0.118)	(0.183)	(0.106)
Post	-0.454***	-0.473***	-0.114***	-0.284***	-0.666***	-0.654***	-0.764***	-0.671***	0.230	-0.247***
	(0.00818)	(0.00863)	(0.00782)	(0.0116)	(0.0122)	(0.0129)	(0.214)	(0.0441)	(0.152)	(0.0306)
Asset (log)	0.0252***	0.0209**	0.0197***	-0.0476***	0.0661***	0.0519***	-0.0348	0.000194	0.218*	-0.0460*
	(0.00850)	(0.0100)	(0.00639)	(0.0110)	(0.0116)	(0.0143)	(0.118)	(0.0348)	(0.129)	(0.0259)
Other bank controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Quarterly fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	64,848	64,838	58,091	58,125	58,039	58,096	680	21,964	1,906	41,909
Number of banks	8,807	8,806	7,931	7,918	7,912	7,943	103	4,722	362	6,708
R squared	0.883	0.880	0.171	0.708	0.819	0.775	0.768	0.389	0.278	0.121
H_1 : Funding cost for DW banks in post Lehman period ($DW_{pre} \times Post$) $\leq$ Funding cost for TAF banks in post Lehman period ($TAF_{pre} \times Post$)										
10% significance	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT
5% significance	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A natural hypothesis to test from our theoretical model is

$$\text{Hypothesis 1 } (H_1, \text{ Funding Cost}): \alpha_{DW} \leq \alpha_{TAF}. \tag{19}$$

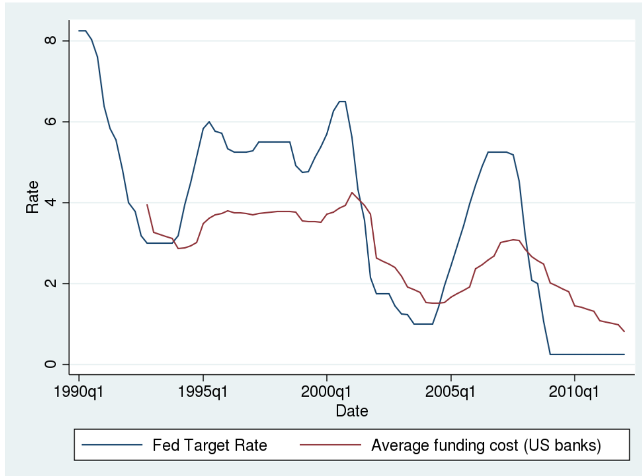
Hypothesis 1 is based on the empirical implications of the theoretical model presented in the previous section, more precisely Lemma 1 and Eq. 4. If we reject Hypothesis 1, then we find empirical evidence that banks that access the DW in the pre-Lehman period have a higher funding cost (in the post-Lehman period) than banks that access the TAF. We can test Hypothesis 1 by considering the total funding costs, or different types of funding used by every bank.

The estimated parameters of the fixed-effects regression for the funding cost of model (18) are presented in Table 2. We have omitted most bank variable controls for space considerations. Most coefficients of interest are negative, which implies that all banks experienced a significant drop in their 2010 overall funding costs relative to 2007, reflecting the environment of low nominal interest rates that prevailed during this period (see Figure 8). Consistent with the prediction of the model, total funding costs of TAF banks decreased more than DW banks (about 10 basis points for TAF banks and 3 basis points for DW banks). The tests of significance shows that these differences are statistically significant at the 5% level.

We also look closely at the different sources of funding. We find a significant and economically large effect on interbank borrowing. TAF banks paid lower funding costs for interbank borrowing compared with DW banks (a difference of $33 - 2 = 31$ basis points). Intuitively, lenders and borrowers in the interbank lending market collect more information regarding their counterparties than in other types of funding (e.g. deposits) and therefore, their rates paid are more likely to be affected by the perceived quality of their counterparties.

We also find a difference between DW and TAF banks when considering Foreign Deposits, which are deposits that are usually corresponding to more sophisticated and informed lenders than the domestic deposits. The difference has a lower level of statistical significance than the case of interbank borrowing (a difference of $31 - 16 = 15$ basis points). When considering other sources of funding, such as individual deposits, we do not find significant differences. We expect to observe a small effect for domestic deposits, since the deposit insurance limit was increased to \$250,000

Figure 8: Fed target rate vs. average funding cost for U.S. banks



per beneficiary in the middle of our sample.[18] For robustness, we have repeated this analysis by considering only TAF and DW banks, and we find similar results as DW banks tend to have higher funding cost in the post-Lehman period than TAF banks.

Compared with DW banks, this lower funding cost for TAF banks found in the regressions translates into annual savings of \$122.4 million when considering interbank borrowing, and \$1,323 million when considering the funding costs for total liabilities. Interestingly, these savings are much larger than the additional funding costs (compared with DW banks) of \$172.6 million paid by TAF banks at the auction of September 22, 2008. This result suggests that, overall, TAF banks were obtaining a profit from using the TAF, despite the initial larger cost paid at the height of the crisis, as shown by our model.

Our results also show that the "OTHER" banks tend to have larger funding costs in the post-Lehman period compared to DW and TAF banks. The difference is especially larger when considering interbank borrowing. We can attribute this result to the much smaller size of the "OTHER" banks and the special characteristics of the interbank borrowing market and its tiered structure. Mainly due to the presence of scale economies, the interbank borrowing market has a multi-tiered structure in which small banks are net lenders to medium sized banks, and medium-sized banks, in turn, are net lenders on average to large banks (Furfine, 1999a; Beck and Atalay, 2008; Pritsker,

[18] From October 14, 2008 until December 2012, the FDIC increased the deposit insurance from \$100,000 to \$250,000. Unfortunately, the Call Reports do not show deposits of less than \$250,000 for the years before 2009. Therefore, we cannot use the new deposit insurance limit in our difference-in-difference regressions that use 2007 and 2010.

2013). As a result, small institutions tend to pay higher rates[19] so the exogenous structure of the interbank borrowing market is driving the result for the "OTHER" banks.

4.2.2 Intensity of access to DW and TAF

The previous results assume that the effect on funding costs for banks that use the DW or TAF is independent of the total amount borrowed. This is a simplistic view of the behaviour of banks. We would expect that the more aggressive the banks are using these two liquidity facilities, the larger the effect on the funding cost. Since signalling is costly for TAF banks because they have to pay more than DW banks, funding markets should take this into account and react differently to banks that are more aggressive in using these facilities.

Actually, there is some anecdotal evidence that some banks used the TAF marginally without having a real need for it. For instance, in August 2007, Citigroup, Bank of America, JPMorgan Chase and Wachovia each borrowed $500 million from the DW, which is an insignificant amount compared with their size. In a joint statement, JPMorgan, Bank of America and Wachovia alleged that they were using the discount window in an effort to *"encourage its use by other financial institutions."*[20] According to Jerry Dubrowski, a spokesman for Bank of America *"we participated at the request of the Federal Reserve to help stabilize the global banking system in a period of unprecedented stress [...] At the time we were participating, we weren't experiencing liquidity issues."*[21] This anecdotal evidence shows that some banks may have used some Fed liquidity facilities for reasons that did not have anything to do with their financial situation. Hence, we would expect that banks that had a real need to use these two facilities would be much more aggressive in using them.

To verify this effect, we modify model (18) by considering the intensity of access to the TAF or

[19] Furfine (1999b) cites a difference of about 20 basis points when comparing institutions over $100 billion in assets with institutions with less than $250 million in assets.
[20] *"Big U.S. banks use discount window at Fed's behest"*, The New York Times, August 23, 2007.
[21] *"Bank of America Kept Tapping Fed Facility After 2007 Show of 'Leadership'"*, Bloomberg, March 31, 2011.

the DW. We estimate the following equation:

$$\begin{aligned}\text{FundingCost}_{i,t} = {} & \alpha_{TAF} AmtTAF_{i,pre} \times Post_t + \alpha_{DW} AmtDW_{i,pre} \times Post_t \\ & + \alpha_T AmtTAF_{i,pre} + \alpha_D AmtDW_{i,pre} + \alpha_O Post_t + \alpha_X X_{i,t} + c_t + \mu_i + \varepsilon_{i,t}, \qquad (20)\end{aligned}$$

where $AmtTAF_{i,pre}$ and $AmtDW_{i,pre}$ are defined as the log of the ratio of the total amounts borrowed in the TAF and DW as a percentage of total assets.

The results we find are consistent with our prior conjecture and are shown in Table 3. Banks that increased their borrowing from the TAF (as a fraction of their total assets) by 1% experience a decrease in the post-Lehman funding cost in the interbank borrowing markets of 16 basis points. The effect for the DW is about 4.2 basis points; therefore, the difference between both types of banks is about 11.8 basis points. When considering other types of funding, we do not find an effect in domestic deposits when comparing TAF and DW banks, We find an effect in foreign deposits and other types of borrowing. When considering total funding costs, the difference is economically small, and equal to about 3 basis points.

4.2.3 Interacting with bank riskiness pre-Lehman

The equilibrium in our model predicts that the only banks that use the DW are bad banks, therefore we should expect that banks that are in relatively poor condition tend to use more DW than TAF. We test this prediction by extending the model in (18) to study the specific effect on banks that were considered to take risks that were too high in the pre-Lehman period. In particular, we augment (18) by including an interaction term $HighRisk_i$ which is a dummy variable equal to 1 if bank i was in the lowest 6th sextile of the distribution of the Z-score ratio in 2007 (lower Z-score ratio implies higher riskyness of the bank). This interaction term is our main variable of interest. We can test a similar hypothesis as in (19) for these two variables.

Table 3: Regressions for funding cost for years 2010 and 2007 considering the intensity of access to DW and TAF.

This table shows results of fixed-effects regressions of funding cost by type of funding source, where we control for the intensity of use of the DW or TAF. We use the same regressors as in Table 2. AmountDW and AmountTAF is measured as the log of the total amount borrowed in every liquidity facility in the pre-Lehman period as % of total assets in 2007. Post= Indicator variable equal to one for the post-Lehman period (2010), and equal to zero for 2007. Standard errors clustered at bank-level.

	Total funding cost	Domestic deposits					Foreign deposits	Interbank borrowing	Subordin. debt	Other borrowing
		All deposits	Transaction accounts	Saving accounts	Time depos. (<100)	Time depos. (>100)				
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$AmtDW_{pre} \times Post$	-0.00981**	-0.00320	0.0117***	-0.0110	-0.0107	-0.00976	0.0190	-0.0423***	-0.0492	-0.0280***
	(0.00382)	(0.00361)	(0.00375)	(0.00688)	(0.00974)	(0.00845)	(0.0188)	(0.0152)	(0.0421)	(0.0109)
$AmtTAF_{pre} \times Post$	-0.0219	0.00695	0.00379	-0.0379	0.0105	-0.0147	-0.0651	-0.159***	0.0472	-0.0951**
	(0.0217)	(0.0154)	(0.00941)	(0.0241)	(0.0208)	(0.0278)	(0.0490)	(0.0440)	(0.0851)	(0.0389)
$Post$	-0.454***	-0.473***	-0.114***	-0.284***	-0.667***	-0.655***	-0.854***	-0.669***	0.242	-0.247***
	(0.00820)	(0.00865)	(0.00781)	(0.0116)	(0.0122)	(0.0130)	(0.213)	(0.0439)	(0.156)	(0.0305)
Asset (log)	0.0263***	0.0216**	0.0201***	-0.0477***	0.0660***	0.0541***	-0.0219	-0.000910	0.230*	-0.0444*
	(0.00851)	(0.0100)	(0.00642)	(0.0110)	(0.0116)	(0.0144)	(0.116)	(0.0347)	(0.131)	(0.0259)
Other bank controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Quarterly fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	64,848	64,838	58,091	58,125	58,039	58,096	680	21,964	1,906	41,909
Number of banks	8,807	8,806	7,931	7,918	7,912	7,943	103	4,722	362	6,708
R squared	0.883	0.880	0.171	0.708	0.819	0.774	0.764	0.389	0.282	0.122
H_1 : Funding cost for DW banks in post Lehman period ($DW_{pre} \times Post$) $\leq$ Funding cost for TAF banks in post Lehman period ($TAF_{pre} \times Post$)										
10% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	REJECT	ACCEPT	REJECT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	REJECT	ACCEPT	REJECT

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The hypothesis we want to test is

$$\text{Hypothesis 2 } (H_2, \text{ Funding Cost}): \tag{21}$$

$$\text{H2a: } \alpha_{TAF} \leq \alpha_{DW} \text{ (for smaller banks).}$$

$$\text{H2b: } \alpha_{TAF} \leq \alpha_{DW} \text{ (for riskier banks).}$$

$$\text{H2c: } \alpha_{TAF} \leq \alpha_{DW} \text{ (for less liquid banks).} \tag{22}$$

Table 4 shows the results of the estimates. We omit the estimates corresponding to bank controls and the variable *Post* to simplify the exposition of the results. We find that our previous result that rejects Hypothesis 1 for the case of interbank borrowing rates is confirmed for the case of high-risk banks. The difference between TAF and DW banks is $29.6 - 4.3 = 25.3$ basis points. Additionally, as we have shown in Table 1, a great majority of banks that failed in the post-Lehman period accessed the DW rather than the TAF before the failure of Lehman.

It could be argued that banks that used the DW were troubled banks that were forced to access the secondary window because they did not qualify for the primary window. However, as we have shown in Figure 2b and Figure 4, most DW banks were considered as primary before the failure of Lehman, and therefore should have been able to access the primary window if necessary. Gilbert *et al.* (2012) show that only a few banks that failed during the 2008-10 period borrowed from the Fed during their last year prior to failure, and only a few had outstanding Fed loans when they failed. They also show that the Fed did not provide significant credit to undercapitalized or critically undercapitalized banks. In summary, the majority of banks that borrowed from the Fed and failed used the DW. But this use occurred mainly at the beginning of the crisis, in the pre-Lehman period, when some of these banks were not yet perceived as risky. This suggests that the access to the DW by banks affected the perceptions of the markets about banks in financial stress, which could have led to their default in a later period.

Table 4: Regressions for funding cost for years 2010 and 2007 (total and by type of funding source), including interaction effects with banks of different types (as in 2007).

This table shows results of fixed-effects regressions of funding cost by type of funding source where we control for riskiness, size and liquidity of banks as measured in 2007. HighRisk=Indicator variable equal to 1 if the bank is in the highest sextile of the distribution of the ratio of risk-weighted assets over assets. LowL= Indicator variable equal to 1 if the bank is in the lowest sextile of the distribution of liquidity risk. Small= Indicator variable equal to 1 if the bank has less than 1 billion dollar in assets. Standard errors clustered at bank-level.

	Total	Domestic deposits					Foreign	Interbank	Subordin.	Other
	funding	All	Transaction	Saving	Time depos.	Time depos.	deposits	borrowing	debt	borrowing
	cost	deposits	accounts	accounts	(<100)	(>100)				
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$DW_{pre} \times Post$	-0.0426***	-0.0140	-0.0314	0.0310	0.0225	-0.164***	-0.169*	0.00116	0.203	-0.0564
	(0.0156)	(0.0135)	(0.0389)	(0.0269)	(0.0314)	(0.0576)	(0.0872)	(0.0666)	(0.241)	(0.0503)
$TAF_{pre} \times Post$	-0.101***	-0.0736*	0.117**	-0.0635	-0.0821	0.0477	-0.292***	-0.149	-0.0997	-0.0464
	(0.0242)	(0.0402)	(0.0540)	(0.0851)	(0.0581)	(0.0747)	(0.0991)	(0.129)	(0.179)	(0.204)
$DW_{pre} \times Post \times LowZScore$	-0.0197	-0.0318	0.00849	-0.0845*	0.0729	-0.0588	-0.00142	-0.0435	0.0163	0.0597
	(0.0259)	(0.0279)	(0.0350)	(0.0462)	(0.0607)	(0.0761)	(0.139)	(0.116)	(0.223)	(0.0647)
$TAF_{pre} \times Post \times LowZScore$	-0.0768*	-0.149	-0.201	-0.0391	0.286*	-0.551***	-0.163	-0.296	-0.327	-0.640**
	(0.0455)	(0.118)	(0.220)	(0.105)	(0.161)	(0.182)	(0.396)	(0.182)	(0.289)	(0.312)
$DW_{pre} \times Post \times LowL$	-0.0661***	-0.0954***	-0.0169	-0.126***	0.0752	-0.0567	0.152	0.0575	-0.725***	0.0411
	(0.0188)	(0.0181)	(0.0338)	(0.0401)	(0.0466)	(0.0791)	(0.173)	(0.0764)	(0.204)	(0.0577)
$TAF_{pre} \times Post \times LowL$	0.0299	-0.0108	-0.0682	0.145	0.0639	0.0833	0.542***	0.0688	0.858**	-0.0967
	(0.0504)	(0.0643)	(0.0707)	(0.0938)	(0.0874)	(0.169)	(0.0962)	(0.244)	(0.401)	(0.211)
$DW_{pre} \times Post \times Small$	0.0391**	0.0192	0.0230	-0.0332	-0.0454	0.135**		-0.0645	-0.0855	-0.0129
	(0.0169)	(0.0153)	(0.0390)	(0.0310)	(0.0364)	(0.0575)		(0.0723)	(0.305)	(0.0558)
$TAF_{pre} \times Post \times Small$	0.0328	0.129***	-0.177	0.00792	-0.0424	-0.293**		-0.472**		0.265
	(0.0524)	(0.0484)	(0.147)	(0.0876)	(0.0755)	(0.142)		(0.208)		(0.257)
Bank controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Quarterly fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	63,809	63,802	57,289	57,343	57,324	57,278	672	21,831	1,902	41,572
Number of banks	8,591	8,590	7,757	7,745	7,747	7,761	103	4,675	361	6,608
R squared	0.891	0.890	0.173	0.706	0.829	0.777	0.767	0.381	0.272	0.119
H_2 : Cost for DW banks in post-Lehman period ($DW_{pre} \times Post$) $\leq$ Cost for TAF banks in post-Lehman period ($TAF_{pre} \times Post$)										
10% significance	REJECT	REJECT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT
5% significance	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT
H_{2a} : Cost for small DW banks in post-Lehman period ($DW_{pre} \times Post \times Small$) $\leq$ Cost for small TAF banks in post-Lehman period ($TAF_{pre} \times Post \times Small$)										
10% significance	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT	REJECT	ACCEPT	REJECT	ACCEPT	ACCEPT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	REJECT	ACCEPT	ACCEPT
H_{2b} : Cost for high risk DW banks in post-Lehman period ($DW_{pre} \times Post \times HighRisk$) $\leq$ Cost for high risk TAF banks in post-Lehman period ($TAF_{pre} \times Post \times HighRisk$)										
10% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT
H_{2c} : Cost for low liq. DW banks in post-Lehman period ($DW_{pre} \times Post \times LowL$) $\leq$ Cost for low liq. TAF banks in post-Lehman period ($TAF_{pre} \times Post \times LowL$)										
10% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We also study how size interacts with the results found so far. We consider an interaction term $Small$, which corresponds to banks that have less than \$1 billion in assets. We would expect that these banks would be more interested in signalling, since their smaller size makes them more opaque. On the contrary, very large banks are considered by external markets as too-big-to-fail and their incentives for signalling are lower. The higher opacity is particularly relevant for the interbank borrowing market, which is motivated by the special characteristics of this market and its tiered structure, mainly due to the presence of scale economies. Therefore, smaller banks are very opaque in this market and are subject to more scrutiny by funding markets. Table 4 shows the results of the interaction effect of size, which suggests that smaller banks that access TAF have a lower funding cost than small banks that access the DW.

These results can be linked to the hypothesis that banks may have a high demand for opacity (Gorton, 2013) which was analyzed in an extension to the theoretical model previously presented. If access to the TAF is opaque, then the post-Lehman interest rate for TAF banks is smaller than the case of no opacity, $r_2(\xi_T = \alpha) \geq r_2(\xi_{0T})$. Therefore, since smaller banks are more opaque, second period rate must be smaller for these banks, which is consistent with our empirical results shown in Table 4.

4.3 Effect on funding structure

We next study the changes in the structure of funding by DW and TAF banks in the post-Lehman period. This analysis complements the results on the cost of funding obtained in previous sections, and helps us to better understand the effect of using these two liquidity facilities on the banks' liabilities. The use of wholesale funds can be a good indicator of markets' perceptions of a bank's financial soundness. A large literature that tries to explain the role of wholesale funds, and their increasing use during the last decades (Feldman and Schmidt, 2001), emphasizes that these funds are less stable than the traditional insured retail deposits, and therefore are considered to provide market discipline to banks (Calomiris, 1999). As shown by Calomiris and Kahn (1991), wholesale funding is provided by sophisticated financiers who discipline bad banks through monitoring and refinance solvent ones. Showing evidence of a relationship between banks' usage of wholesale funding in the second period, and their decision to borrow from the DW or TAF is a relevant empirical exercise that can provide some evidence of the "signalling effect" in our model.

In our stylized model we explored the perception of a bank's quality on funding costs. The markets belief about bank quality can also be reflected in quantities of funding sources. For example the huge literature on depositor discipline documents that bank quality affects its funding mix. In the context of our paper we would expect that TAF banks increase the use of certain types of funding that are more sensitive to the perceived quality of banks. We estimate a similar equation to (18) where we consider different sources of funding measured as a percentage of total liabilities:

$$\begin{aligned}\text{SourceFunding}_{i,t} &= \beta_{TAF} TAF_{i,pre} \times Post_t + \beta_{DW} DW_{i,pre} \times Post_t + \\ &+ \beta_T TAF_{i,pre} + \beta_D DW_{i,pre} + \beta_O Post_t + \beta_X X_{i,t} + c_t + \mu_i + \xi_{i,t}, \end{aligned} \tag{23}$$

where $\text{SourceFunding}_{i,t}$ is the percentage of a certain type of funding source over total liabilities. We use controls similar to model (18). Our variables of interest are β_{TAF} and β_{DW}. Our objective is to understand the types of funding that TAF banks tended to depend upon more in the post-Lehman period, compared to DW banks. Therefore, we want to focus on the sources of funding where we can reject the following hypothesis:

$$\text{Hypothesis 3 } (H_3, \text{ Sources of Funding}): \ \beta_{TAF} \leq \beta_{DW}. \tag{24}$$

Table 5 shows results of the estimates of model (23) for relative amounts of funding by type. We use the amount of wholesale funding (as a percentage of total liabilities), a narrower definition of wholesale funding, and we also use more specific sources of funding (domestic deposits, savings accounts, foreign deposits, interbank borrowing, subordinated debt other borrowing, etc).

In line with the prediction of our model that accessing the TAF signals quality, we find that TAF banks were able to attract more deposits than DW banks during the financial crisis, which is consistent with a large literature on depositor discipline (see e.g., Goldberg and Hudgins, 2002; Park and Peristiani, 1998; Oliveira *et al.*, 2015). Most of that increase comes from savings accounts.

Table 5: Fixed effects regression for sources of funding for years 2010 and 2007 (total and by type of funding source).

This table shows the results of fixed-effects regressions of different sources of funding (as a % of total liabilities) between 2010 and 2007. Wholesale funding in (1); wholesale funding (narrow definition) in (2); domestic deposits in (3); transaction accounts in (4); savings accounts in (5); time deposits of less than 100,000 USD in (6); time deposits of more than 100,000 USD in (7); foreign deposits in (8); interbank borrowing in (9); subordinated debt in (10); and other liabilities in (11). DW= Indicator variable equal to 1 if bank was DW mainly in the pre-Lehman period. TAF= Indicator variable equal to 1 if bank was TAF mainly in the pre-Lehman period. Post= Indicator variable equal to 1 for the post-Lehman period (2010), and equal to zero for 2007. Standard errors clustered at bank-level.

	Wholesale funding	Wholesale funding narrow	Domestic deposits					Foreign deposits	Interbank borrowing	Subordin. debt	Other borrowing
			All deposits	Transaction accounts	Saving accounts	Time depos. (<100)	Time depos. (>100)				
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$DW_{pre} \times Post$	-2.429***	-1.741***	1.185***	0.416	0.563	1.394**	-1.265***	-0.0730	-0.522**	-0.00570	-0.666**
	(0.612)	(0.620)	(0.400)	(0.382)	(0.620)	(0.558)	(0.485)	(0.0684)	(0.264)	(0.0153)	(0.289)
$TAF_{pre} \times Post$	-0.518	0.999	5.773**	1.056	4.350**	3.399***	-2.706	0.531	-3.758*	-0.368*	-1.154
	(2.542)	(2.495)	(2.894)	(1.308)	(1.788)	(0.897)	(1.682)	(1.319)	(1.931)	(0.189)	(2.271)
postLehman	-6.320***	-5.209***	2.150***	4.046***	6.278***	-7.852***	-0.348	-0.0544	-0.497**	0.0357**	-1.143***
	(0.549)	(0.552)	(0.587)	(0.382)	(0.562)	(0.467)	(0.504)	(0.0484)	(0.247)	(0.0149)	(0.382)
Asset (log)	0.917	-1.787***	-1.372**	-3.437***	-0.280	1.167**	1.483***	0.121	-0.0865	0.0167	2.683***
	(0.569)	(0.607)	(0.581)	(0.408)	(0.604)	(0.455)	(0.504)	(0.0897)	(0.237)	(0.0119)	(0.443)
Bank controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Quarterly fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	65,012	65,000	65,041	65,041	65,041	58,910	65,041	65,041	65,039	65,041	65,041
Number of banks	8,807	8,807	8,807	8,807	8,807	7,998	8,807	8,807	8,807	8,807	8,807
R squared	0.499	0.492	0.0426	0.0512	0.0957	0.190	0.0355	0.00315	0.0295	0.00740	0.0503
H_3 : Funding for TAF banks in post Lehman period ($TAF_{pre} \times Post$) $\leq$ Funding for DW banks in post Lehman period ($DW_{pre} \times Post$)											
10% significance	ACCEPT	ACCEPT	REJECT	ACCEPT	REJECT	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We also observe a shift from larger term deposits (above \$100,000) to smaller term deposits.[22] We do not find a significant difference for transaction accounts, which is consistent with the introduction of the Transaction Account Guarantee Program (TAGP) by the FDIC on October 14, 2008. This program guaranteed in full all domestic non-interest-bearing transaction deposits and low-interest negotiable order of withdrawal (NOW) accounts through December 2012.

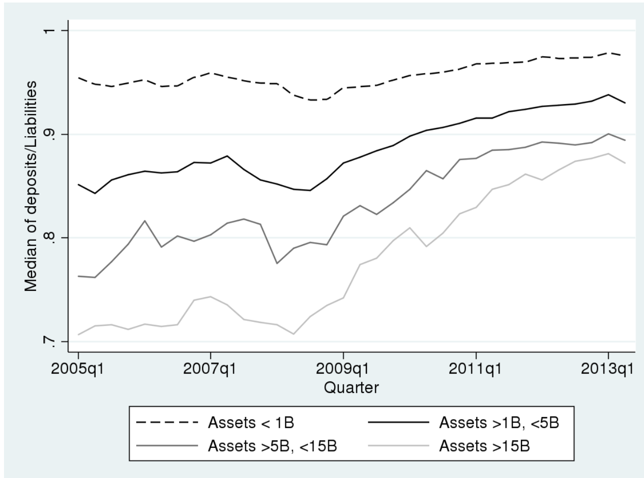
There is usually a greater use of retail deposits during crisis periods owing to explicit and implicit government guarantees, which insulate banks from liquidity risks (Gatev and Strahan, 2006; Cornett *et al.*, 2011). Figure 9 shows a very clear trend toward a greater use of retail deposits for banks of different sizes which is consistent with the positive sign of the parameter estimates found for deposits. Acharya and Mora (2015) also show a similar trend for the post-Lehman period of the recent financial crisis. Deposits are attractive for banks because they usually offer a more stable and less expensive source of funding than wholesale funds. In addition, there was probably a greater demand for insured deposits by investors, reflecting a flight to safety out of more risky investment instruments during the post-Lehman period.

We can reconcile the previous results on funding costs with the obtained results in the structure of funding. We found previously that TAF banks pay a lower rate than DW banks in the interbank lending market, but we could not find a statistically different effect[23] for other types of sources of funding, such as deposits. The findings in this subsection imply that TAF banks were able to expand their use of savings accounts and smaller time deposits without significantly changing the rates paid. Depositors seem to be less price elastic. This is particularly true for deposits such as current accounts, which provide customers with a safe place to keep their savings and the option to withdraw cash or make electronic payments. In contrast, lenders and borrowers in the interbank lending market collect more information regarding their counterparties and, therefore, their rates paid are more likely to be affected by the perceived quality of their counterparties.

[22] During normal times, we would interpret such a shift as an increase of insured deposits at the expense of uninsured deposits, since the deposit insurance limit is \$100,000 in the United States. However, on October 14, 2008 the deposit insurance limit was temporarily raised to \$250,000 until December 2009, through the Emergency Economic Stabilization Act of 2008. We therefore do not have a good interpretation of this shift in the granularity of time deposits.

[23] See also Stigum's Money Market book : "The federal funds market resembles a river with tributaries: money is collected in many places and then flows through various channels".

Figure 9: Use of deposits by U.S. commercial banks



4.4 Matched-sample analysis

As a robustness check, we can provide an alternative specification to the model in (18) by using a matching method combined with bank-level fixed effects (see Lemmon and Roberts, 2010; Duchin and Sosyura, 2014, among others). We use the propensity score to match the banks that accessed the DW or the TAF in the pre-Lehman period to the banks that did not access any facility. This allows us to select banks that are similar in 2007, based on the observed control variables. Then, we can use these matched observations in a fixed-effects model as in (18). This method provides a robustness check of our baseline model and provides a number of advantages. First, the matching estimator helps to relax the linearity assumption existing between funding costs/sources of funding and bank characteristics. Using the fixed-effects estimator helps to eliminate selection bias due to unobservable time-invariant bank effects. This methodology can also alleviate potential concerns over the violation of the unconfoundedness assumption of the traditional propensity score matching model (see Lemmon and Roberts, 2010; Roberts and Whited, 2013).

In the first stage of this method, we do a matching of covariates using a propensity score. We separately match banks that did not use the TAF or the DW in the pre-Lehman period with DW and TAF banks. We use a logit probabilistic model to find the score of every sample and use similar control variables as in the baseline model. Table C.3 shows the quality of the match. We test differences between means of covariates for treated and matched samples to show the quality of the match. Matched samples are observationally equivalent to a relatively high level of significance for most covariates.

Table C.4 shows the fixed-effects regression for matched samples for the case of funding costs. We find similar results to those shown in Table 2. The difference in funding costs for interbank borrowing of TAF banks with respect to DW banks decreases to about 15 basis points compared with the baseline model, but the difference is significant at a 10% significance level. The difference in terms of total funding costs between TAF and DW banks decreases slightly but stays significant at about 4 basis points.

5 Conclusion

In this paper, we have discussed the importance of the TAF liquidity facility in helping banks to signal themselves as financially sound during the recent financial crisis. We show that a "one size fits all" approach with respect to LOLR policy is not useful. In addition, the characteristics of these facilities have relevant implications. A fully flexible TAF would not be very helpful for banks to signal that they are financially sound because it would be equivalent to the DW, and separation would not be costly.

We also provide empirical evidence that the choices made by banks in the period of financial turbulence have later consequences in terms of the cost of funding, access to wholesale markets and perceived riskiness. We use several econometric specifications that are in general robust to the predictions we expect from our model.

Our results contribute to a better understanding of the functioning of financial markets during the recent financial crisis, and highlight the importance of an appropriate design of liquidity facilities in periods of high asymmetric information. Aspects that are unfavourable for banks, such as the lack of flexibility of certain liquidity facilities, are crucial because they can be used by sound financial institutions to separate themselves from banks that are in worse financial condition.

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Appendices

A The Discount Window Before the Crisis

Sound DIs facing liquidity shortages can borrow from the Fed's primary lending facility — the discount window — at the "primary lending rate".[24] Before 2003, the discount rate was set below the target federal funds rate, which made borrowing from the Fed cheaper than borrowing on the interbank market, and created potential arbitrage opportunities.[25] Accordingly, DIs were required to show that they had exhausted private sources of funding and that they really needed funds for their business purposes, on top of the regular scrutiny of their soundness. This additional requirement seems to have created a perception of stigma associated with DW borrowing, since it might signal a financial weakness of the borrower if it became known to both peers and the Fed. These concerns may have deterred sound DIs with liquidity shortages from borrowing at the DW, even if their terms and amounts were not made public.[26]

To address concerns about DW stigma, the Fed changed its approach to DW lending in 2003. It had put in place a penalty-rate regime, and classified DW loans into primary and secondary credit. Primary credit, the DW main source of short-term liquidity, is available on a "no-questions asked" basis to financially sound DIs that meet a certain capital threshold. These institutions pay the primary credit rate, which was originally set to 100 basis points above the target federal funds rate. Secondary credit is available to DIs not eligible for primary credit, and entails a higher level of administrative burden. At the outset of the program, the secondary credit rate was 150 basis points above the Fed's target rate.

[24] The primary lending rate is more commonly known as the "discount rate". Prior to the recent financial crisis, DW operations were the Fed's primary means of implementing its lender-of-last-resort function. Lending through the DW allows DIs to borrow against collateral that is not accepted elsewhere. The Fed would accept virtually anything as collateral, including U.S. Treasury securities, state and local government securities, AAA-rated collateralized mortgage obligations, consumer loans, commercial and agricultural loans, and investment-grade certificates of deposits. In some cases, the Fed even accepted the bank's buildings and furniture (Cecchetti (2009)).

[25] Banks could re-lend cheap DW funds on the interbank market at higher rates, potentially leading to larger reserves and lower rates than levels targeted by the Fed's monetary policy (Courtois and Ennis (2010)).

[26] DW stigma and associated banks' reluctance do not necessarily make DW useless. Acharya *et al.* (2012) show that stigma effects rather limit the surplus banks can squeeze out of needy banks.

Table A.1: Summary Statistics for Banks that are DW mainly or TAF mainly

	mean	sd	min	p1	p25	p50	p75	p90	p99	max	N
Before Lehman, DW mainly: Borrowers/Day	29	35	1	1	16	22	29	38	197	209	160
Before Lehman, DW mainly: Amount (millions)	659	2,900	0	0	5	32	148	617	14,200	44,110	4,619
Before Lehman, DW mainly: Term (days)	17	42	0	1	1	1	14	56	140	729	4,619
Before Lehman, DW mainly: Access Frequency	12	63	1	1	1	2	6	22	154	1,156	388
After Lehman, DW mainly: Borrowers/Day	55	20	15	16	40	54	68	83	107	118	337
After Lehman, DW mainly: Amount (millions)	923	3,865	0	0	3	10	37	600	23,500	61,000	18,511
After Lehman, DW mainly: Term (days)	11	68	0	1	1	1	3	27	93	1,753	18,511
After Lehman, DW mainly: Access Frequency	21	114	1	1	1	3	10	49	188	3,097	900
Before Lehman, TAF mainly: Borrowers/Day	17	8	5	5	12	16	23	25	32	32	21
Before Lehman, TAF mainly: Amount (millions)	832	1,354	5	5	50	150	1,000	3,000	5,000	7,500	349
Before Lehman, TAF mainly: Term (days)	31	12	28	28	28	28	28	28	84	84	349
Before Lehman, TAF mainly: Access Frequency	7	5	1	1	2	7	10	16	19	19	47
After Lehman, TAF mainly: Borrowers/Day	9	5	1	1	4	8	11	18	20	20	37
After Lehman, TAF mainly: Amount (millions)	1,349	2,602	5	5	60	250	1,500	3,500	15,000	15,000	328
After Lehman, TAF mainly: Term (days)	57	28	13	17	28	70	84	84	85	85	328
After Lehman, TAF mainly: Access Frequency	9	7	2	2	4	6	12	18	28	28	38

B Proofs of Theory Model

B.1 Proof of Lemma 2

We know that $r_2(\xi) = \frac{\theta(1-\xi)}{\theta\xi-\theta+1}$ and $\xi_0 = \frac{\alpha}{\alpha+(1-\alpha)(1-\rho)}$. Note that

$$\frac{\partial \xi_0}{\partial \alpha} = \frac{\alpha + (1-\alpha)(1-\rho) - (1-1+\rho)\alpha}{[\alpha + (1-\alpha)(1-\rho)]^2} = \frac{1-\rho}{[\alpha + (1-\alpha)(1-\rho)]^2} > 0 \tag{25}$$

$$\frac{\partial \xi_0}{\partial \rho} = \frac{\alpha(1-\alpha)}{[\alpha + (1-\alpha)(1-\rho)]^2} > 0. \tag{26}$$

Note that $r_2(\xi)$ is increasing in θ:

$$\begin{aligned} \frac{\partial r_2}{\partial \theta} &= \frac{(1-\xi)(\theta\xi - \theta + 1) - (\xi - 1)(\theta - \theta\xi)}{(\theta\xi - \theta + 1)^2} = \\ &= \frac{(1-\xi)}{(\theta\xi - \theta + 1)^2} > 0, \end{aligned} \tag{27}$$

which is intuitive: If θ increases, the probability of having a bad outcome is higher, and therefore the risk premium increases. We can also obtain the cross partial derivative:

$$\begin{aligned} \frac{\partial^2 r_2}{\partial \theta \partial \xi} &= \frac{-(\theta\xi - \theta + 1)^2 - 2(\theta\xi - \theta + 1)\theta(1-\xi)}{(\theta\xi - \theta + 1)^4} \\ &= \frac{(\theta\xi - \theta + 1)[-(\theta\xi - \theta + 1) - 2\theta(1-\xi)]}{(\theta\xi - \theta + 1)^4} < 0. \end{aligned} \tag{28}$$

We can also show that $r_2(\xi)$ is increasing in ξ:

$$\begin{aligned} \frac{\partial r_2}{\partial \xi} &= \frac{-\theta(\theta\xi - \theta + 1) - \theta(\theta - \theta\xi)}{(\theta\xi - \theta + 1)^2} = \\ &= \frac{-\theta}{(\theta\xi - \theta + 1)^2} < 0. \end{aligned} \tag{29}$$

Therefore, we obtain the following comparative statics:

$$\frac{dr_2(\xi = \xi_0)}{d\alpha} = \frac{\partial r_2(\xi = \xi_0)}{\partial \xi} \frac{\partial \xi_0}{\partial \alpha} < 0 \tag{30}$$

$$\frac{dr_2(\xi = \xi_0)}{d\rho} = \frac{\partial r_2(\xi = \xi_0)}{\partial \xi} \frac{\partial \xi_0}{\partial \rho} < 0 \tag{31}$$

$$\frac{dr_2(\xi = \xi_0)}{d\theta} = \frac{\partial r_2(\xi = \xi_0)}{\partial \theta} > 0. \tag{32}$$

B.2 Additional properties of equilibrium

We characterize some of the properties of the equilibrium in Proposition 2.

Proposition 2. *Properties of separating equilibrium:*

- *If r_D is small enough, then $r_T > r_D$.*
- *If $\rho \to 1$, then $r_T = r_D + r_2(0) - r_2(\alpha)$ and $r_T > r_D$ for any $r_D \geq 0$. Also, the equilibrium region of r_T is shifted up (i.e., r_T increases) as $\rho \to 1$.*
- *If θ increases, the equilibrium region of r_T does not have a clear behaviour (I_2 increases, but I_1 does not have a clear pattern). However, if $\theta \to 1$ then $r_D \to +\infty$.*
- *If α increases, the equilibrium region of r_D is shifted down (i.e., r_T decreases).*

In Figure 6, it is easy to see that when r_D is small enough, then the equilibrium region for r_T is such that $r_T > r_D$.

In order to find comparative statics results of the equilibrium rates with respect to α, ρ and θ, we need to study how the equilibrium region defined by (10) and (15) changes with these parameters. The equilibrium conditions can be written as $r_T \leq r_D + I_2$ and $r_T \geq \rho r_D + I_1$. We find a simple expression for the intercept of (15), $I_1 \equiv \rho r_2(0) + (1-\rho) r_2(\xi_0) - r_2(\alpha)$:

$$I_1 \equiv \rho r_2(0) - r_2(\alpha) + (1-\rho) r_2(\xi_0) = \rho \frac{\theta}{1-\theta} - \frac{\theta(1-\alpha)}{\theta\alpha - \theta + 1} + (1-\rho)\frac{\theta(1-\xi_0)}{\theta\xi_0 - \theta + 1}$$
$$= \theta\left[\frac{\rho}{1-\theta} - \frac{1-\alpha}{\theta\alpha - \theta + 1} + (1-\rho)\frac{1-\xi_0}{\theta\xi_0 - \theta + 1}\right]. \tag{33}$$

I_1 can also be written as

$$I_1 = \rho r_2(0) - r_2(\alpha) + (1-\rho) r_2(\xi_0) = \rho(r_2(0) - r_2(\xi_0)) + r_2(\xi_0) - r_2(\alpha). \tag{34}$$

To study the sign of $\frac{\partial I_1}{\partial \rho}$, we differentiate (34):

$$\frac{\partial I_1}{\partial \rho} = r_2(0) - r_2(\xi_0) + (1-\rho)\frac{dr_2(\xi_0)}{d\rho}.$$

Since $r_2(0) - r_2(\xi_0) > 0$ and from (31) we have $\frac{dr_2(\xi_0)}{d\rho} < 0$, then the sign of $\frac{\partial I_1}{\partial \rho}$ is ambiguous. However, if $\rho \to 1$, then $\frac{\partial I_1}{\partial \rho} > 0$.

To study the sign of $\frac{\partial I_1}{\partial \theta}$, we differentiate (34):

$$\frac{\partial I_1}{\partial \theta} = \rho\frac{\partial r_2(0)}{\partial \theta} - \frac{\partial r_2(\alpha)}{\partial \theta} + (1-\rho)\frac{\partial r_2(\xi_0)}{\partial \theta}.$$

This can be positive or negative depending on the value of the parameters. Because (28) is satisfied, if $\rho \to 0$, then $\frac{\partial I_1}{\partial \theta} > 0$, and if $\rho \to 1$, then $\frac{\partial I_1}{\partial \theta} < 0$. Also, using (33), if $\theta \to 1$, then $I_1 \to +\infty$ and if $\theta \to 0$, then $I_1 \to 0$.

Finally, using (30), we obtain $\frac{\partial I_1}{\partial \alpha} < 0$.

We also study the intercept of (10), $r_2(0) - r_2(\alpha)$,

$$I_2 \equiv r_2(0) - r_2(\alpha). \tag{35}$$

It is easy to show that

$$\frac{\partial I_2}{\partial \rho} = 0 \tag{36}$$

$$\frac{\partial I_2}{\partial \alpha} = 0. \tag{37}$$

Also,

$$\frac{\partial I_2}{\partial \theta} = \frac{\partial r_2(0)}{\partial \theta} - \frac{\partial r_2(\alpha)}{\partial \theta}.$$

Because (28) is satisfied, then we have

$$\frac{\partial I_2}{\partial \theta} > 0. \tag{38}$$

Using the derivatives of I_1 and I_2, and the graph with the equilibrium (see Figure 6), we show the following:

If $\rho \to 1$, then $r_T = r_D + r_2(0) - r_2(\alpha)$, and the equilibrium region of r_T is shifted up (i.e., r_T increases).

If θ increases, the equilibrium region of r_T does not have a clear behaviour (I_2 increases, but I_1 does not have a clear pattern). However, if $\theta \to 1$, then $r_D \to +\infty$.

If α increases, the equilibrium region of r_D is shifted down (i.e., r_T decreases).

B.3 Extension: Demand for opacity

Since we assume that only bad banks are subject to runs, accessing the DW fully reveals the bank's type and thus $\xi_D = 0$ (like in the original model). Therefore, an equivalent lemma to Lemma 1 can be obtained. Lemma 2 can also be modified such that we consider now the second-period interest rate for banks that do not access a liquidity facility or go to TAF, $r_2(\xi_{0T})$.

Using these results, we can rank the second-period interest rates as a function of the banks' first-period financing needs as we did with Eq. (4):

$$r_2(\xi_D = 0) = \frac{\theta}{1-\theta} \geq r_2(\xi_T = \alpha) \geq r_2(\xi_{0T}) \geq r_2(\xi_0) \geq r_2(\xi = 1) = 0. \tag{39}$$

Therefore, banks that access TAF or do not access any facility can still receive a more favourable second period interest rate, $r_2(\xi_{0T})$, than banks that access the DW, $r_2(\xi_D = 0)$. The only difference with previous results is that now $r_2(\xi_T = \alpha) \geq r_2(\xi_{0T})$. Since markets cannot differentiate between banks that access the TAF or no facility, we have now that $r_2(\xi_T = \alpha) \geq r_2(\xi_{0T}) \geq r_2(\xi_0)$.

In order to characterize the equilibrium, we can rewrite Eqs. (5), (6), (7), and (8) as follows:

$$\pi_{g,l} = R - (r_T + r_2(\xi_{0T})). \tag{40}$$

$$\pi_{g,n} = R - r_2(\xi_{0T}). \tag{41}$$

$$\pi_{b,l} = (1-\theta)(R - (r_T + r_2(\xi_{0T}))). \tag{42}$$

$$\pi_{b,n} = (1-\theta)(R - \rho(r_D + r_2(0)) - (1-\rho)r_2(\xi_{0T})). \tag{43}$$

Equilibrium conditions for the separating equilibrium are

$$R - (r_T + r_2(\xi_{0T})) \geq R - (r_D + r_2(0)) \Leftrightarrow \tag{44}$$

$$r_D + r_2(0) - r_2(\xi_{0T}) \geq r_T \tag{45}$$

for the good bank and

$$(1-\theta)(R - (r_T + r_2(\xi_{0T}))) \geq (1-\theta)(R - (r_D + r_2(0))), \tag{46}$$

which is identical for the bad bank.

Also, if the good bank does not receive a liquidity shock, it could still access the TAF and invest the proceeds in a riskless storage technology, for which we assume a normalized return of zero. The corresponding incentive compatibility constraint is

$$R - r_2(\xi_{0T}) \geq R - (r_T + r_2(\xi_{0T})) \Leftrightarrow \tag{47}$$

$$r_2(\xi_{0T}) - r_2(\xi_{0T}) = 0 \leq r_T. \tag{48}$$

Third, the bad bank could access the TAF even if it has had no liquidity shock and store the proceeds. The bank could then avoid accessing the DW and avoid being identified as a bad bank if there is a run. The corresponding incentive compatibility constraint is

$$(1-\theta)(R-\rho(r_D+r_2(0))-(1-\rho)r_2(\xi_{0T}))\geq(1-\theta)(R-(r_T+r_2(\xi_{0T})))\Leftrightarrow \tag{49}$$

$$\rho r_D+\rho r_2(0)+(1-\rho)r_2(\xi_{0T})-r_2(\xi_{0T})=\rho r_D+\rho r_2(0)-\rho r_2(\xi_{0T})\leq r_T. \tag{50}$$

Note that equations (45) and (46) are identical, so we can discard one of them. Also, because we assume that $r_D \geq 0$ and $r_T \geq 0$, and $r_2(0) \geq r_2(\xi_{0T})$, equation (48) can be discarded. Therefore, a separating equilibrium is defined by (45) and (50), which leads to Proposition 3.

Proposition 3. *The separating equilibrium is fully characterized by equations (45) and (50).*

C Empirical Model

C.1 Definition of variables

Next, we define the bank-level variables that we use (which are similar to the variables used in Duchin and Sosyura (2014)):

Camels proxies:

- Capital adequacy: Tier-1 risk-based capital ratio, measured by the ratio of Tier-1 capital to risk-weighted assets.
- Asset quality: Negative of non-current loans and leases scaled by total loans and leases.
- Management quality: Negative of the number of corrective actions that were taken against bank executives by the corresponding banking regulator (Fed, OTS, FDIC, and OCC) each year.
- Earnings: return on equity (ROE), measured by the ratio of quarterly net income to total equity capital.
- Liquidity: cash divided by deposits.
- Sensitivity to market risk: sensitivity to interest rate risk, measured by the ratio of the absolute difference between short-term assets and short-term liabilities to earning assets.

Bank fundamentals:

- Size: natural logarithm of book assets.
- Age: age in years since the year an institution was established.
- Exposure to regional economic shocks: weighted average of quarterly changes in the state-coincident macro indicator ("State Coincident Index") from the Federal Reserve Bank of Philadelphia across all states in which a given bank maintains active branches. This index combines four state-level indicators (non-farm payroll employment, average hours worked in manufacturing, the unemployment rate, and wages and salaries deflated by a price index) to summarize current economic conditions in a single statistic. The weights represent the percentage of the bank's deposits held in the branches in a given state.

- Foreclosures: backward-looking measure of loan quality and exposure to the crisis, measured as the value of foreclosed assets divided by net loans and leases.
- Loan charge-offs: ratio of net loan charge-offs to total loans.
- Funding mix: ratio of deposit funding from purchased money to core deposits.

Investment portfolios:

- Lower-risk securities: U.S. Treasury securities and securities issued by states and political subdivisions.
- Riskier securities: mortgage-backed securities (excluding government-sponsored agency obligations), other domestic and foreign debt securities, and investments in mutual funds and equity products.
- Long-term debt securities: debt securities with the remaining maturity greater than five years.

Bank risk:

- ROA volatility: standard deviation of quarterly ROA over the trailing year.
- Z-score: ROA plus capital asset ratio divided by the standard deviation of ROA.

Liquidity access variables:

- DW: Indicator variable equal to 1 if the bank obtained at least 95% of its Fed funds from DW (as a percentage of total funds from TAF+DW) before the Lehman Brothers failure.
- TAF: Indicator variable equal to 1 if the bank obtained at least 95% of its Fed funds from TAF (as a percentage of total funds from TAF+DW) before the Lehman Brothers failure.
- TARP: Indicator variable equal to 1 if the bank accessed the TARP program.

Funding:

- Interest expenses are categorized as
  - Interest expense on domestic deposits (total)
  - Interest expense on domestic deposits (transaction accounts)
  - Interest expense on domestic deposits (savings accounts)
  - Interest expense on domestic deposits (time deposits of less than 100,000 USD)
  - Interest expense on domestic deposits (time deposits of more than 100,000 USD)
  - Interest expense on foreign deposits
  - Interest expense on Fed funds purchased (interbank borrowing)

  - Subordinated notes and debentures: interest expense on subordinated notes and debentures
  - Demand notes and other borrowed money: interest expense on demand notes issued to the U.S. Treasury, other borrowed money and interest on mortgage indebtedness and obligations under capitalized leases on a consolidated basis.

- Wholesale funding:

  - % wholesale funds: Ratio of total liabilities (excluding insured deposits) to total liabilities.
  - % wholesale funds (narrow): Ratio of (total liabilities excluding insured deposits, subordinated debt, and other borrowed money) to total liabilities. "Other borrowed money" excludes deposits, federal funds purchased, securities sold under agreements to repurchase in domestic offices of the bank, and trading liabilities.

Table C.1: Summary Statistics for mainly TAF, mainly DW and all other banks

We show descriptive statistics for banks that were classified as DW main, TAF main, BOTH and REST in the pre-Lehman period. Several t-tests for significant differences in the means of the different categories of banks appear in the last columns. We also show statistics for the pre-Lehman period and the post-Lehman period. *, **, and *** indicate statistical significance at the 0.10, 0.05, and 0.01 levels, respectively.

	Pre-Lehman (2007)								t-test of differences				
	DW banks		TAF banks		Both banks		Rest banks		DW-TAF	DW-Rest	TAF-Rest	BOTH-TAF	BOTH-REST
	mean	se	mean	se	mean	se	mean	se	t	t	t	t	t
Assets (billions)	7.71	1.73	60.06	13.57	54.93	14.55	0.53	0.03	-3.83***	4.15***	4.39***	-.26	3.74***
Asset quality (%)	-1.011	0.033	-1.114	0.112	-0.699	0.052	-1.048	0.012	.89	1.07	-.59	3.38***	6.59***
Return on assets (%)	0.99	0.04	1.27	0.06	1.33	0.12	0.88	0.02	-3.73***	2.65***	5.74***	.45	3.62***
Return on equity (%)	10.25	0.27	11.80	0.47	11.61	0.66	8.62	0.07	-2.83***	5.76***	6.64***	-.23	4.49***
Tier 1 ratio (%)	13.78	0.40	16.58	1.85	10.82	0.27	22.20	0.63	-1.48	-11.33***	-2.87***	-3.08***	-16.61***
Leverage ratio	11.20	0.07	12.36	0.23	12.57	0.26	9.98	0.02	-4.76***	17.16***	10.17***	.6	9.87***
Sens. market risk (%)	23.20	0.44	23.65	1.44	23.65	1.95	23.81	0.10	-.3	-1.35	-.11	0	-.08
Foreclosures (%)	0.05	0.01	0.07	0.01	0.04	0.00	0.05	0.00	-2.05**	-.22	2.22**	-2.71***	-1.5
Loan chargeoffs (%)	0.19	0.01	0.64	0.17	0.36	0.06	0.20	0.01	-2.64***	-.14	2.64***	-1.58	2.87***
Funding mix (%)	1.35	0.03	1.08	0.03	12.06	6.71	1.60	0.09	5.93***	-2.6***	-5.47***	1.64	1.56
Low risk secur. (%)	3.49	0.11	1.31	0.13	2.10	0.24	4.07	0.03	12.65***	-4.89***	-20.64***	2.89***	-8.26***
High risk secur. (%)	1.04	0.11	1.41	0.41	0.87	0.13	0.49	0.01	-.89	5.04***	2.25**	-1.27	2.83***
Long-term secur. (%)	6.28	0.21	4.68	0.39	5.14	0.34	6.49	0.05	3.62***	-.96	-4.6***	.89	-3.9***
Std. deviation ROA	0.25	0.02	0.15	0.01	0.23	0.03	0.29	0.01	4.4***	-2.35**	-11.76***	2.5**	-1.96*
z-score	225.53	13.72	252.57	33.08	161.61	15.03	239.15	3.50	-.75	-.96	.4	-2.5**	-5.03***
Liquidity ratio (%)	4.88	0.33	4.56	0.37	5.58	0.73	58.11	13.06	.65	-4.07***	-4.1***	1.24	-4.02***
Macro index (%)	1.48	0.03	1.17	0.11	1.60	0.09	1.63	0.01	2.79***	-4.74***	-4.33***	3.13***	-.34
Enforcement (%)	0.18	0.01	0.36	0.04	0.27	0.03	0.09	1.00	-4.97***	9.52***	7.86***	-1.83*	5.56***
Bank age (years) (%)	60.04	1.16	74.28	3.84	52.48	4.33	67.60	0.24	-3.55***	-6.4***	1.73*	-3.77***	-3.49***
TARP access	0.21	0.01	0.36	0.04	0.36	0.04	0.07	0.00	-3.55***	-6.4***	1.73*	-3.77***	-3.49***
Observations	1,520		188		176		32,501						

Table C.2: Fixed effects regression for funding cost for years 2010 and 2007 (total and by type of funding source). Only DW and TAF banks.

This table shows results of fiÂĚxed-effects regressions of funding cost by type of funding source. We only consider banks that accessed the DW or TAF. We show the results of total interest expense (as a % of total liabilities) in (1); interest expense for domestic deposits (as % of domestic deposits) in (2); interest expense for transaction accounts (as % of transaction accounts) in (3); interest expense for savings accounts (as % of savings accounts) in (4); interest expense for time deposits of less than 100,000 USD (as %) in (5); interest expense for time deposits of more than 100,000 USD (as %) in (6); interest expense for foreign deposits (as %) in (7); interest expense for interbank borrowing (as % of interbank borrowing) in (8); interest expense for subordinated debt (as % of subordinated debt) in (9); and interest expense for other borrowing (as % of other borrowing) in (10). All regressions use quarterly data for banks in 2010 (post-Lehman period) and 2007 (pre-Lehman period). DW= Indicator variable equal to 1 if bank was DW mainly in the pre-Lehman period. TAF= Indicator variable equal to 1 if bank was TAF mainly in the pre-Lehman period. Post= Indicator variable equal to 1 for the post-Lehman period (2010), and equal to zero for 2007. Standard errors clustered at bank-level.

	Total	Domestic deposits					Foreign	Interbank	Subordin.	Other
	funding	All	Transaction	Saving	Time depos.	Time depos.	deposits	borrowing	debt	borrowing
	cost	deposits	accounts	accounts	(<100)	(>100)				
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$TAF_{pre} \times Post$	-0.0481	-0.0230	0.0334	0.0136	0.00101	-0.0366	-0.0701	-0.283**	-0.0374	-0.0562
	(0.0296)	(0.0351)	(0.0523)	(0.0450)	(0.0595)	(0.0783)	(0.114)	(0.135)	(0.293)	(0.104)
TARP	-0.0187	-0.00887	-0.0190	-0.0361	0.0228	0.00951	0.339**	0.0423	-0.0933	-0.115**
	(0.0155)	(0.0165)	(0.0315)	(0.0306)	(0.0349)	(0.0419)	(0.152)	(0.0775)	(0.299)	(0.0563)
Asset (log)	-0.0444	-0.0363	0.0960***	-0.128**	-0.0168	-0.0731	-0.0794	-0.0272	-0.114	-0.0621
	(0.0338)	(0.0280)	(0.0362)	(0.0515)	(0.0670)	(0.0762)	(0.261)	(0.172)	(0.388)	(0.0868)
Other bank controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Quarterly fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	3,166	3,166	2,840	2,845	2,836	2,830	236	1,760	412	2,632
Number of banks	427	427	383	382	382	383	34	306	72	393
R squared	0.875	0.911	0.142	0.738	0.736	0.732	0.837	0.472	0.323	0.173

H_1 : Funding cost for DW banks in post Lehman period ($DW_{pre} \times Post$) $\leq$ Funding cost for TAF banks in post Lehman period ($TAF_{pre} \times Post$)

10% significance	REJECT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.3: Differences between treated and matched samples (funding cost regressions).

Test of differences between covariates of treated samples (DW and TAF) and matched samples. Matching is done using covariates used in funding cost FE regressions. We report mean values for the entire sample, the DW banks, the TAF banks, the matched banks and the p-values of the test of differences.

		DW matching				TAF matching			
	All	DW	others	Difference	p-value	TAF	others	Difference	p-value
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log asset	-1.929	-0.461	-0.457	-0.004	0.639	1.975	2.144	-0.169	0.276
ROE	8.479	10.204	9.822	0.382	0.637	11.727	9.396	2.332	0.071
Risk weighted assets	0.698	0.770	0.770	0.000	0.990	0.784	0.751	0.032	0.444
Leverage	10.003	11.206	11.272	-0.066	0.669	12.391	11.790	0.601	0.417
Liquidity ratio	0.044	0.034	0.032	0.001	0.556	0.027	0.029	-0.002	0.621
Wholesale funding (narrow)	25.275	34.006	33.856	0.150	0.975	43.216	39.460	3.756	0.427
Insured deposits	22.010	28.611	27.603	1.008	0.358	32.575	28.305	4.269	0.317
Real state	46.993	52.267	52.022	0.245	0.790	47.036	48.711	-1.675	0.744
Non performing assets	1.714	1.597	1.698	-0.101	0.390	1.571	1.576	-0.005	0.988
Subprime mortgages	12.013	12.132	12.194	-0.062	0.710	12.499	12.516	-0.017	0.976
Unemployment	4.475	4.588	4.597	-0.009	0.900	4.344	4.368	-0.024	0.925

Table C.4: Fixed effects regression of matched samples for funding cost for years 2010 and 2007 (total and by type of funding source).

This table shows results of fixed effects regression of funding cost by type of funding source for matched samples. We show results total interest expense ("eintexp", as a % of total liabilities) in (1); interest expense for domestic deposits (as fraction of value of domestic deposits) in (2); interest expense for transaction accounts (as fraction of value of transaction accounts) in (3); interest expense for saving accounts (as fraction of value of saving accounts) in (4); interest expense for time deposits of less than 100,000 USD (as fraction of value of time deposits of less than 100,000 USD) in (5); interest expense for time deposits of more than 100,000 USD (as fraction of value of time deposits of more than 100,000 USD) in (6); interest expense for foreign deposits (as fraction of value of foreign deposits) in (7); interest expense for interbank borrowing (as fraction of value of interbank borrowing) in (8); interest expense for subordinated debt (as fraction of value of subordinated debt) in (9); and interest expense for other borrowing (as fraction of value of other borrowing) in (10). All regressions use quarterly data for banks in 2010 (post-Lehman period) and 2007 (pre-Lehman period). DW= Dummy equal to 1 if bank was DW mainly in the pre-Lehman period. TAF= Dummy equal to 1 if bank was TAF mainly in the pre-Lehman period. Post= Dummy equal to one for the post-Lehman period (2010), and equal to zero for 2007. TARP= Dummy equal to 1 if bank was part of the TARP program.

	Total	Domestic deposits					Foreign	Interbank	Subordin.	Other
	funding	All	Transaction	Saving	Time depos.	Time depos.	deposits	borrowing	debt	borrowing
	cost	deposits	accounts	accounts	(<100)	(>100)				
Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DW_main	-0.0194**	-0.0145*	-0.0126	-0.00405	0.0127	-0.0675***	-0.0757	-0.00607	0.0624	-0.0322
	(0.00821)	(0.00815)	(0.0143)	(0.0134)	(0.0164)	(0.0214)	(0.0999)	(0.0383)	(0.162)	(0.0279)
TAF_main	-0.0439	-0.0187	0.0255	0.00153	-0.0324	-0.00871	-0.318*	-0.156	-0.0671	-0.00798
	(0.0280)	(0.0364)	(0.0478)	(0.0470)	(0.0460)	(0.0733)	(0.173)	(0.117)	(0.182)	(0.108)
Bank-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Quarterly fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	29,442	29,438	26,442	26,420	26,396	26,417	661	13,060	1,619	22,311
Number of banks	3,991	3,991	3,604	3,589	3,592	3,609	100	2,507	309	3,428
R squared	0.890	0.894	0.161	0.737	0.790	0.767	0.774	0.428	0.313	0.136

H_1 : Funding cost for DW banks in post Lehman period ($DW_{pre} \times Post$) $\leq$ Funding cost for TAF banks in post Lehman period ($TAF_{pre} \times Post$)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
15% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	REJECT	ACCEPT	ACCEPT
10% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT	ACCEPT
5% significance	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT	ACCEPT

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1