# Borrowing Stigma and Lender of Last Resort Policies

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#### Abstract

How should the lender of last resort provide liquidity to banks during periods of financial distress? During the 2008-2010 crisis, banks avoided borrowing from the Fed's long-standing discount window but actively participated in its special monetary program, the Term Auction Facility, although both programs had the same borrowing requirements. Using an adverse selection model with endogenous borrowing decisions, we explain why the two programs suffer from different stigma costs and how the introduction of TAF incentivized banks' borrowing. We discuss the empirical relevance of the model's predictions.

**Keywords:** lender of last resort, discount window stigma, Term Auction Facility, adverse selection

**JEL:** G01, E52, D44, E58

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"[Banks] deliberately did not ask for the liquidity they needed for fear of damaging their reputation—the "stigma" problem... I do not think we were conscious of this before the crisis started and I do not think central banks have a convincing answer to it... This is, I think, still a challenge in how to manage the process of central bank provision of liquidity support. This is one of the big intellectual issues that has not been fully resolved."

- Governor Mervyn King (Bank of England, 2016)

"For various reasons, including the competitive format of the auctions, [Term Auction Facility] has not suffered the stigma of conventional discount window lending and has proved effective for injecting liquidity into the financial system... Another possible reason that [Term Auction Facility] has not suffered from stigma is that auctions are not settled for several days, which signals to the market that auction participants do not face an immediate shortage of funds."

- Ben Bernanke (2010) testimony to US House of Representatives

# 1 Introduction

Financial crises are typically accompanied by liquidity shortages in the banking sector, in which case the central bank should act as the lender of last resort (LOLR) (Bagehot, 1873). How should LOLR lend to depository institutions and provide liquidity during such episodes? The answer is not obvious. The discount window (DW) has been the primary lending facility used by the Fed, but it was severely underutilized when the interbank market froze at the beginning of the financial crisis in late 2007 (Armantier et al., 2015). A main reason for the underutilization is believed to be the stigma associated with DW borrowing: Tapping DW conveys a negative signal about borrowers' financial condition to their counterparties, competitors, regulators, and the public.<sup>1</sup>

In response to the credit crunch and banks' reluctance to borrow from DW, the Fed created a temporary program, the Term Auction Facility (TAF), in December 2007. TAF held an auction every other week and provided a preannounced amount of loans with *identical* loan maturity, collateral margins, and eligibility criteria to those of DW.

<sup>&</sup>lt;sup>1</sup>Banks have regularly paid more for loans from the interbank market than for loans they could readily get from DW (Peristiani, 1998; Furfine, 2001, 2003, 2005). Although the Fed does not publicly disclose which institutions have received loans from DW, the Board of Governors publishes weekly the total amount of DW lending by each of the 12 Federal Reserve Districts. Therefore, a surge in total DW borrowing could send the market scrambling to identify loan recipients. Because of the interconnectedness of the interbank lending market, it is not impossible for other banks to infer which institutions went to DW. Market participants and social media could also infer from other activities. See footnote 7 for some anecdotal evidence.

Surprisingly, TAF provided much more liquidity than DW: Figure 1a shows that the outstanding balance in TAF far exceeded that in DW during 2007–2010; the outstanding balance in DW was sometimes less than one-fifth of that in TAF between 2007 and 2010. Even more surprisingly, banks sometimes paid a higher interest rate to obtain liquidity through TAF auction: Figure 1b shows that the *stop-out rate*—the rate that clears the auction—was higher than the concurrent *discount rate*—the rate readily available in DW—in 21 of the 60 auctions, especially from March to September 2008, the peak of the financial crisis.<sup>2</sup>





This episode suggests the importance of the design of emergency lending programs to cope with liquidity shortages effectively. More specifically, it raises a series of questions about LOLR policies. Why could TAF overcome the stigma and generate more borrowing than DW? Shouldn't the same stigma also prevent banks from participating in TAF? How did banks decide to borrow from DW and/or TAF? Was there any systematic difference between the banks that borrowed from the two facilities? How could the program be further improved? There is no consensus on the answers to the questions (Armantier and Sporn, 2013; Bernanke, 2015).

This paper provides a theory of LOLR in the presence of borrowing stigma. We introduce a model in which banks have private information about their financial condition. Weaker banks have more urgent liquidity needs and enjoy higher borrowing benefits. Two lending facilities are available. An auction allocates a set amount of liquidity, and DW is always available—before, during, and after the auction. Importantly, TAF delays its release of funds. Borrowing from each

<sup>&</sup>lt;sup>2</sup>The stop-out rate ranged from 1.5 percentage points above (on September 25, 2008) to 0.83 percentage points below (on December 4, 2008) the concurrent discount rate. The stop-out rate was above the concurrent discount rate for almost all auctions between March 2008 (when Bear Stearns filed for bankruptcy) and September 2008 (when Lehman Brothers filed for bankruptcy).

facility incurs a stigma cost, which is endogenously determined by the financial condition of participating banks.

In equilibrium, banks self-select into different programs. The weakest banks borrow immediately from DW because they have the highest demand for liquidity, and it will be very costly for them to wait. Stronger banks, in contrast, are lured to participate in the auction because the potential of borrowing cheap renders the auction more attractive than DW. Their liquidity needs are not as imperative, and they value the lower expected price in the auction more than weaker banks do. Of the banks that participate in TAF, some may bid higher than the discount rate because they would like to avoid DW stigma brought by being pooled with the weakest banks. As a result, the clearing price in the auction may exceed the discount rate. Of the banks that have lost in TAF, relatively weaker ones might still borrow from DW.

We demonstrate that TAF, used in accordance with DW, could increase liquidity provision through three channels. First, by setting a low reserve price in the auction, TAF attracted moderately weak banks (that would have borrowed from DW without TAF) to participate and take their chances on borrowing cheaply. Second, participating banks can submit bids to internalize any stigma cost associated with TAF, so TAF also attracted moderately strong banks (that would not have borrowed at all without TAF) to participate. Finally, due to the selection by stronger banks into the auction, the auction stigma is endogenously lower than DW stigma, which further encourages stronger banks to participate in TAF. Hence, the combination of TAF and DW expands the set of banks who try to, and may obtain, liquidity, thus increasing the overall supply of short-term credit to the economy.

Our model generates some empirically testable implications. First, financially weaker banks borrowed relatively more from DW than TAF, compared with their stronger peers. Given so, DW carries a higher stigma cost than TAF. This result also explains why banks might want to bid more in TAF than the concurrent discount rates. Moreover, DW alone may not be effective in providing liquidity during the crisis. Indeed, when banks face higher liquidity risks, they might borrow less from DW. In addition, introducing TAF could further increase the stigma of DW relative to the situation when there is only DW.

## Literature

The paper contributes to the literature on LOLR policies, starting from Bagehot (1873). Freixas et al. (1999) offer an earlier review of this literature. Theoretically, our paper discusses how to design LOLR facilities to mitigate the participation stigma. Philippon and Skreta (2012) and Tirole (2012) use a mechanism-design approach to study government intervention in markets

plagued by adverse selection. In the dynamic context, Fuchs and Skrzypacz (2015) show trading restrictions and subsidies could be optimal. Our paper contributes to this literature by allowing for multiple and dynamic policy intervention programs, which have the potential of separating heterogeneous participants. We show how one program could have a higher stigma cost than the other, although both have *identical* requirements. More relevantly, our paper contributes to the theoretical understanding of LOLR (Rochet and Vives, 2004) and the associated stigma (Ennis and Weinberg, 2013; Lowery, 2014; Ennis, 2019). La'O (2014) also explains how TAF may alleviate DW stigma from the perspective of predatory trading. The explanation focuses on the signaling perspective of TAF borrowing. We offer a complementary explanation of how delayed funding settlement creates separation, which according to Bernanke (2015), is crucial to the design of TAF. Moreover, La'O (2014) predicts that in equilibrium, banks always pay a premium for TAF loans over the discount rate, which is at odds with the empirical observation. Che et al. (2023) show that a stigma could have a salutary effect: refusing bailouts could be a useful signal that firms send to their market participants. Gorton and Ordoñez (2020) also study central bank liquidity provision and show that stigma is desirable to implement opacity. Our paper rationalizes the borrowing behavior in the last financial crisis and improves the understanding of appropriate interventions during a financial crisis.

The rest of the paper is organized as follows. Section 2 describes LOLR facilities during the financial crisis. Section 3 sets up the model. Section 4 characterizes the equilibrium of the model and discusses liquidity provision under different settings. Section 5 discusses the empirical relevance of the model. Section 6 concludes, and the appendix contains omitted proofs and our empirical analysis.

# 2 Background

Stress in the interbank lending market began to loom in the summer of 2007 (Figure 1 of Angelini et al. (2011)). In June, two of Bear Stearns' mortgage-heavy hedge funds reported large losses. On July 31, they declared bankruptcy. On August 9, BNP Paribas, France's largest bank, barred investors from withdrawing money from investments backed by US subprime mortgages, citing evaporated liquidity as the main reason (Paribas, 2007). Subsequently, many other banks and financial institutions experienced liquidity dry-ups in wholesale funding in the form of assetbacked commercial paper or repurchase agreements (see Kacperczyk and Schnabl (2010) and Gorton and Metrick (2012)).

With the growing scarcity of short-term funding, banks were supposed to borrow from LOLR.<sup>3</sup>

<sup>&</sup>lt;sup>3</sup>The Federal Home Loan Bank (FHLB) system also helped reduce financial stress at the onset of the crisis. How-

In the US, the role of LOLR has largely been fulfilled by DW, which allows eligible institutions mostly commercial banks—to borrow money from the Fed on a short-term basis to meet temporary shortages of liquidity caused by internal and external disruptions. DW loans were extended to sound institutions with good collateral. Since its founding in 1913, the Fed has never lost a penny on a DW loan.<sup>4</sup> However, banks were reluctant to use DW, due to the widely held perception that a stigma was associated with borrowing from the Fed. As advised by Bagehot (1873), a penalty—1 percentage point above the target federal funds rate—was charged on DW loans, with the goal of encouraging banks to look first to private markets for funding. However, this penalty generated a side effect for banks: Banks would look weak if it became known that they had borrowed from the Fed.

Individual banks' DW borrowing was kept confidential.<sup>5</sup> However, banks were nervous that investors, in particular money market participants, could guess when they had come to the window by observing banks' behavior and carefully analyzing the Fed's balance sheet figures.<sup>6</sup>

The Fed subsequently made a few changes to DW policies. In particular, on August 16, 2007, it halved the interest rate penalty on DW loans. The maturity of loans was also extended from overnight to up to 30 days with an implicit promise of further renewal. Moreover, the Fed tried to persuade some leading banks to borrow at the window, thereby suggesting that borrowing did not equal weakness. On August 17, Timothy Geithner and Donald Kohn hosted a conference call with the Clearing House Association, claiming that the Fed would consider borrowing at DW "a sign of strength." Following the call, on August 22, Citi announced that it was borrowing \$500 million for 30 days. JPMorgan Chase, Bank of America, and Wachovia subsequently announced

ever, Ashcraft et al. (2010) show that FHLB system was not enough to ease liquidity stress by the end of 2007. Also, many institutions such as foreign banks and primary dealers were ineligible for FHLB membership. For example, Dexia Group, the bank that borrowed the most from DW, was not a member of FHLB. A list of FHLB-member banks is maintained by Federal Housing Finance Agency (2023).

<sup>&</sup>lt;sup>4</sup>https://www.federalreserve.gov/faqs/banking\_12841.htm. Initially, DW was a teller window staffed by a lending officer, hence the name.

<sup>&</sup>lt;sup>5</sup>The Dodd-Frank Act required the disclosure of details of DW loans after July 2010 on a 2-year lag from the date on which the loan was made.

<sup>&</sup>lt;sup>6</sup>The stigma associated with borrowing from the government was also significant in the UK. In August 2007, Barclays twice tapped the emergency lending facility offered by the Bank of England. The news came out on Thursday, August 30, when the Bank of England said it had supplied almost 1.6 billion pounds as a LOLR without naming the borrower(s). Journalists and the market scrambled to find out. Barclays declined to confirm that it had used the central bank's standing borrowing facility, but later, it cited a technical breakdown in the clearing system as the reason for the large pile of cash. In its statement, Barclays said, " Had there not been a technical breakdown, this situation would not have occurred."

Shin (2009) described the bank run on Northern Rock, UK's fifth-largest mortgage lender. On September 13, 2007, the BBC broke the news that Northern Rock had sought the Bank of England's support. The next morning, the Bank of England announced that it would provide emergency liquidity support. It was only *after* the announcement—that is after the central bank had announced its intervention to support the bank—that retail depositors started queuing outside the branch offices.

that they had borrowed the same amount, increasing the total amount borrowed at DW by \$2 billion. However, the four big banks—with the borrowing stigma in mind—made it clear in their announcements that they did not need the money. Thirty days later, DW borrowing fell back to \$207 million.<sup>7</sup> On December 11, 2007, the Fed lowered its discount rate to 4.75%, but the attempt was unsuccessful in injecting liquidity to the financial system. The weekly average balance of DW's primary credit program, \$3,009 million in the week of December 13, 2007, for example (Federal Reserve, 2007), was tiny compared to the amount of outstanding borrowing during the rest of the crisis (see Figure 1a).

To further relieve stress in the short-term lending market, the Fed established TAF in December 2007. The rule of the auction was as follows. Every other Monday, banks phoned their local Fed regional banks to submit their bids specifying their interest rate (and loan amount) and to post collaterals. On the next day, the Fed secretly informed the winners and publicly announced the stop-out rate (as well as the number of banks receiving loans), determined by the highest losing bid (or the minimum reserve price if the auction was undersubscribed). On Thursday of the same week, the Fed released the loans to the banks. Throughout the whole auction process, banks were free to borrow from DW. The following Monday, each regional Fed published total lending from last week; banks may be inferred from these summaries or other channels. The first auction, held on December 17, released \$20 billion in the form of 28-day loans. The participation requirement was the same as for DW. The Fed received over \$61 billion in bids and released the full \$20 billion to 93 institutions. In February 2008, Dick Fuld, CEO of Lehman Brothers, urged the Fed to include Wall Street investment banks in auctions, which would require invoking Section 13(3) to allow the Fed to have authority to lend to non-bank institutions, but the Fed refused. From March to September 2008, the stop-out rate in TAF consistently exceeded the concurrent discount rate. The final auction was held on March 8, 2010, as the auctions had been consistently undersubscribed since 2009.

As shown in Figure 1, TAF was clearly more successful than DW in providing liquidity, and banks were also willing to pay a higher interest rate in TAF than the concurrent discount rate in DW. As Bernanke (2015) acknowledged, before implementing TAF, policymakers were also concerned that the stigma that had kept banks away from DW would also be attached to the auctions. The program was implemented as "give it a try and see what happens," but turned out to be quite successful.

<sup>&</sup>lt;sup>7</sup>Records released later show that JPMorgan and Wachovia returned most of the money the next day, whereas Bank of America and Citi—already showing signs of problems—kept the money for a month (Bernanke, 2015).

## 3 The Model

We introduce a static model, and Figure 2 offers a sketch.



Figure 2: Timeline of the Model

The number of banks, *n*, is finite. Each bank is endowed with one unit of an illiquid asset which pays off at the end. Given the potential of liquidity shocks (explained below), each bank can preemptively borrow liquidity from one of the two facilities sponsored by the government: DW and TAF. DW is available before and after TAF bidding date, and the borrowing bank can immediately obtain funding from it. By contrast, TAF releases funds with a delay: there is a gap between TAF bidding date and TAF funding release. Before the asset pays off, each bank faces the potential of a liquidity shock. The liquidity shock could be early (i.e., before TAF releases funds) or late (i.e. after TAF releases funds). When the liquidity shock hits, the bank fails if it has not obtained liquidity yet. In this case, the asset is liquidated with zero payoff. Finally, borrowing banks may incur a penalty if detected borrowing.

Below, let us provide more details.

### 3.1 Preferences, Technology, and Shocks

All banks are risk neutral and do not discount future cash flows. Each bank has one unit of long-term, illiquid assets that will mature at the end of the game. The asset generates cash flows of *R* upon maturity, but nothing if the bank fails and the asset gets liquidated early. Each bank may be hit with a liquidity shock à la Holmström and Tirole (1988). Throughout the paper, we normalize the size of the liquidity shock to one unit. Let  $1 - \theta_i \in [0, 1]$  be the probability that the liquidity shock affects bank *i*, where  $\theta_i$  follows the independently and identically distributed cumulative distribution function (cdf) *F* with associated probability density function (pdf) *f* on the support [0, 1]. Assume that *F* is log-concave. This assumption is not restrictive, as many standard distributions satisfy it; it is imposed to guarantee equilibrium uniqueness.<sup>8</sup> We assume

<sup>&</sup>lt;sup>8</sup>Distributions on a bounded support with a log-concave pdf, which implies a log-concave cdf, include (1) uniform distribution on any convex set and beta if both shape parameters are no less than 1; and (2) truncated distributions

that  $\theta_i$  is private information and only known by the bank itself. For the rest of the paper, we drop subscript *i* whenever no confusion arises. Type  $\theta$  is also referred to as a bank's financial strength. We sometimes refer to a type- $\theta$  bank as bank  $\theta$ .<sup>9</sup>

Conditional on a liquidity shock hitting, the bank immediately fails and receives a zero payoff if it does not have one unit of liquidity in stock to defray it. Therefore, if the bank never borrows any liquidity, its expected payoff is  $\theta R$ . The liquidity shock can be early or late. Specifically, let  $1 - \delta$  be the probability of the shock being early and  $\delta$  be the probability of the shock being late. Receiving a loan with an interest rate of r before the early liquidity shock will help the bank defray the liquidity shock with certainty so that the bank's payoff becomes R - r. Therefore, Bank  $\theta$ 's expected payoff from borrowing a rate-r loan is  $(1 - \theta)R - r$  if it receives the loan before the early liquidity shock, and  $\delta(1 - \theta)R - r$  if it receives the loan before the liquidity shock.<sup>10</sup>

We describe the two lending facilities in the next subsection.

### 3.2 Lending Facilities

Any bank is able to borrow from either DW or TAF.<sup>11</sup>

### 3.2.1 Discount Window

DW is a facility that offers loans at a fixed interest rate  $r_D$ , which is commonly referred to as the discount rate and is exogenously set by the Fed. Since a bank can always borrow from DW with certainty, the net borrowing benefit is  $(R - r_D) - \theta R = (1 - \theta)R - r_D$ .

of the following distributions on unbounded support: normal; exponential; uniform over any convex set; logistic; extreme value; Laplace; chi; Dirichlet if all parameters are no less than 1; gamma if the shape parameter is no less than 1; Weibull if the shape parameter is no less than 1; and chi-square if the number of degrees of freedom is no less than 2 (Bagnoli and Bergstrom, 2005, Theorem 9). (3) For any distribution F, we can redefine banks' type as  $F(\theta)$  so that banks' types are distributed according to uniform [0, 1], which is a log-concave distribution.

<sup>&</sup>lt;sup>9</sup>In reality, one can proxy a bank's strength  $\theta$  by its reserve of liquid assets net the level of its demandable liabilities that can be quickly withdrawn. Following such an interpretation, financially weaker banks are more likely to run into liquidity shortages and therefore have a higher demand for liquidity. Another interpretation is that financially weaker banks have more toxic assets on their balance sheet, and the liquidation value of these assets is necessarily low. These banks are also more likely to run into liquidity shortages in the crisis as well. If a bank only invested in safe (and liquid) assets and did not have any risky projects, then it would not be considered weak.

<sup>&</sup>lt;sup>10</sup>According to Bernanke (2015), one main reason to implement TAF was that it would take time to conduct an auction and determine the winning bids so that borrowers would receive funds with a delay, and thus signal that they were not desperate for cash.

<sup>&</sup>lt;sup>11</sup>Note that for simplicity, we do not allow banks to borrow from the interbank market. Previous research has documented that during the 2007-2008 financial crisis, the interbank market was stressed but not completely frozen (Afonso et al., 2011). In addition, our results are unchanged if the interbank rate gets very high, which was the case during most time of the crisis (see for example Figure 1 and 2 of Thornton et al. (2009)).

#### 3.2.2 Term Auction Facility

TAF allocates preannounced *m* units of liquidity through an auction. In the auction, banks that decide to participate submit simultaneously their sealed bids, which are required to be higher than the preannounced minimum bid  $r_A$ . After receiving all of the bids, the auctioneer ranks them from highest to lowest. The auction takes a uniform-price format: All winners pay the same interest rate, which is referred to as the stop-out rate *s*, and losers do not pay anything. If there are fewer bids than the units of liquidity provided, each bidder receives a loan and pays  $r_A$ . If there are more bidders than the total liquidity, each of the *m* highest bidders receives one unit of liquidity by paying the highest *losing* bid. Formally, suppose there are *l* bidders in total. If  $l \leq m$ , each bidding bank receives a loan by paying  $s = r_A$ . If l > m, each of the *m* highest bidding banks receives a loan of pay anything the  $m + 1^{st}$  highest bid. The remaining l - m banks do not pay anything and, of course, do not receive any liquidity.

We have modeled TAF as an extended second-price auction: All winning parties pay the highest losing bid. In reality, TAF is closer to an extended first-price auction: All winning banks pay the lowest winning bid. The two auctions generate the same revenue for the auction and the same expected payoffs for the bidders, by the revenue equivalence theorem (Myerson, 1981), and consequently make the same borrowing decisions. We present the analysis with the extended second-price auction because it is notationally simpler, as it is a weakly dominant strategy for each bank to bid the maximum interest rate it is willing to pay (Vickrey, 1961).<sup>12</sup>

In reality, winners receive their TAF funds three days after the auction. Recall that there is a probability,  $1 - \delta$ , that an early liquidity shock hits each bank before it receives the funds. Note that if the early liquidity shock has occurred but a TAF winning bank is still waiting for funds to be settled, it cannot borrow from DW. In reality, both DW and TAF loans are collateralized. Thus, if a bank has already pledged its collaterals to TAF, it could no longer borrow from DW had a liquidity shock hit. This assumption is consistent with the narratives in Bernanke (2015), which emphasizes that winning in TAF signals that the bank is likely to survive at least during the three-day settlement period.<sup>13</sup> Hence, the expected net borrowing benefit of a winner who

On the other hand, we would like to stress that the same endogenous separation in bank borrowing from DW

<sup>&</sup>lt;sup>12</sup>In contrast, in the first-price auction, banks shade their bids, which depend on the liquidity supply m and the number of potentially participating banks n.

<sup>&</sup>lt;sup>13</sup>On page 157, Bernanke (2015) wrote, "because it takes time to conduct an auction and determine the winning bids, borrowers would receive their funds with a delay, making clear that they were not desperate for cash." Moreover, Carlson and Rose (2017) wrote, "TAF had several features designed to minimize stigma. TAF featured delayed settlement, with funds generally being delivered two days after the auction, so use of the facility would not signal that the bank had an immediate funding need. The rate at which institutions could borrow at TAF was determined by auction, so that it was market-determined." Courtois and Ennis (2010) wrote in an economic brief, "A three-day settlement period between the close of the auction and disbursement of funds may have reduced the appearance of a desperate need for cash and thus financial distress."

pays stop-out rate *s* is  $\delta(1-\theta)R-s$ , where  $\delta(1-\theta)R$  is the discounted expected investment return when the bank does not face a liquidity shock before TAF fund arrives and *s* is the borrowing cost of TAF fund, regardless of whether it solves liquidity issues. Losers, upon learning the result of the auction, may borrow from DW if needed.

### 3.3 Borrowing Stigma Costs

Banks are assumed to incur a facility-dependent stigma cost. We have argued that a key reason that banks were reluctant to borrow from LOLR is stigma cost. Detected borrowing may signal financial weakness to counterparties, investors, and regulators. Although  $\theta$  is private information, the public can infer based on whether the bank has borrowed or which facility the bank has used if it has borrowed. We assume that upon detection, the public can perfectly tell whether the borrowing has been achieved through DW or TAF.

We capture the notion of stigma cost in a parsimonious way. We assume that after all of the borrowings are complete, banks that have successfully borrowed may be detected independently. Denote the probability of a bank's being detected borrowing from a particular facility to be p. Let  $G_D$  and  $G_A$  be the type distributions of the banks that have borrowed from DW and from TAF, respectively. Let the stigma cost depend on the expected financial condition of the bank. For simplicity, we assume linear dependence. That is, for any detected borrowing decision  $\omega \in \{D, A\}$ ,

$$k_{\omega} \equiv k(G_{\omega}) = K - \kappa \int_0^1 \theta dG_{\omega}(\theta).$$

If the dependence is non-linear, our model will in general have multiple equilibrium, but the qualitative features remain unchanged. For the same reason, we assume the degree of stigma is low relative to the borrowing benefits:  $\kappa \leq \min\left\{\frac{\delta R}{p}, \frac{(1-\delta)R}{p}\right\}$ . For the rest of the paper, we normalize the stigma cost of a bank believed to have an unconditional average condition to be 0,  $k_{\emptyset} \equiv 0.^{14}$ 

Note that financially weaker banks, i.e., those with lower  $\theta$ , will receive a higher stigma cost upon being detected. This cost can be understood as the bank's deteriorated reputation, a reduced chance to find counterparties, the cost of a heightened chance of runs and increasing with-drawals by creditors, fines imposed by regulatory authorities, and an increase in future regulatory scrutiny and compliance costs.

and TAF can be generated even without the delayed settlement. In Online Appendix B, we present such a model, in which TAF is only held once every other week, whereas DW is always immediately available. The only qualitative difference between the two models is whether bids in TAF are monotonic in the bank's type. We decide to focus on the current model because the remarks by policymakers and bank regulators have highlighted the particular feature of the three-day delay in settlement.

<sup>&</sup>lt;sup>14</sup>This implies  $K \equiv \kappa \int_0^1 \theta dF(\theta)$ .

## 3.4 Definition of Equilibrium

In summary, the setting is summarized by the return R, type distribution F of banks, discount rate  $r_D$  in DW, number m of units of liquidity auctioned, minimum bid  $r_A$  in TAF, and the penalty function  $k : G \mapsto \mathbb{R}_+$  attached to different belief distributions of bank's type.

Without loss of generality, we restrict each bank's strategy to be type-symmetric. Each bank  $\theta$ 's strategy can be succinctly described by  $\sigma(\theta) = (\sigma_{D1}(\theta), \sigma_A(\theta), \beta(\theta), \sigma_{D2}(\theta))$ , where  $\sigma_{\omega}(\theta)$  is the probability of borrowing from  $\omega \in \{D1, A, D2\}$ , and  $\beta(\theta)$  is its bid if it participates in the auction. *D1* and *D2* refer to borrowing from DW before and after TAF, respectively. Given strategies  $\sigma$ , beliefs about the financial situation can be inferred by Bayes' rule; in this case, we say that aggregate strategies  $\sigma$  generate a posterior belief system  $G = (G_A, G_D)$ .

**Definition 1.** Borrowing and bidding strategies  $\sigma^*$  and belief system  $G^*$  form an equilibrium if (i) each type- $\theta$  bank's strategy  $\sigma^*(\theta)$  maximizes its expected payoff given belief system  $G^*$ , and (ii) the belief system  $G^*$  is consistent with banks' aggregate strategies  $\sigma^*$ .

Clearly, the best (i.e., type-1) bank has no intention of borrowing, because it would pay a price, incur a stigma cost, and receive no benefit from borrowing. We assume that the borrowing benefit of the worst (i.e., type-0) bank is so high that it has a strict incentive to borrow even given the most pessimistic belief about banks that borrow:  $R - r_D - k(\underline{G}) > 0$ , where  $\underline{G}(\theta) = 1$  for all  $\theta > 0$ .

# 4 Theoretical Analysis

We present the solution of the benchmark design (only DW) and the solution of the actual design (DW and TAF with a delayed release of funds). Then we discuss four alternative designs (only TAF, DW and TAF with immediate release of funds, two DWs with different releases of funds, and two DWs with different interest rates). Finally, since it remains unclear how the public detects banks' borrowing decisions, we discuss our results under alternative detection technologies.

## 4.1 Only DW

We start by examining the equilibrium when the government only sets up DW. The optimal borrowing decision can be characterized by one threshold: Weaker banks borrow from DW, and stronger banks do not borrow at all.

Note (again) that the best bank never borrows because it knows that a liquidity shock could never affect it and therefore it never needs the liquidity; instead, borrowing incurs an interest cost and a stigma cost. The larger the probability a liquidity shock affects the bank, the more incentive

the bank has to borrow. Under the assumption  $r_D < R - k(\underline{G})$ , the worst bank is incentivized to borrow from DW.

Furthermore, there is a unique equilibrium, which is guaranteed by the assumption of a logconcave cdf F.

**Theorem 1 (Equilibrium with only DW).** Suppose only DW is available, i.e., m = 0. There exists a unique equilibrium characterized by a threshold  $\theta^{DW} > 0$ : Banks  $\theta \in [0, \theta^{DW}]$  borrow from DW, and banks  $\theta \in (\theta^{DW}, 1]$  do not borrow. The equilibrium DW stigma is

$$k^{DW}(\theta^{DW}) = K - \kappa \int_0^{\theta^{DW}} \theta dF(\theta) / F(\theta^{DW})$$

where the threshold  $\theta^{DW}$  satisfies

$$(1 - \theta^{DW})R - r_D - pk^{DW}(\theta^{DW}) = 0.$$
 (DW)

DW provides liquidity to all banks worse than  $\theta^{DW}$ , but banks better than  $\theta^{DW}$  do not borrow, because the real economic benefits of borrowing to save the unrealized assets are dwarfed by the interest cost and the stigma cost. The change in the returns, interest rate, and stigma costs will affect liquidity provision as follows.

**Proposition 1 (Liquidity Provision with only DW).** The expected total liquidity to be provided with only DW,  $L^{DW}$ , is  $nF(\theta^{DW})$ . It increases as (i) the return R increases, (ii) the discount rate  $r_D$  decreases, (iii) the probability of detection p decreases, and (iv) the stigma severity  $\kappa$  decreases.

How total liquidity depends on the change in the distribution of banks' types is interesting, though: It may decrease when banks face higher liquidity risks overall.

**Proposition 2** (Market Condition and Liquidity Provision with only DW). Total liquidity with only DW,  $L^{DW}$ , changes ambiguously when the type distribution F shifts in a first-order stochastic dominance (FOSD) way.

To understand this result, note that there are two effects. First, when the distribution of banks becomes worse, holding the stigma cost unchanged, more banks would choose to borrow from DW, increasing total liquidity provision. However, there is a second countervailing force. When banks worse than  $\theta^{DW}$  face even higher liquidity risks than before, banks that borrow from DW are perceived to be of even lower quality than before. As a result, the stigma cost rises, and bank  $\theta^{DW}$ , which was indifferent between borrowing from DW and not, is no longer interested in borrowing. In other words, *the worsened conditions of infra-marginal borrowing banks adversely* 

*affect the borrowing decision of the marginal borrowing bank.* As a result of the stigma cost, DW may not effectively provide liquidity when the worst banks become worse.

This result implies that when banks face higher liquidity risks, they might borrow less from DW because the heightened stigma cost may dominate the increased liquidity demand. The fact that banks were initially reluctant to borrow from DW before introducing TAF suggests that the worst banks in the economy were facing higher liquidity risks.

### 4.2 DW and TAF

We now solve for the equilibrium when both DW and TAF with delayed release of funds are available.

**Lemma 1.** Only banks  $\theta \le \theta_D$  would borrow from DW if they have lost in the auction, where  $\theta_D = 1 - (r_D + pk_D)/R$  and  $k_D$  is the equilibrium stigma cost from DW borrowing.

**Lemma 2.** Banks  $\theta \in (\theta_1, \theta_A]$  participate in the auction, where

$$\theta_1 = 1 - \frac{r_D - r_A + pk_D - pk_A}{(1 - \delta)R}, \quad \theta_A = 1 - \frac{r_A + pk_A}{\delta R}$$

and bid

$$\beta(\theta) = \begin{cases} r_D + pk_D - pk_A - (1 - \delta)R(1 - \theta) & \text{if } \theta < \theta_D \\ \delta R(1 - \theta) - pk_A & \text{if } \theta \ge \theta_D \end{cases}$$

Note that bids are increasing in  $\theta$  when  $\theta < \theta_D$  and decreasing in  $\theta$  when  $\theta \ge \theta_D$ . Intuitively, banks  $\theta < \theta_D$  will always borrow; they will still tap DW after losing in TAF. However, if they win in the auction, chances are that the early liquidity shock could hit them before the funds get settled. In this case, the bank will have to fail. Therefore, delayed settlement is more costly for worse banks that are more likely to be hit by the early liquidity shock. As a result, they bid less. In fact, the bids increase at the rate of  $(1 - \delta)R$  for banks worse than  $\theta_D$ . On the other hand, banks  $\theta > \theta_D$  will choose not to borrow at all after losing in TAF, so they are borrowing only to hedge the late liquidity shock. Among them, worse banks will bid more since they are more likely to be hit by the late liquidity shock. In fact, the bids decrease at the rate of  $\delta R$  for banks better than  $\theta_D$ . Therefore, bank  $\theta_D$  has the highest willingness to pay, and banks further away from  $\theta_D$  have lower willingness to pay. Winners in the auction are going to be the banks that are the closest to  $\theta_D$ . For any bank, as long as its willingness to pay is above  $r_A$ , it will participate in the auction by submitting a bid higher than  $r_A$ . Figure 3 shows the willingness to pay (i.e., bid) in TAF and the optimal facility choice of different banks.



Figure 3: Facility Choice and TAF Bids in the DW-and-TAF Design

The difference in the stigma cost between the two borrowing facilities could lead to banks bidding more than the discount rate  $r_D$ . Specifically, bank  $\theta_D$  is willing to bid up to  $r_D + pk_D - pk_A$  to avoid the stigma cost. As we will show later,  $k_D > k_A$  in equilibrium, so that bank  $\theta_D$  always bids more than  $r_D$ . In general, if the realized bank distribution is concentrated around  $\theta_D$ , the stop-out rate in TAF will be above the discount rate  $r_D$ . The relation between  $\theta_1$  and  $\theta_D$  in the lemmas depends on the equilibrium stigma costs and will be determined in equilibrium, as characterized by Corollary 2 below.

**Lemma 3** (Equilibrium with Both DW and TAF: High Chance of Early Liquidity Shock). Suppose DW and TAF are both available, and there is a sufficiently high chance of an early liquidity shock: m > 0,  $r_D < R - k(\underline{G})$ , and  $\delta \leq [r_A + k(\theta^{DW})] / [r_D + pk^{DW}(\theta^{DW})]$ . In the unique equilibrium, banks  $\theta \in [0, \theta^{DW}]$  borrow from DW, and banks  $\theta \in (\theta^{DW}, 1]$  do not borrow.

Note that the condition on  $\delta$  is less likely to satisfy as  $r_A$  gets higher. We can interpret a low  $\delta$  as a longer delay in releasing the funds from TAF. Therefore, delaying the release of the funds from TAF for too long (and/or setting the minimum bid too high) will render the program ineffective.

**Theorem 2** (Equilibrium with Both DW and TAF: Low Chance of Early Liquidity Shock). Suppose DW and TAF are both available, and there is a sufficiently low chance of an early liquidity shock: m > 0,  $r_D < R - k(\underline{G})$ , and  $\delta > [r_A + k(\theta^{DW})] / [r_D + pk^{DW}(\theta^{DW})]$ . Suppose  $\delta R \ge p\kappa$  and  $(1 - \delta)R \ge p\kappa$ . In the unique equilibrium, there exist three thresholds  $\theta_1$ ,  $\theta_D$ , and  $\theta_A$  such that (i) banks  $\theta \in [0, \theta_1]$  are indifferent between borrowing from DW before the auction and borrowing from DW after the auction; (ii) banks  $\theta \in (\theta_1, \theta_D]$  bid in the auction and borrow from DW if they lose in the auction; (iii) banks  $\theta \in (\theta_D, \theta_A]$  bid in the auction and do not borrow if they lose in the auction; and (iv) banks  $\theta \in (\theta_A, 1]$  neither borrow from DW nor participate in the auction.<sup>15</sup>

Theorem 2 immediately implies:

### **Corollary 1.** In equilibrium, DW stigma $k_D^*$ is larger than auction stigma $k_A^*$ .

Three forces separate banks that borrow in DW and those that borrow in TAF. First, the possibility of early liquidation due to the delayed release of funds in TAF forces the worst banks to borrow from DW and deters them from participating in TAF. Second, excluding the worst banks from the auction ensures that the average quality of banks that borrow from TAF is not too low, which implies that the stigma associated with TAF is not too high, thus further attracting more banks to borrow from TAF. Finally, the competitive nature of the auction attracts banks that would not have borrowed with only DW by offering them a chance to borrow cheaper than the discount rate. TAF serves as an alternative to DW for banks that are close to and worse than  $\theta^{DW}$ . They try borrowing in the auction first before borrowing in DW. TAF serves as a complement for DW in terms of total lending. Banks that are close to and better than  $\theta^{DW}$  switch to borrowing in the auction from not borrowing. This result implies that the presence of TAF could increase the stigma of DW, consistent with some arguments made by policymakers (Carlson and Rose, 2017)

Our next result offers a definitive comparison of the marginal borrower  $\theta^{DW}$  when only DW is offered and  $\theta_D$  and  $\theta_1$  when TAF is offered in addition to DW.

### **Corollary 2.** In comparison, $\theta_1 < \theta_D < \theta^{DW}$ .

When some banks decide to bid in the auction in equilibrium (i.e., the setting described in Theorem 2), the introduction of TAF will attract some marginal borrowers of the original DW to try the auction first before settling on DW. Furthermore, the expected marginal borrowers of DW in the presence of TAF (i.e.,  $\theta_D$ ) will be worse than the marginal borrowers of DW without TAF (i.e.,  $\theta^{DW}$ ), because the higher stigma cost associated with DW in the presence of TAF discourages the marginal borrowers in DW only setting.

**Liquidity Provision.** For total liquidity, consider the expected marginal borrower. The expected marginal borrower is better than  $\theta^{DW}$ , because they borrow from the auction, and the distribution of the types of banks participating in the auction in DW-and-TAF setting first-order

<sup>&</sup>lt;sup>15</sup>The indifference result (i) can be easily broken. For example, if the early liquidity shock has a probability  $\varepsilon > 0$  of occurring between the first DW and TAF bids, then banks between 0 and  $\theta_1$  will strictly prefer DW before TAF. Our baseline model can be thought of as the limiting case whereby  $\varepsilon \to 0$ .

stochastically dominates the distribution of the types of banks borrowing from DW.

**Proposition 3 (Liquidity Provision with Both DW and TAF).** The combination of TAF and DW provides more total liquidity in expectation than does DW alone:  $L^* > L^{DW}$ . The liquidity provided by DW decreases when TAF is introduced.

Even though the combination of TAF and DW provides more liquidity in expectation, it is still possible that the combination of the two facilities can lead to less liquidity provision in realization. In particular, if many realized banks' types are slightly below  $\theta_D$ , then they will bid in TAF, hoping to take advantage of the low reserve price. The losing banks, which would have borrowed from DW if TAF were not available, would choose not to borrow at all.

*Remark.* An important decision the Fed makes is on *m*. In the model, it is the number of winners in the auction. It is also the amount of liquidity released by TAF (or the quantity limit on each bank so that more banks receive the funding and get pooled together in TAF). On the one hand, an increase in *m* will bring more healthy banks into TAF and pool them with less healthy banks to create a lower stigma. More participation may also reduce the chance of banks being detected. However, on the other hand, this will also bring in less healthy banks who are now more willing to wait for the lower stigma. In equilibrium though, the first effect must dominate the second effect; a proof of contradiction can show this claim: If the stigma cost of TAF actually increases when *m* increases, then there should be more banks who borrow from DW directly, which in turn lowers the stigma cost of TAF. Hence, an increase in *m* lowers TAF stigma and hence increases participation in TAF and liquidity provision.

## 4.3 Alternative Designs

Instead of the combination of a periodic TAF and the always available DW, could the Fed have improved liquidity provision? We explore a few alternative designs in this subsection.

### 4.3.1 Only TAF

Next, we examine the equilibrium when the government only sets up the auction. The equilibrium can also be characterized by one threshold: Weaker banks bid their willingness to pay in the auction, and stronger banks do not participate in the auction and do not borrow at all.

**Proposition 4 (Equilibrium with only TAF).** Suppose only TAF is available. Assume  $\delta R - pk(0) > r_A$ . There exists a unique equilibrium characterized by a threshold  $\theta^{TAF}$ : (i) banks  $\theta \in [0, \theta^{TAF}]$  bid  $\beta^{TAF}(\theta) = \delta(1-\theta)R - pk_A$  in TAF, and (ii) banks  $\theta \in (\theta^{TAF}, 1]$  do not bid. Equilibrium

auction stigma is

$$k^{TAF}(\theta^{TAF}) = K - \kappa \int_0^{\theta^{TAF}} \int_0^{\theta_s} \frac{\theta dF(\theta)}{F(\theta_s)} h(\theta_s) d\theta_s - \kappa \int_{\theta^{TAF}}^1 \int_0^{\theta^{TAF}} \frac{\theta dF(\theta)}{F(\theta^{TAF})} h(\theta_s) d\theta_s.$$

where  $h(\theta_s) = {n \choose m} F^{m-1}(\theta_s) f(\theta_s) (1 - F(\theta_s))^{n-m}$  is the pdf of the m<sup>th</sup> weakest bank, and the threshold  $\theta^{TAF}$  satisfies

$$\delta R(1 - \theta^{TAF}) - r_A - pk_A^{TAF}(\theta^{TAF}) = 0.$$
 (TAF)

The two double integrals correspond to the case where the realization of the *m*-th weakest bank falls below and above  $\theta^{TAF}$ , respectively. Our result shows that TAF alone is not necessarily more effective than DW in providing liquidity. If the facilities are used alone, it is unclear which one will provide more liquidity. Therefore, the combination of DW and TAF is needed to increase liquidity provision compared with DW-only design.

### 4.3.2 DW and Immediate TAF

Suppose TAF immediately releases funds to winners, and DW is always available. This is essentially a special case of the DW-and-TAF design above, with a probability  $1 - \delta = 0$  of encountering a liquidity shock between winning the auction and receiving the loan. In this case, TAF becomes a free option. DW no longer possesses an immediacy advantage, so all of the weakest banks bid in the auction first. All of the banks that would borrow from DW after losing in the auction—banks  $\theta \leq \theta'_D$ —bid the same rate  $r_D + pk_D - pk_A$ , and all of the banks that would not borrow from DW after losing in the auction—banks  $\theta > \theta'_D$ —bid lower rates. In summary, as Figure 4 illustrates, banks  $\theta \in [0, \theta'_A]$  participate in the auction. Winners receive loans from TAF, and losers with sufficiently weak financial conditions—banks  $\theta \leq \theta'_D$ —borrow from DW afterward.

**Proposition 5 (Equilibrium with DW and Immediate TAF).** Suppose TAF releases funds immediately and DW is always available. In the unique equilibrium, there exist two thresholds  $\theta'_D$  and  $\theta'_A$  such that banks  $\theta \in [0, \theta'_D]$  bid in TAF and borrow from DW if they lose in TAF, and banks  $\theta \in (\theta'_D, \theta'_A)$  bid in TAF and do not borrow if they lose in TAF.

Compared with the original design, this design could provide less liquidity for two reasons. First, the weakest banks—banks  $\theta \leq \theta_1$ —no longer immediately borrow from DW but participate in the auction, so they take away liquidity from stronger banks that would not have borrowed from DW if they lost in the auction, i.e., banks  $\theta \in [\theta'_D, \theta'_A]$ . Second, the increased participation of the weakest banks in TAF increases its stigma, which discourages stronger banks from bidding in TAF and further increases its stigma cost.





### 4.3.3 DW or Immediate TAF

Suppose DW and TAF are simultaneously offered, and banks can *only* choose to borrow from one facility. Then in equilibrium, there continues to be a separation between TAF and DW borrowing.

**Proposition 6 (Equilibrium with Simultaneous DW and Immediate TAF).** Suppose DW and TAF are simultaneously offered. In the unique equilibrium, there exist two thresholds  $\theta''_D$  and  $\theta''_A$  such that banks  $\theta \in [0, \theta''_D]$  bid borrow from DW, and banks  $\theta \in (\theta''_D, \theta''_A)$  bid in TAF and do not borrow if they lose in TAF.

This hypothetical situation highlights the importance of the competitive nature of the auction in the separation of banks, in addition to the channel of delayed release of funds. Intuitively, TAF introduces uncertainty in terms of whether a bidding bank is able to borrow at a low rate, lower than its willingness to pay, at the cost of potentially failing to borrow and hedge the early liquidity shock. This cost is lower for stronger banks because their borrowing benefits are lower. Therefore, they are more inclined to participate in the auction and take advantage of the opportunity to borrow when rates are sufficiently low. In this case, borrowing is able to divide borrowers into two groups by the so-called "single crossing" condition. It is worthwhile to point out that our result on separation does not depend on the assumption that delaying cost is bigger for weaker banks. To see this, note that a bank's overall payoff has three components that vary with  $\theta$ . First, a stronger bank has lower borrowing benefits. Second, in equilibrium, a stronger bank submits a

lower bid and is less likely to win in the auction. However, third, conditional on winning in the auction, it pays less in expectation. When a bank bids optimally, it is indifferent between raising the bid to increase the winning probability and paying more conditional on winning. Therefore, the last two effects cancel out. As a result, the overall effect is the decreasing benefits of borrowing times the probability of winning in the auction, which is increasing in bank's financial weakness.

### 4.3.4 DWs with Immediate and Delayed Release of Funds

If the delay in releasing funds is important, why doesn't the Fed simply set up a separate DW D' that releases funds later? The main problem with this separate DW is that banks are separated into the two facilities only for certain combinations of discount rate  $r_D$  and discount factor  $\delta$ . Let's explore this possibility and see how this design does not inject liquidity as desired. Suppose DW D' charges the interest rate  $r_{D'}$ .

**Proposition 7** (Equilibrium with Two Differentially Timed DWs). Suppose there are two *DWs*: *D* releases funds immediately and *D'* releases funds with a delay. Suppose  $\delta R \ge p\kappa$  and  $(1 - \delta) \ge p\kappa$ . In the unique equilibrium, there exist two thresholds  $\theta_1$  and  $\theta_2$  such that, banks  $\theta \in [0, \theta_1]$  borrow from *D*, and if  $\theta_2 \ge \theta_1$ , banks  $\theta \in [\theta_1, \theta_2]$  borrow from *D'*.

To guarantee the separation of banks into two facilities, the conditional probability of the early liquidity shock  $1 - \delta$  can be neither too large nor too small.<sup>16</sup> Otherwise, all banks borrow from the early DW (when the chance of an early liquidity shock is high) or borrow from the late DW (when the chance of an early liquidity shock is low). The possible inability to separate banks into two facilities may render the design less useful, as the main purpose of such a design is to separate banks to inject liquidity into stronger banks with a delay. The DW-and-TAF design circumvents this potential problem by setting a relatively low minimum required bid to attract banks to participate in the auction and to allow individual bids, so that those willing to pay the most emerge as winners and separate themselves from other banks.

### 4.3.5 Cheap and Expensive DWs

Setting up two DWs with different interest rates does not provide more liquidity. It provides less liquidity than simply setting up the cheaper DW.

**Proposition 8** (Equilibrium with Two Differentially Priced DWs). Suppose there are two DWs: D charges interest rate  $r_D$  and D' charges interest rate  $r_{D'} > r_D$ . In equilibrium, banks are

<sup>&</sup>lt;sup>16</sup>The specific expression is  $\frac{r_D + pk_D^*}{R} \left[ 1 - \frac{r_{D'} + pk_{D'}^*}{r_D + pk_D^*} \right] < 1 - \delta < 1 - \frac{r_{D'} + pk_{D'}^*}{r_D + pk_D^*}$ .

indifferent between the two DWs. The design offers less liquidity than setting up only the cheaper DWD.

In equilibrium, it must be that all banks are indifferent between the two DWs; otherwise, they would borrow from the one with strictly lower total costs, including borrowing and the stigma cost. Bank  $\theta$  gets  $(1 - \theta)R - r_D - pk_D$  from D, and gets  $(1 - \theta)R - r_{D'} - pk_{D'}$  from D'. All banks are indifferent between the two facilities if  $r_D + pk_D^* = r_{D'} + pk_{D'}^*$ . Therefore, the average bank borrowing from D is worse than the average bank borrowing from D', and consequently, the average bank of all borrowing banks is better than the average bank borrowing from D.

### 4.4 Alternative Detection Technologies

In this subsection, we discuss how alternative assumptions on detection technology could affect our equilibrium results.

**Pooled DW and TAF Detection.** Suppose borrowing from DW faces the same stigma cost and the same probability of detection as borrowing from TAF. In other words, the public can only tell whether a bank has borrowed from the Fed but not whether the borrowing was from DW or TAF. The equilibrium borrowing behavior is qualitatively the same as characterized in Section 4.2: Weaker banks immediately borrow from DW, and stronger banks first bid in the auction. However, no bank would be willing to bid more than the discount rate because the auction would not have a lower stigma cost than DW, as the borrowing cannot be distinguished. This predicted borrowing behavior—bids being capped at the concurrent discount rate—is against the observed pattern that in more than a third of the auctions each winning bank was paying more than the discount rate and in more than two-thirds of the auctions some banks were bidding more than the discount rate.

**Separate Early and Late DW Detection.** Suppose non-auction-week DW and auction-week DW borrowing can be separately detected, as the Fed publishes its balance sheets weekly. Such finer detection technology could further deter banks from borrowing immediately from the early (i.e., non-auction-week) DW, as the stigma cost of early DW increases. It would encourage more banks to bid in the auction, as the auction is a substitute for the early DW. It would also encourage more banks to borrow from the late DW, because the weakest banks that borrow in the early DW are not associated with the late DW stigma anymore. A consequence of a lower late DW stigma cost is lower bids submitted by banks in TAF; nonetheless, the late DW stigma cost is still higher than TAF stigma cost, so some banks still bid higher than the concurrent discount rate.

**Separate TAF Participation and Borrowing Stigma.** Suppose participating in but not borrowing from TAF also incurs a stigma cost. This additional stigma cost would decrease the participation in the auction—as some stronger banks choose not to try in the auction—and as a consequence may reduce aggregate borrowing, as the auction may end up undersubscribed. Safeguarding and not disclosing the participation list would encourage borrowing.

**Public Stop-Out Rate.** In reality, the Fed announces the stop-out rate after each auction. However, whether or not the actual market-clearing borrowing rate is announced does not affect banks' bidding decisions ex-ante. Banks rationally and correctly expect the distribution of stopout rates in equilibrium and make appropriate borrowing and bidding decisions accordingly. The late DW borrowing decision may be affected by the disclosed stop-out rate, as opposed to an expected stop-out rate when it is not publicly announced. The actual borrowing from the postauction DW may change due to the disclosure policy, but the expected aggregate borrowing is unaffected by the disclosure policy.

**Different Detection Probabilities.** Suppose the probability of being detected borrowing in DW is different from being detected in TAF. For example, the equilibrium probability of being detected can depend on the number of banks that actually participate in liquidity provision programs. It is straightforward to show that Theorem 2 continues to hold. Mathematically, the terms involving stigma costs all cancel out in the single-crossing conditions. Intuitively, heterogeneous detection probability does not affect the relative trade-off between using DW and TAF across banks with different financial strengths  $\theta$ .

# 5 Empirical Relevance

This section discusses the empirical relevance of our model. We will summarize existing empirical evidence and very briefly describe empirical analysis conducted by ourselves. A full empirical test of our theory is beyond the scope of this paper. But the evidence here offers partial support to some of the assumptions and implications of the theory. Detailed specifications and results are available in Appendix C.

The issue of DW stigma has been documented since at least Peristiani (1998) and Furfine (2001, 2003, 2005), who offer evidence that banks prefer the federal funds market to DW. During the recent financial crisis, Armantier et al. (2015) use TAF as a laboratory to show the existence of DW stigma and estimate its magnitude. Armantier and Holt (2020) use lab experiments to test policies that have been proposed to mitigate the stigma.

Several empirical papers have studied how government intervention affects liquidity provision during a crisis. Acharya and Mora (2015) show government-sponsored facilities such as FHLB advances and Federal Reserve liquidity facilities enabled banks to continue to provide liquidity during the crisis. Acharya et al. (2017) further show that dealers with lower equity returns and greater leverage were more likely to participate in the Securities Lending Facility (TSLF) and bid higher (and thus borrow more) in the Primary Dealer Credit Facility (PDCF). Using data during the European Sovereign Debt Crisis, Drechsler et al. (2016) show that weakly-capitalized banks borrowed more from LOLR and subsequently invested in risky assets. TAF was shown to be effective in reducing liquidity concerns (Wu, 2011), lowering LIBOR (McAndrews et al., 2017), and conferred a benefit on the real economy (Berger et al., 2017; Moore, 2017).

A central prediction of our model is that financially weaker banks borrowed relatively more from DW than TAF, compared with their stronger peers. To test this hypothesis, we collect granular data on DW and TAF borrowing during the crisis and match them with the regulatory Y-9C data. We show that compared with TAF banks, DW banks have less core deposit, higher leverage, lower tier-1 capital ratio, more unused loan commitment, and rely more on short-term wholesale funding after controlling for bank size, profitability, and bank- and time-fixed effects. According to Cornett et al. (2011), banks that relied more on core deposits continued to lend relative to other banks during the financial crisis because core deposits are stable sources of financing. Therefore, these banks could be less affected by liquidity shortages. Moreover, they argue that unused commitments expose banks to liquidity risk and find that banks with higher levels of unused commitments hoarded more liquidity and cut more lending during the crisis. Given so, our result can be interpreted as DW banks were more exposed to liquidity risks compared to TAF banks. Leverage and tier-1 capital ratios capture banks' loss-absorbing capacities.<sup>17</sup> Finally, the subprime risks taken by banks were funded mostly by short-term market borrowing, and our result on short-term wholesale funding suggests that DW banks may be more exposed to subprime risks than TAF ones.

# 6 Conclusion

In this paper, we investigate how the design of emergency lending facilities can mitigate the stigma associated with borrowing from the central bank's LOLR. We constructed an auction model with endogenous participation and showed that auction bidding strategies that internalized the stigma increased participation and consequently mitigated the borrowing stigma.

<sup>&</sup>lt;sup>17</sup>Demirguc-Kunt et al. (2013) document that during the crisis, banks with higher tier-1 capital ratios also performed better in the stock market.

We derive several theoretical predictions from the model for empirical tests. First, banks with strong financial health are reluctant to borrow from DW due to their reluctance to associate themselves with banks worse than them. Second, when both DW and TAF are available, weaker banks borrow from DW, and stronger ones participate in TAF. Of those that lose in the auction, weaker ones borrow from DW. Third, we show that the introduction of TAF may or may not expand the set of banks that obtain liquidity; it is the combination of TAF and DW that mitigates borrowing stigma and increases liquidity provision. Lastly, the stop-out rate of TAF may be higher or lower than the discount rate.

Our analysis provides a better understanding of the role of a special monetary program, TAF, played during the financial crisis, and suggests how to better design LOLR programs in the future. Our results show that the Fed's design of DW and delayed-funds-release TAF achieved its intended goal of lowering the borrowing stigma by separating the banks into distinct groups, encouraging participation by stronger banks, and providing more liquidity to the economy. The improvement over the current design is a quantitative matter of setting the more appropriate discount rate, minimum bid, and number of days to delay the release of funds. We leave this important quantitative exercise to future research.

## A Omitted Proofs

**Proof of Theorem 1.** Bank  $\theta$  prefers borrowing from DW over not borrowing if and only if

$$u_D(\theta) = (1-\theta)R - r_D - pk_D - (1-p)k_{\emptyset} \ge 0.$$

Since we normalize  $k_{\emptyset}$  to be 0, we can simplify the condition to

$$(1-\theta)R-r_D-pk_D\geq 0.$$

Clearly, the gain from borrowing from DW is strictly decreasing in  $\theta$ . Therefore, for any given  $k_D$ , bank  $\theta$  borrows from DW if and only if

$$\theta \le 1 - \frac{r_D + pk_D}{R}.$$

Therefore, there exists a threshold-let's denote it by  $\theta^{DW}$ -such that bank  $\theta^{DW}$  is indifferent between borrowing from DW and not borrowing; banks worse than  $\theta^{DW}$  borrow from DW; and

banks better than  $\theta^{DW}$  do not borrow. In equilibrium,  $k_D$  depends on  $\theta^{DW}$ :

$$k_{D} = K - \kappa \int_{0}^{\theta^{DW}} \frac{\theta dF(\theta)}{F(\theta^{DW})}$$

Plugging equilibrium  $k_D$  into the equilibrium condition above, we see that  $\theta^{DW}$  is determined by

$$\left(1-\theta^{DW}\right)R-r_D-p\left[K-\kappa\int_0^{\theta^{DW}}\frac{\theta dF\left(\theta\right)}{F\left(\theta^{DW}\right)}\right]=0,$$

which is rearranged as

$$R - r_D - \theta^{DW} R + p\kappa \int_0^{\theta^{DW}} \frac{\theta dF(\theta)}{F(\theta^{DW})} = 0.$$
 (DW)

The terms involving  $\theta^{DW}$  can be rearranged as

$$-\theta^{DW}(R-p\kappa)-p\kappa\left[\theta^{DW}-\int_{0}^{\theta^{DW}}\frac{\theta dF(\theta)}{F(\theta^{DW})}\right].$$

The first term,  $-\theta^{DW}(R - p\kappa)$ , is decreasing in  $\theta^{DW}$ , because  $R > 1 > p\kappa$ . For the second term,  $-p\kappa \left[\theta^{DW} - \int_0^{\theta^{DW}} \frac{\theta dF(\theta)}{F(\theta^{DW})}\right]$ , the expression in the square brackets is *mean advantage over inferiors*, as Bagnoli and Bergstrom (2005) name it. Because the distribution is assumed to be log-concave, by Bagnoli and Bergstrom (2005, Theorem 5), the term in the square brackets is weakly increasing in  $\theta^{DW}$ , so the second term is weakly decreasing in  $\theta^{DW}$ . In summary, the left-hand side of Equation (DW) is strictly decreasing in  $\theta^{DW}$ .

To show the existence of a unique solution to Equation (DW), it remains to show that its left-hand side is positive for  $\theta^{DW} = 0$  and negative for  $\theta^{DW} = 1$ . When  $\theta^{DW} = 0$ , the left-hand side is

$$R-r_D-p\kappa\int_0^1\theta dF(\theta)=R-r_D-pK>0,$$

where the equality follows from the normalization of  $K = \kappa \int_0^1 \theta dF(\theta)$ , and the inequality comes from the assumption that  $R > r_D + pK$ . When  $\theta^{DW} = 1$ , the left-hand side is

$$-r_D + p\kappa \int_0^1 \theta dF(\theta) = -r_D + pK < 0,$$

where the inequality follows from  $r_D > 1 > pK$ . Hence, there is a unique equilibrium.

**Proof of Proposition 1.** The left-hand side of Equation (DW) strictly shifts up when (i) *R* in-

creases, (ii)  $r_D$  decreases, (iii) p increases, or (iv)  $\kappa$  increases. Since the left-hand side of Equation (DW) is strictly decreasing in  $\theta^{DW}$ , the equilibrium  $\theta^{DW}$  increases as a result of any of the changes (i)-(iv).

**Proof of Proposition 2.** The left-hand side of Equation (DW) strictly shifts down when *F* for  $\theta < \theta^{DW}$  shifts in a first-order stochastically dominated way, because the only term affected by the change,  $\int_{0}^{\theta_{DW}} \frac{\theta dF(\theta)}{F(\theta^{DW})}$ , strictly decreases. Hence, the new threshold  $\tilde{\theta}^{DW}$  is strictly smaller than  $\theta^{DW}$ . Total liquidity expected to be provided,  $\tilde{L}^{DW} = nF(\tilde{\theta}^{DW})$ , is also smaller than  $L^{DW} = nF(\theta^{DW})$ .

**Proof of Proposition 3.** From the previous proof we see that the equilibrium condition for the banks that borrow from DW in the DW-and-TAF setting is

$$(1-\theta_D^*)R-r_D-pk_D^*=0.$$

Compare this condition to the equilibrium condition for banks that borrow from DW in the DWonly setting:

$$(1-\theta^{DW})R-r_D-pk^{DW}=0.$$

As long as  $k^{DW} < k_D^*$ , fewer banks are willing to borrow from DW in the DW-and-TAF setting. This condition indeed holds, because the strongest banks of the banks worse than  $\theta_D$  win in the auction.

For total liquidity, consider the expected marginal borrower. The expected marginal borrower is better than  $\theta^{DW}$ , because they borrow from the auction, and in the DW-and-TAF setting, the type distribution of banks winning in TAF first-order stochastically dominates that of banks borrowing form DW.

**Proof of Proposition 4.** Bank  $\theta$  bids (gross) interest rate  $\beta(\theta)$  such that its payoff from winning in the auction with this rate is the same as the payoff from not borrowing,

$$\delta(1-\theta)R - \beta(\theta) - pk_A = 0.$$

In other words, the bid is the bank's maximum willingness to pay (WTP) for the loan:

$$\beta(\theta) = \delta(1-\theta)R - (pk_A).$$

Note that the bid is strictly decreasing in  $\theta$ . Therefore, worse banks are willing to bid higher interest rates. Consequently, given any stigma cost  $k_A$ , there exists a threshold bank  $\theta^{TAF}$  such

that banks worse than  $\theta^{TAF}$  are willing to bid more than the minimum bid  $r_A$ , and all banks better than  $\theta^{TAF}$  are not willing to bid more than  $r_A$ . Bank  $\theta^{TAF}$  bids exactly the prespecified minimum bid  $r_A$ :

$$\beta(\theta^{TAF}) = r_A \Longrightarrow \theta^{TAF} = 1 - \frac{pk_A + r_A}{\delta R}.$$

Now, consider the equilibrium stigma cost:

$$k_A(\theta^{TAF}) = K - \kappa \int_0^{\theta^{TAF}} \int_0^{\theta_s} \frac{\theta dF(\theta)}{F(\theta_s)} dH(\theta_s) - \kappa \int_{\theta^{TAF}}^1 \int_0^{\theta^{TAF}} \frac{\theta dF(\theta)}{F(\theta^{TAF})} dH(\theta_s)$$

where  $H(\theta_s)$  is the distribution of the  $m^{\text{th}}$  weakest bank of all; that is,  $H(\theta_s) = \int_0^{\theta_s} h(\theta) d\theta$ , where

$$h(\theta) = \binom{n}{m} F^{m-1}(\theta) f(\theta) (1 - F(\theta))^{n-m}.$$

Rearranging the expression for  $\theta^{TAF}$ , we have

$$[\delta R - r_A] - [\delta R \theta^{TAF} + pk_A(\theta^{TAF})] = 0.$$
 (TAF)

The terms in the first pair of square brackets do not depend on  $\theta^{TAF}$ . The terms in the second pair of square brackets can be expanded and rearranged as

$$(\delta R - p\kappa)\theta^{TAF} + pK + p\kappa \int_0^{\theta^{TAF}} \int_{\theta_s}^{\theta^{TAF}} \frac{\theta dF(\theta)}{F(\theta_s)} dH(\theta_s) + p\kappa \left[\theta^{TAF} - \int_0^{\theta^{TAF}} \frac{\theta dF(\theta)}{F(\theta^{TAF})} dH(\theta_s)\right].$$

The square bracket in the integral is increasing in  $\theta^{TAF}$ , and the second term is also increasing in  $\theta$  because each term in the integral (Bagnoli and Bergstrom, 2005, mean advantage over inferiors) is positive, as long as  $\delta R > p\kappa$ . The term in the third pair of square brackets in Equation (TAF) is decreasing in  $\theta^{TAF}$ . Therefore, the left-hand side of Equation (TAF) is strictly decreasing in  $\theta^{TAF}$ .

To show the existence of a unique solution to Equation TAF, it remains to show that its lefthand side is positive for  $\theta^{TAF} = 0$  and negative for  $\theta^{TAF} = 1$ . When  $\theta^{TAF} = 0$ , its left-hand side is  $\delta R - r_A - pk(0) > 0$ , and when  $\theta^{TAF} = 1$ , its left-hand side equals  $-r_A < 0$ . Hence, there is a unique equilibrium.

**Proof of Lemma 1.** Bank  $\theta$  would borrow in DW if and only if  $(1 - \theta)R - r_D - pk_D \ge 0$ , which simplifies to  $\theta \ge \theta_D \equiv 1 - (r_D + pk_D)/R$ .

Proof of Lemma 2. Banks that could still get a positive payoff from borrowing in DW if they

lose in the auction are willing to pay up to  $\beta^D(\theta)$ :

$$R(1-\theta) - r_D - pk_D = \delta R(1-\theta) - c - \beta^D(\theta) - pk_A$$

Rearrange:

$$\beta^D(\theta) = r_D + pk_D - pk_A - (1 - \delta)R(1 - \theta) - c.$$

Note that the bid is increasing in  $\theta$ , for  $\theta < \theta_D$ .

On the other hand, for banks that could not get a positive payoff from borrowing in DW, they are willing to pay up to  $\beta^{N}(\theta)$ :

$$0 = \delta R(1-\theta) - c - \beta^{N}(\theta) - pk_{A}$$

Rearrange:

$$\beta^N(\theta) = \delta R(1-\theta) - c - pk_A.$$

Note that the bid is decreasing in  $\theta$ , for  $\theta > \theta_D$ .

Altogether, the maximum WTP in the auction is

$$\beta(\theta) = \begin{cases} \beta^{D}(\theta) = r_{D} + pk_{D} - pk_{A} - (1 - \delta)R(1 - \theta) - c & \text{if } \theta < \theta_{D}, \\ \beta^{N}(\theta) = \delta R(1 - \theta) - c - pk_{A} & \text{if } \theta \ge \theta_{D}. \end{cases}$$

Bank  $\theta$  participates in the auction if its maximum WTP in the auction is greater than the minimum required bid  $r_A$ —that is, if the bank's type is between  $\theta_1$  and  $\theta_A$ , where  $\beta^D(\theta_1) = r_A$  and  $\beta^N(\theta_A) = r_A$ . Solving for those conditions and simplifying, we get

$$\theta_1 = 1 - \frac{r_D - r_A + pk_D - pk_A - c}{(1 - \delta)R}, \quad \text{and} \quad \theta_A = 1 - \frac{r_A + c + pk_A}{\delta R}.$$

Proof of Lemma 3. By Lemma 1, banks borrow from DW if and only if

$$\theta \le \theta_D = 1 - \frac{r_D + pk_D}{R}.$$

Of these banks, some are willing to wait for the auction if and only if

$$\theta > \theta_1 = 1 - \frac{r_D - r_A + pk_D - pk_A}{(1 - \delta)R}.$$

Banks that borrow from DW would not participate in the auction if and only if  $\theta_1 \ge \theta_D$ , which is

$$1 - \frac{r_D - r_A + pk_D - pk_A}{(1 - \delta)R} \ge 1 - \frac{r_D + pk_D}{R}.$$

The inequality can be simplified to

$$r_D + pk_D \ge \frac{r_D - r_A + pk_D - pk_A}{1 - \delta}$$

which further simplifies to

$$r_D + pk_D - \delta(r_D + pk_D) \ge r_D + pk_D - r_A - pk_A,$$

which can be further simplified to  $\delta \leq (r_A + pk_A)/(r_D + pk_D)$ . Hence, in equilibrium, if  $\delta \leq r_A/(r_D + pk_D^*)$ , banks that would borrow from DW if they lost in the auction would not participate in the auction in the first place.

Knowing the condition derived above, we can directly verify that banks  $\theta \in [0, \theta^{DW}]$  borrowing from DW immediately is part of an equilibrium. When banks  $\theta \in [0, \theta^{DW}]$  borrow from DW, the equilibrium DW stigma is  $k_D^* = k_D^{DW}(\theta^{DW})$ , and since we have the assumption  $\delta \leq r_A / [r_D + pk_D^{DW}(\theta^{DW})]$ , by the condition derived above, we have that no DW bank would be willing to participate in the auction. Furthermore, since bank  $\theta^{DW}$ , which should have the highest WTP in the auction, is not willing to participate in the auction, no bank will participate in the auction.

**Proof of Theorem 2.** An equilibrium is determined by three thresholds,  $\theta_1$ ,  $\theta_D$ , and  $\theta_A$ , where

$$\begin{aligned} \theta_D &= 1 - \frac{r_D + pk_D}{R}, \\ \theta_1 &= 1 - \frac{r_D + pk_D - r_A - pk_A}{(1 - \delta)R} \\ \theta_A &= 1 - \frac{r_A + pk_A}{\delta R}. \end{aligned}$$

Rearranging the three equations, we have

$$(1-\theta_D)R - r_D - pk_D = 0, \tag{DW2}$$

$$(1-\theta_1)(1-\delta)R - r_D - pk_D = r_A + pk_A,$$
 (DW1)

$$(1 - \theta_A)\delta R = r_A + pk_A. \tag{A}$$

The stigma costs are

$$k_D(\theta_D, \theta_1, \theta_A) = K - \kappa \frac{\int_0^{\theta_1} \theta dF(\theta) + \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_D} \frac{\theta dF(\theta)}{F(\theta_D) - F(\theta_{s1}(s))} dH(s|\theta_1, \theta_A)}{F(\theta_1) + \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_D} \frac{dF(\theta)}{F(\theta_D) - F(\theta_{s1}(s))} dH(s|\theta_1, \theta_A)}$$

and

$$k_A(\theta_1, \theta_A) = K - \kappa \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_{s2}(s)} \frac{\theta dF(\theta)}{F(\theta_{s2}(s)) - F(\theta_{s1}(s))} dH(s|\theta_1, \theta_A)$$

where  $[\theta_{s1}(s), \theta_{s2}(s)]$  is the interval of types of banks winning the auction when *s* is the stop-out rate, and  $H(s|\theta_1, \theta_2)$  is the distribution of the stop-out rate.

Plugging  $k_A(\theta_1, \theta_A)$  into Equation (A), we have

$$\delta R - r_A - pK - (\delta R - p\kappa)\theta_A - p\kappa \left[\theta_A - \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_{s2}(s)} \frac{\theta dF(\theta)}{F(\theta_{s2}(s)) - F(\theta_{s1}(s))} dH(s|\theta_1, \theta_A)\right] = 0.$$

The expression in the square brackets is mean advantage over inferiors for an order statistics distribution. Then by Chen et al. (2009), the order statistics distribution is log-concave. Hence, by Bagnoli and Bergstrom (2005, Theorem 5), the expression in the square brackets is increasing in  $\theta_A$ . If  $\delta R > p\kappa$ , then the left-hand side of the equation above is strictly decreasing in  $\theta_A$ . For each fixed  $\theta_1$ , there is a unique  $\theta_A$  that satisfies the equation. Let  $\tilde{\theta}_A(\theta_1)$  represent this function, and note that  $\tilde{\theta}_A(\theta_1)$  is strictly increasing in  $\theta_1$ .

Plugging  $k_D$  into Equation (DW2) and rearranging, we have

$$R - r_D - pK - \theta_D R + p\kappa \frac{1}{\Delta} \int_0^{\theta_1} \theta dF(\theta) - p\kappa \frac{1}{\Delta} \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_D} \frac{\theta dF(\theta)}{F(\theta_D) - F(\theta_{s1}(s))} dH(s|\theta_1, \widetilde{\theta}_A(\theta_1)) = 0,$$

where  $\Delta = F(\theta_1) + \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_D} \frac{dF(\theta)}{F(\theta_D) - F(\theta_{s1}(s))} dH(s|\theta_1, \theta_A)$  represents the denominator in the fractional part of the expression of  $k_D$ . The terms that include  $\theta_D$  can be rearranged as

$$-\theta_D(R-p\kappa) - p\kappa \left[\theta_D - \frac{\int_0^{\theta_1} \theta dF(\theta) + \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_D} \frac{\theta dF(\theta)}{F(\theta_D) - F(\theta_{s1}(s))} dH(s|\theta_1, \widetilde{\theta}_A(\theta_1))}{F(\theta_1) + \int_{r_A}^{\infty} \int_{\theta_{s1}(s)}^{\theta_D} \frac{dF(\theta)}{F(\theta_D) - F(\theta_{s1}(s))} dH(s|\theta_1, \widetilde{\theta}_A(\theta_1))}\right]$$

Again, the expression in the square brackets is mean advantage over inferiors for a truncated order statistics distribution, which continues to be log-concave, so it is increasing in  $\theta_D$ . Therefore, for each  $\theta_1$ , there is a unique  $\theta_D$  that satisfies Equation (DW2). Let  $\tilde{\theta}_D(\theta_1)$  represent this function. Plugging  $\tilde{\theta}_D(\theta_1)$ ,  $\tilde{\theta}_A(\theta_1)$ ,  $k_D$ , and  $k_A$  into Equation (DW1), we have

$$-r_D - r_A + (1 - \delta)R - \theta_1(1 - \delta)R - pk_D(\theta_1, \widetilde{\theta}_D(\theta_1), \widetilde{\theta}_A(\theta_1)) - pk_A(\theta_1, \widetilde{\theta}_A(\theta_1)) = 0.$$

Using the same trick as before, we extract and rearrange all the terms that include  $\theta_1$ :

$$-\theta_{1}\left[(1-\delta)R-p\kappa\right]-pk_{A}(\theta_{1},\widetilde{\theta}_{A}(\theta_{1}))\\-p\kappa\left[\theta_{1}-\frac{\int_{0}^{\theta_{1}}\theta dF(\theta)+\int_{r_{A}}^{\infty}\int_{\theta_{s1}(s)}^{\theta_{D}}\frac{\theta dF(\theta)}{F(\theta_{D})-F(\theta_{s1}(s))}dH(s|\theta_{1},\theta_{A})}{F(\theta_{1})+\int_{r_{A}}^{\infty}\int_{\theta_{s1}(s)}^{\theta_{D}}\frac{dF(\theta)}{F(\theta_{D})-F(\theta_{s1}(s))}dH(s|\theta_{1},\theta_{A})}\right]$$

The expression is strictly decreasing for the same reason as in the previous argument, as long as  $(1 - \delta)R > p\kappa$ . Therefore, there is a unique  $\theta_1$ .

**Proof of Corollary 2.** By (DW), threshold  $\theta^{DW}$  satisfies

$$(1 - \theta^{DW})R - r_D - pk^{DW}(\theta^{DW}) = 0 \Longrightarrow \theta^{DW} = 1 - [r_D + pk^{DW}(\theta^{DW})]/R$$

By Lemma 1,

$$\theta_D = 1 - [r_D + pk_D]/R.$$

Because  $\theta^{DW}$  has a strict incentive to bid in the auction,  $\theta^{DW} > \theta_D$ .

**Proof of Proposition 5.** Banks  $\theta \leq \theta_D$  prefer borrowing from DW to not borrowing, where  $\theta_D = 1 - (r_D + pk_D)/R$ , as characterized in the proof of Proposition 1. Banks  $\theta \leq \theta_D$  bid  $\beta(\theta) = r_D + pk_D - pk_A$ , which follows from  $(1 - \theta)R - r_D - pk_D = (1 - \theta)R - \beta(\theta) - pk_A$ . If they participate in the auction, banks  $\theta > \theta_D$  would bid  $\beta(\theta) = (1 - \theta)R - pk_A$ , which follows from  $(1 - \theta)R - \beta(\theta) - pk_A$ . If they participate in the auction, banks  $\theta > \theta_D$  would bid  $\beta(\theta) = (1 - \theta)R - pk_A$ , which follows from  $(1 - \theta)R - \beta(\theta) - pk_A = 0$ . Only banks  $\theta$  such that  $\beta(\theta) \geq r_A$  participate in the auction. That is, only banks  $\theta \leq \theta_A$  participate in the auction, where  $\theta_A = 1 - (r_A + pk_A)/R$  is derived from  $(1 - \theta_A)R - pk_A = r_A$ .

Fix cutoffs  $\theta_D$  and  $\theta_A$ . The stigma cost of borrowing from DW is

$$k_D(\theta_D) = K - p\kappa \int_0^{\theta_D} \theta \frac{dF(\theta)}{F(\theta_D)}.$$

The stigma cost  $k_A(\theta_D, \theta_A)$  of borrowing from TAF is lower, as some banks stronger than  $\theta_D$  may obtain liquidity from TAF:

$$K - p\kappa \left[ \int_0^{\theta_D} \int_0^{\theta_D} \frac{\theta dF(\theta)}{F(\theta_D)} dH(\theta_s) + \int_{\theta_D}^{\theta_A} \int_0^{\theta'} \frac{\theta dF(\theta)}{F(\theta')} dH(\theta_s) + \int_{\theta_A}^1 \int_0^{\theta_A} \frac{\theta dF(\theta)}{F(\theta_A)} dH(\theta_s) \right],$$

where  $H(\theta_s)$  is the distribution of the  $m^{\text{th}}$  weakest bank, that is,  $H(\theta_s) = \int_0^{\theta_s} h(\theta) d\theta$ , where

$$h(\theta_s) = \binom{n}{m} F^{m-1}(\theta_s) f(\theta_s) [1 - F(\theta_s)]^{n-m}.$$

In equilibrium,  $\theta'_D$  is uniquely pinned down by  $R(1-\theta) - r_D - pk_D(\theta) = 0$ , and  $\theta'_A$  is uniquely pinned down by  $R(1-\theta) - r_A - pk_A(\theta, \theta'_D) = 0$ . The uniqueness follows from the monotonicity of the left-hand side of the two equations, which is argued in previous proofs.

**Proof of Proposition 6.** A type- $\theta$  bank who would participate in the auction would bid  $\beta(\theta) = (1-\theta)R - pk_A$ , which is a decreasing function of  $\theta$ ; that is, worse banks would bid higher. Hence, the probability of winning,  $w(\theta)$ , is decreasing in  $\theta$ ; that is, worse banks are more likely to win in the auction. The payoff of bank  $\theta$  in the auction would be  $u_A(\theta) = \int_s^{\beta(\theta)} ((1-\theta)R - s - pk_A)h(s)ds$ , where *s* is the realized stop-out rate and h(s) is the probability density of *s*. Alternatively, bank  $\theta$  would get a payoff of  $u_D(\theta) = (1-\theta)R - r_D - pk_D$  from borrowing in DW. The slope of  $u_D(\theta)$  with respect to  $\theta$  is -R, and the slope of  $u_A(\theta)$  is  $-R \int_s^{\beta(\theta)} h(s)ds$ , negative but greater than -R. Hence, there is a single crossing in  $u_D(\theta)$  and  $u_A(\theta)$  such that there exists  $\theta''_D$  such that for any  $\theta \le \theta''_D$ ,  $u_D(\theta) \ge u_A(\theta)$ , and for any  $\theta > \theta''_D$ ,  $u_D(\theta) < u_A(\theta)$ . Banks  $\theta < \theta''_A$  would be willing to participate in the auction, where  $(1 - \theta''_A)R - pk_A = 0$ , which simplifies to  $\theta''_A = 1 - pk_A/R$ .

**Proof of Proposition 7.** Bank  $\theta$ , by borrowing in DW *D*, gets  $u_D(\theta) = (1 - \theta)R - r_D - pk_D$ , and by borrowing in DW *D'* gets  $u_{D'}(\theta) = \delta(1 - \theta)R - r_{D'} - pk_{D'}$ . Therefore, bank  $\theta$  prefers borrowing from *D* to borrowing from *D'* if and only if

$$u_D(\theta) = (1-\theta)R - r_D - pk_D \ge u_{D'}(\theta) = \delta(1-\theta)R - r_{D'} - pk_{D'},$$

which is rearranged as

$$(1-\delta)(1-\theta)R - (r_D - r_{D'}) - (pk_D - pk_{D'}) \ge 0.$$

Hence, banks  $\theta \leq \theta_1$  borrow from DW *D*, where

$$\theta_1 = 1 - \frac{(r_D - r_{D'}) + (pk_D - pk_{D'})}{(1 - \delta)R}$$

Furthermore, bank  $\theta$  prefers borrowing from DW D' to not borrowing if and only if

$$u_{D'}(\theta) = \delta(1-\theta)R - r_{D'} - pk_{D'} \ge 0,$$

which is rearranged as

$$\theta \le \theta_2 \equiv 1 - \frac{r_{D'} + pk_{D'}}{\delta R}$$

To have banks borrowing from DW D', we must have  $\theta_2 > \theta_1$ , that is,

$$1 - \frac{r_{D'} + pk_{D'}}{\delta R} > 1 - \frac{(r_D - r_{D'}) + (pk_D - pk_{D'})}{(1 - \delta)R},$$
$$\frac{r_{D'} + pk_{D'}}{\delta} < \frac{(r_D - r_{D'}) + (pk_D - pk_{D'})}{(1 - \delta)},$$

which is rearranged as

$$\delta(r_D + pk_D) > r_{D'} + pk_{D'}.$$

Since banks  $\theta \in [0, \theta_1]$  borrow from DW *D*, and banks  $\theta \in (\theta_1, \theta_2]$  borrow from DW *D'*, the stigma costs are

$$k_D(\theta_1) = K - \kappa \int_0^{\theta_1} \frac{\theta dF(\theta)}{F(\theta_1)}$$
 and  $k_{D'}(\theta_1, \theta_2) = K - \kappa \int_{\theta_1}^{\theta_2} \frac{\theta dF(\theta)}{F(\theta_2) - F(\theta_1)}$ .

Equilibrium  $\theta_1$  and  $\theta_2$  satisfy

$$(1-\delta)(1-\theta_1)R - (r_D - r_{D'}) - pk_D(\theta_1) + pk_{D'}(\theta_1, \theta_2) = 0 \quad \text{and} \tag{D1}$$

$$\delta(1 - \theta_2)R - r_{D'} - pk_{D'}(\theta_1, \theta_2) = 0.$$
 (D2)

Plug  $k_D(\theta_1)$  into and rearrange the left-hand side of Equation (D1):

$$(1-\delta)R - (r_D - r_{D'}) - pK - [(1-\delta)R - p\kappa]\theta_1 - p\kappa \left[\theta_1 - \int_0^{\theta_1} \frac{\theta dF(\theta)}{F(\theta_1)}\right] + pk_{D'}(\theta_1, \theta_2).$$

The expression is strictly decreasing in  $\theta_1$  as long as  $(1 - \delta R) > p\kappa$ . In addition, the expression is strictly decreasing in  $\theta_2$ . Therefore, given any  $\theta_2$ , there is a unique  $\theta_1(\theta_2)$  that satisfies Equation (D1), and  $\theta_1(\theta_2)$  is strictly decreasing in  $\theta_2$ . Plug  $k_{D'}(\theta_1, \theta_2)$  into and rearrange Equation (D2):

$$\delta R - r_{D'} - pK - (\delta R - p\kappa)\theta_2 - p\kappa \left[\theta_2 - \int_{\theta_1(\theta_2)}^{\theta_2} \frac{\theta dF(\theta)}{F(\theta_2) - F(\theta_1(\theta_2))}\right] = 0.$$
(D2')

Consider the derivative of  $\theta_2 - \int_{\theta_1(\theta_2)}^{\theta_2} \frac{\theta dF(\theta)}{F(\theta_2) - F(\theta_1(\theta_2))}$  with respect to  $\theta_2$ . Fixing  $\theta_1(\theta_2)$ , the derivative is positive, because the expression is a mean advantage over inferiors for the truncated cdf  $F(\theta)$  between  $\theta_1(\theta_2)$  and  $\theta_2$ . The derivative with respect to  $\theta_1(\theta_2)$  is decreasing, but  $\theta'_1(\theta_2) < 0$ . Hence, the derivative overall is increasing. Therefore, the left-hand side of Equation (D2) is strictly de-

creasing in  $\theta_2$ , as long as  $\delta R > p\kappa$ , and there is a unique  $\theta_2$  that satisfies Equation (D2').

**Proof of Proposition 8.** Bank  $\theta$  gets  $(1-\theta)R - r_D - pk_D$  from D, and gets  $(1-\theta)R - r_{D'} - pk_{D'}$  from D'. All banks are indifferent between the two facilities if  $r_D + pk_D^* = r_{D'} + pk_{D'}^*$ . Therefore, the average bank borrowing from D is worse than the average bank borrowing from D', and consequently the average bank of all borrowing banks is better than the average bank borrowing from D. The marginal bank  $\theta^*$  satisfies  $(1 - \theta^*)R - r_D - pk_D^* = 0$ . However, if the average bank of all banks  $\theta \in [0, \theta^*]$  is better than the average bank borrowing from D,  $(1 - \theta^*)R - r_D - p\left[K - \kappa \int_0^{\theta^*} \frac{\theta dF(\theta)}{F(\theta^*)}\right] > 0$ . Some banks  $\theta > \theta^*$  would have borrowed if only D with interest rate  $r_D < r_{D'}$  were offered.

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# **B** Online Appendix: A Model without the Delay of Funds

This appendix shows that the separation of weaker banks to DW and stronger banks to TAF continues to hold without the delayed release of funds (Proposition 1 below). It demonstrates that the competitive nature of the auction and the delayed release of funds from the auction can drive the separation of banks' borrowing behavior in borrowing from different facilities. In the language of the model below, Proposition 1 below holds when  $\delta = 1$  and/or c = 0.

### B.1 Model

We introduce a two-period, *n*-bank model. The timeline of the model is as follows. Each bank is endowed with an illiquid asset that pays off after the second week. Before the asset pays off, a liquidity shock may hit a bank with a probability that is privately known by the bank; the shock may arrive in the first week or the second week. Before the shock, each bank can borrow from DW and TAF. Borrowing banks may incur a penalty if detected of borrowing. Figure B1 sketches the timing and sequence of events, which we will describe in detail next.



Figure B1: Timeline of the model

**Technology, Preferences, Shocks.** All parties are risk neutral and do not discount future cash flows. At the beginning of the first week, each bank has one unit of long-term, illiquid assets that will mature at the end of the second week. The asset generates cash flows *R* upon maturity but nothing if liquidated early. Shortly before the end of the second week, each bank may be hit with a liquidity shock. The size of the shock is normalized as one unit. Let  $1 - \theta_i \in [0, 1]$  be the probability that the liquidity shock hits bank *i*, where  $\theta_i$  follows the independent and identically distributed cdf *F* and associated pdf *f* on the support [0, 1]. We assume that  $\theta_i$  is private information and only known by bank *i* itself. Without loss of generality, we drop the subscript *i* subsequently.

A loan in the first week will help the bank defray the liquidity shock and therefore brings net benefits  $(1 - \theta) R$  at the cost of interest rate r. Finally, to capture the idea that earlier liquidity may be more valuable, we assume that the liquidity shock may arrive in the first week with probability  $1 - \delta$  and in the second week with probability  $\delta$ , conditional on the shock arriving. To capture the same idea, there can be an additive delayed cost of  $c \ge 0$ , which can be interpreted as the cost

incurred when banks sell illiquid assets at fire-sale prices in order to satisfy immediate liquidity needs. To summarize, a type- $\theta$  bank's payoff is  $\pi_1(\theta, r) = (1 - \theta)R - r$  if it borrows in week 1, and is  $\pi_2(\theta, r) = \delta(1 - \theta)R - r - c$  if it borrows in week 2.

**Borrowing.** A bank can borrow from DW or TAF. DW offers loans at a fixed interest rate  $r_D$ . TAF allocates pre-announced *m* units of liquidity through an auction. In the auction, banks who decide to participate simultaneously submit their sealed bids. Bid  $\beta_i$  specifies the maximum interest rate bank *i* is willing to pay. The bid needs to be higher than the reserve interest rate  $r_A$ . After receiving all the bids, the auctioneer ranks them from the highest to the lowest. All winners pay the same interest rate while losers do not pay anything. If there are fewer bids than the units of liquidity provided, each bidder receives a loan and pays  $r_A$ . If there are more bidders than the total offering liquidity, each of the *m* highest losing bid is also called the stop-out rate *s*, which is the clearing price at which aggregate demand in the auction matches the aggregate supply. Let  $w(\theta, \beta)$  denote the (equilibrium) probability that bank  $\theta$  can win the auction by bidding  $\beta$ . We will focus on symmetric strategies in bidding and as a result can write  $w(\theta, \beta(\theta))$  as  $w(\theta)$  without loss of generality.

**Stigma.** Denote the probability of being detected of borrowing from DW, borrowing from TAF, and the probability of verifying that a bank has not borrowed to be  $p_D$ ,  $p_A$ , and  $p_N$ , respectively. Let  $G_D$ ,  $G_A$ , and  $G_N$  be the type distributions of the banks that have borrowed from DW, from TAF, and have not borrowed, respectively. We capture the notion of stigma in a parsimonious way. Specifically, we assume that after all the borrowings are accomplished, the banks that have successfully borrowed may be detected independently, after which a penalty will be imposed. This penalty can be understood as a cost in bank's deteriorated reputation, a cost in a reduced chance to find counterparties, or a cost from a heightened chance of runs and increasing withdrawals by creditors. Let the stigma cost be  $k(\theta, G_\omega)$ , where  $\omega \in \{D, A, N\}$ . The stigma cost is naturally assumed to be higher when the borrowing banks are worse. Formally,  $k(\theta, G) > k(\theta, G')$ if *G* is strictly first-order stochastically dominated by *G'*. In the baseline model, we eliminate the dependence of stigma cost on a bank's private type and instead assume that it only depends on the borrowing facility  $\omega \in \{D, A, N\}$ . In other words,  $k(\theta, G_\omega) = k(G_\omega) \equiv k_\omega$ . For simplicity, we normalize  $k_N$  to be 0.

**Equilibrium.** In summary, the setting is summarized by the return *R*, probability  $\delta$  of late shock, type distribution *F* of banks, discount rate  $r_D$  in DW, number *m* of units of liquidity auctioned, minimum bid  $r_A$  in TAF, and the penalty function k(G) attached to different belief distributions of bank's type. A type- $\theta$  bank's strategy can be succinctly described by  $\sigma(\theta) = (\sigma_D(\theta), (\sigma_A(\theta), \beta(\theta)))$ , where  $\sigma_{\omega}(\theta)$  is the probability of participating in  $\omega \in \{D, A\}$  and

 $\beta(\theta)$  is its bid if it participates in the auction. Given strategies  $\sigma$ , beliefs about the financial situation can be inferred by the Bayes' Rule. In this case, we say aggregate strategies  $\sigma(\cdot)$  generate posterior belief system  $G = (G_A, G_D, G_N)$ . Note that we have restricted each bank's strategy to be symmetric so that  $\sigma(\cdot)$  only depends on  $\theta$ . Strategies  $\sigma^*$  and beliefs  $G^*$  form an equilibrium if (i) each type- $\theta$  bank's strategy  $\sigma^*(\theta)$  maximizes its expected payoff given belief system  $G^*$ , and (ii) the belief system  $G^*$  is consistent with banks' aggregate strategies  $\sigma^*$ . Clearly, the best (i.e., type-1) bank has no intention to borrow at all, because it would only pay a price and stigma cost but has no benefit from borrowing. We assume that the borrowing benefit of the worst (i.e., type-0) bank is so high that it has a strict incentive to borrow even given the most pessimistic belief about the banks who borrow:  $\delta R - r_D - k(G) > 0$  when  $G(\theta) = 1$  for all  $\theta > 0$ .

### **B.2 Equilibrium Characterization**

We now solve for the equilibrium when both DW and TAF are available. We first describe a bank's bidding strategy in TAF, followed by its incentives in choosing between DW and TAF. Our result shows that relatively stronger banks have more incentives to bid in TAF rather than borrow immediately from DW, which is the key force behind the separation of types in equilibrium.

Let's start by describing a bank's bid in the auction. In general, a bank's bidding strategy depends on its plan after losing in the auction: It can either borrow from DW in the second period or not to borrow at all. Clearly in this case, the incentive to borrow declines with a bank's financial strength.

**Lemma 1.** Only banks  $\theta \leq \theta_2$  will borrow from DW in the second week if they have not borrowed.

**Proof of Lemma 1.** The payoff of not borrowing is  $u_N(\theta) = 0$ , and the payoff of borrowing from DW in the second week is  $u_2(\theta) = \delta(1-\theta)R - r_D - k_D - c$ . Bank  $\theta$  borrows from DW in week 2 if and only if  $u_2(\theta) \ge u_N(\theta)$ , which is rearranged as  $\theta \le 1 - (r_D + k_D + c)/(\delta R) \equiv \theta_2$ .

Let  $\beta^D(\theta)$  be a type- $\theta$  bank's bid if it plans to borrow from DW after losing the auction. Let  $\beta^N(\theta)$  be its bid if it doesn't plan to borrow after losing the auction. Given that a bank's bid does not (directly) affect its payment conditional on winning the auction, a bank bid its own willingness to pay (WTP), as follows.

**Lemma 2.** Bank  $\theta$  who borrows from DW after losing in the auction bids

$$\beta^D(\theta) = r_D + k_D - k_A. \tag{1}$$

Bank  $\theta$  who does not borrow from DW after losing in the auction bids

$$\beta^{N}(\theta) = \delta(1-\theta)R - k_{A}.$$
(2)

**Proof of Lemma 2.** In the auction, the winning bank pays the highest bid among the losers. Therefore, its own bid does not affect its equilibrium payment but only its chance of winning the auction. Therefore, it is its dominant strategy to bid its own willingness to pay. Bank  $\theta$ 's willingness to pay  $\beta(\theta)$  satisfies  $\delta(1-\theta)R - \beta(\theta) - k_A - c = \max \{\delta(1-\theta)R - r_D - k_D - c, 0\}$ . If  $\delta(1-\theta)R - r_D - k_D \ge 0$  so that the losing bank will go to DW,  $\beta(\theta) = r_D + k_D - k_A$ . Otherwise,  $\beta(\theta) = \delta(1-\theta)R - c$ .

Note that  $\beta^{D}(\theta)$  does not depend on  $\theta$ . In other words, any bank who plans to go to DW bids up to the same amount, which equals the sum of  $r_D$ , the discount rate, and  $k_D - k_A$ , the net stigma cost of DW relative to TAF. Intuitively, these banks will always borrow in equilibrium, from either DW or TAF. Therefore, since DW charges the same rate to all borrowers and the stigma cost is also homogeneous across all borrowers from the same facility, their willingnesses to pay are also the same. On the other hand,  $\beta^{N}(\theta)$ , however, does depend on  $\theta$ . Among these banks, weaker ones have higher willingnesses to pay because they have stronger demand for liquidity but will not borrow if they lose in TAF.

Proposition 1 is our main result. It describes the incentive to borrow from DW1 against participating in the auction. In particular, it shows the skimming property that stronger banks are more willing to wait for TAF.

**Proposition 1.** Let  $u_1(\theta)$  be bank  $\theta$ 's expected equilibrium payoff if it borrows from DW in period 1, and  $u_A(\theta)$  its expected payoff if it bids in the auction. In any equilibrium,  $u_1(\theta) - u_A(\theta)$  is decreasing in  $\theta$ .

**Proof of Proposition 1.** The benefit of borrowing in week 1's DW is  $u_1(\theta) = (1 - \theta)R - r_D - k_D$ . Let  $\tau \in [0, 1]$  be the highest losing bank and  $H(\tau)$  its distribution. First consider  $u_A(\theta)$  for  $\theta < \theta_2$ . If  $\tau < \theta_2$ , bank  $\theta$ 's payoff from winning the auction is  $\delta(1 - \theta)R - \beta^D(\theta) - k_A - c$ , which simplifies to  $\delta(1 - \theta)R - r_D - k_D - c$ . If it loses, it turns to DW and receives the same payoff. If  $\tau \ge \theta_2$ , bank  $\theta < \theta_2$  wins the auction for sure and receives payoff  $\delta(1 - \theta)R - \beta^N(\tau) - k_A - c$ , which simplifies to  $\delta(\tau - \theta)R$ . Therefore,  $u_A(\theta) = \delta(1 - \theta)R - (r_D + k_D + c)H(\theta_2) - \int_{\theta_2}^1 [\delta(1 - \tau)R] dH(\tau)$  if  $\theta < \theta_2$ . Next, consider  $u_A(\theta)$  for  $\theta \ge \theta_2$ . In this case, bank  $\theta$  receives  $\delta(\tau - \theta)R - c$  if it wins in the auction. Therefore,  $u_A(\theta) = \int_{\theta}^{1} [\delta(\tau - \theta)R - c] dH(\tau)$  if  $\theta \ge \theta_2$ . Taking the difference, we have

$$u_1(\theta) - u_A(\theta) = \begin{cases} (1-\delta)(1-\theta)R - H(\theta_2)c - \int_{\theta_2}^1 [\delta(1-\tau)R + r_D + k_D] dH(\tau) & \text{if } \theta < \theta_2 \\ (1-\theta)R - r_D - k_D - \int_{\theta}^1 [\delta(\tau-\theta)R + c] dH(\tau) & \text{if } \theta \ge \theta_2. \end{cases}$$

Clearly,  $u_1(\theta) - u_A(\theta)$  is continuous and decreasing at the rate of  $(1 - \delta)R$  when  $\theta < \theta_2$ . When  $\theta > \theta_2$ ,  $\frac{d(u_1(\theta) - u_A(\theta))}{d\theta} = [-1 + \delta(1 - H(\theta))]R < 0$ .

Intuitively, auction introduces uncertainty in terms of whether a bidding bank is able to borrow and if so at what price. Specifically, it introduces one mechanism that enables a bank to borrow at a low rate, lower than its own willingness to pay, at the cost of potentially failing to borrow (for banks  $\theta \in [\theta_2, 1]$ ) or delaying to borrow (for banks  $\theta \in [0, \theta_2]$ ). This cost of not borrowing (or delayed borrowing) is lower for stronger banks because their borrowing benefits are lower. Therefore, they are more inclined to participate in the auction and take advantage of the opportunity to borrow when rates are sufficiently low. In this case, auction is able to separate borrowers into two groups, the so-called "single-crossing" condition. Mathematically, a bank  $\theta \in [0, \theta_2]$  will always borrow even if it chooses to participate in TAF: it will turn to DW in week 2 in the event of losing in TAF, in which case the cost of delay is  $(1 - \delta) (1 - \theta) R$ , decreasing in  $\theta$ . Bank  $\theta \in [\theta_2, 1]$ no longer borrows if it loses in the auction, with the cost of failing to borrowing being  $(1 - \theta) R$ .

Our result on separation does not depend on the assumption that delaying cost is bigger for weaker banks; that is, the result continues to hold when c = 0 and/or  $\delta = 1$ . We would like to emphasize that not any mechanism that offers a trade-off between probability of winning and price paid can separate borrower. To see this, note that a bank's overall payoff has three components that vary with  $\theta$ . First, a stronger bank has lower borrowing benefits. Second, in equilibrium, a stronger bank is less likely to win in the auction. However, conditional on winning in the auction, it pays less in expectation. When a bank bids optimally, it is indifferent between raising the bid to increase the winning probability and paying more conditional on winning. Therefore, the last two effects exactly cancel out. As a result, the overall effect is simply the decreasing benefits of borrowing times the probability of winning in the auction:  $-R[1-H(\theta)]$ . Next, let us consider a mechanism ( $w(\theta), b(\theta)$ ) where  $w(\theta)$  is the probability of receiving one unit of liquidity and  $b(\theta)$  is the price paid. Let  $u_{\omega}(\theta)$  be bank  $\theta$ 's payoff in this mechanism.

$$u_1(\theta) - u_M(\theta) = w(\theta) \left[ b(\theta) + k_\omega + c - r_D - k_D \right] + \left[ 1 - w(\theta) \right] \left[ (1 - \theta) R - r_D - k_D \right]$$

By taking derivatives with respect to  $\theta$ , we can see clearly that the overall effect is ambiguous. Given Proposition 1, in any equilibrium, weaker banks choose to borrow from DW in week 1, and stronger banks bid in the auction. Among the banks who lose in the auction, relatively stronger ones (if any) will still go to the auction.

**Theorem 1.** There exists an equilibrium. Equilibrium borrowing decision is characterized by three thresholds,  $\theta_1$ ,  $\theta_2$ , and  $\theta_A$ : (i) Banks  $\theta \in [0, \theta_1]$  borrow directly from week 1's DW; (ii) Banks  $\theta \in (\theta_1, \theta_A]$  participate in the auction; (iii) Banks  $\theta \in [\theta_2, \theta_A]$  borrow in week 2's auction if they lose in the auction; and (iv) Banks  $\theta \in (\theta_A, 1]$  do not borrow at all.

**Proof of Theorem 1.** Denote the three thresholds by  $\theta_1$ ,  $\theta_2$ , and  $\theta_A$ . Let  $u_{\omega}(\theta|\theta_1, \theta_2, \theta_A)$ ,  $\omega \in \{1, 2, A\}$ , denote bank  $\theta$ 's expected payoff of participating in mechanism  $\omega$ . The three equilibrium thresholds are determined by three conditions:  $u_1(\theta_D|\theta_1, \theta_2, \theta_A) = u_A(\theta_D|\theta_1, \theta_2, \theta_A)$ ,  $u_2(\theta_2|\theta_1, \theta_2, \theta_A) = 0$ , and  $u_A(\theta_A|\theta_1, \theta_2, \theta_A) = 0$ . Let  $h_m^n(x) \equiv {n \choose m} x^m (1-x)^{n-m}$ . Define three correspondences:

$$\phi_1(\theta_1, \theta_2, \theta_A) = \left\{ \theta : u_1(\theta|\theta_1, \theta_2, \theta_A) - \max\{u_A(\theta|\theta_1, \theta_2, \theta_A), u_N(\theta|\theta_1, \theta_2, \theta_A)\} \ge 0 \right\} \cup \{0\},$$
  
$$\phi_2(\theta_1, \theta_2, \theta_A) = \left\{ \theta : u_2(\theta|\theta_1, \theta_2, \theta_A) - u_N(\theta|\theta_1, \theta_2, \theta_A) \ge 0 \right\} \cup \{0\},$$

and

$$\phi_A(\theta_1, \theta_2, \theta_A) = \left\{ \theta : u_A(\theta | \theta_1, \theta_2, \theta_A) - u_N(\theta | \theta_1, \theta_2, \theta_A) \ge 0 \right\} \cup \{0\}.$$

Economically, if it is believed that (i)  $[0, \theta_1]$  is the set of banks willing to borrow from DW 1, (ii)  $[0, \theta_A]$  is the set of banks willing to bid if it has not borrowed from discount window 1, and (iii)  $[0, \theta_2]$  is the set of banks willing to borrow from DW 2 if it has not borrowed after auction, then optimally, (i)  $\phi_1(\theta_1, \theta_2, \theta_A)$  is the set of banks willing to borrow from DW 1, (ii)  $\phi_A(\theta_1, \theta_2, \theta_A)$  is the set of banks willing to borrow from DW 2 if it has not borrowed after auction. We have an equilibrium if the belief is consistent with the optimal action:  $[0, \theta_1] = \phi_1(\theta_1, \theta_2, \theta_A)$ , and  $[0, \theta_A] = \phi_A(\theta_1, \theta_2, \theta_A)$ ; or more simply, if  $(\theta_1, \theta_2, \theta_A) \in \phi(\theta_1, \theta_2, \theta_A)$ ,  $[0, \theta_2] = \phi_2(\theta_1, \theta_2, \theta_A)$ , and  $[0, \theta_A] = \phi_A(\theta_1, \theta_2, \theta_A)$ ; or more simply, if  $(\theta_1, \theta_2, \theta_A) \in \phi(\theta_1, \theta_2, \theta_A) = (\phi_1(\theta_1, \theta_2, \theta_A), \phi_2(\theta_1, \theta_2, \theta_A), \phi_A(\theta_1, \theta_2, \theta_A))$ . Hence, to prove the existence of an equilibrium, it suffices to show that the correspondence  $\phi \equiv (\phi_1, \phi_2, \phi_A)$  has a fixed point. Each of the three correspondences is well-defined on  $X \equiv [0, 1]^3 \cap \{(\theta_1, \theta_2, \theta_A) : \theta_1 \le \theta_A\}$ , a non-empty, compact, and convex subset of the Euclidean space  $\mathbb{R}^3$ , and is upperhemicontinuous with the property that  $\phi_\omega(x)$  for each  $\omega \in \{1, 2, A\}$  is non-empty, closed, and convex for all  $x \in X$ . By Kakutani's fixed point theorem,  $\phi : X \to 2^X$  has a fixed point  $x \in X$ .

# **C** Online Appendix: Empirical Implications

A main prediction of our theory is that the banks that borrowed more from DW over time were fundamentally weaker than the banks that borrowed more from TAF. In this section, to examine this hypothesis, we use data from various sources, including banks' regulatory reporting, subsequent failure, and credit default swap (CDS) spread. Throughout this section, all analysis is conducted at the bank holding company (BHC) level, so our sample is restricted to large banks. Although under Section 23A of the Federal Reserve Act, it is illegal for a member bank to channel funds borrowed from LOLR to other affiliates within the same BHC, temporary exemptions of Section 23A were granted in late 2007 (Bernanke, 2015). Therefore, by conducting our analysis at the BHC level, we implicitly assume an efficient internal capital market within a BHC, which is consistent with the evidence in Cetorelli and Goldberg (2012) and Ben-David et al. (2017).

## C.1 Descriptive Statistics of DW and TAF Borrowing

Let us start by describing the BHCs' borrowing behaviors from DW and TAF. The main dataset we use is obtained through Bloomberg and includes 407 institutions that borrowed from the Fed between August 1, 2007 and April 30, 2010. These data were released by the Fed on March 31, 2011, under a court order, after Bloomberg filed a lawsuit against the Fed.<sup>18</sup> The data contain information on each institution's daily outstanding balance of its borrowing from DW, TAF, and five other related programs. We will merge this dataset with the banks' regulatory database and CDS spreads to study how financial conditions affected the BHCs' borrowing decisions.

Since the Bloomberg dataset was collected by scraping over 29,000 pages of PDF files released from the Fed, data processing could be compromised. To evaluate the data's quality, we calculate the aggregate weekly outstanding balance in DW and TAF programs from the Bloomberg dataset and compare these numbers with the official ones released by Board of Governors of the Federal Reserve System (2019). Figure B2 shows the comparison. Clearly, the Bloomberg data managed to capture the vast majority of borrowing in both DW and TAF.

Table B1 provides the summary statistics of the BHCs' borrowing behavior during the crisis. Approximately 73 percent of borrowing institutions (313 out of 407) are banks, together with diversified financial services (mostly asset management firms), insurance companies, savings and loans,

<sup>&</sup>lt;sup>18</sup>For details, see Torres (2011). In May 2008, Bloomberg News reporter Mark Pittman filed a FOIA request with the Fed, requesting data about details of DW lending and collateral. Unsurprisingly, it was stonewalled by the Fed. In November 2008, Bloomberg LP's Bloomberg News filed a lawsuit challenging the Fed, with the Fox News Network later filing a similar lawsuit. Other news organizations also showed support by filing legal briefs. In March 2011, the US Supreme Court ruled that the Fed must release information on DW loans in response to the lawsuits. Later that month, the Fed released the data, in the form of 894 PDF files with more than 29,000 pages on two CD-ROMS. Bloomberg News later published an exhaustive analysis that included the detailed data.

and other financial service firms. Foreign banks that borrowed through their U.S. subsidiaries were also included. Banks' choices of borrowing facilities were heterogeneous: 260 borrowing institutions tapped both facilities, 18 used only TAF, and 86 used only DW. Borrowing frequencies in both programs exhibit large skewness. While the median bank tapped DW twice, the Alaska USA Federal Credit Union used it 242 times. Similarly, for the 60 TAF auctions, while the median bank borrowed only three times, Mitsubishi UFJ Financial Group borrowed 28 times. On average, TAF lent more liquidity (\$3,174 million) than DW (\$1,529 million) to an average bank, consistent with the evidence in Figure 1a that TAF was more successful in providing liquidity. However, the Dexia Group—the BHC that borrowed the most from DW—borrowed approximately \$190 billion over the 3-year period, far exceeding \$100 billion from the largest borrower in TAF (Bank of America Corporation). This evidence suggests that DW banks were in need of larger amount of liquidity than TAF banks.

## C.2 Evidence from Banks' Fundamentals

### C.2.1 Domestic Banks

We link the Bloomberg data to FR Y-9C reports, the Consolidated Financial Statements for Holding Companies. The Y-9C reports collect financial-statement data from BHCs on a quarterly basis, which are then published in the Federal Reserve Bulletin. All domestic BHCs are required to submit these reports within 40 or 45 calendar days following the end of a quarter. While this merge allows us to use proxies for banks' financial condition, it excludes all foreign banks from the borrowing sample, which took out about 60% of total TAF loans (Benmelech, 2012). Among the 289 U.S.-based banks that borrowed from either DW or TAF, we managed to merge Y-9C reports to 135 of them. These banks account for 42.2% of all American banks' loans from DW, and 81.8% from TAF. Given the reasons for missing matches, our subsequent analysis essentially compare the relatively healthier subsample among DW-borrowing banks with (almost) the whole sample among U.S. TAF-borrowing banks.<sup>19</sup> Therefore, the later results that DW-borrowing banks are on average weaker than TAF-borrowing banks would go through if we could have found all the matches for DW-borrowing banks.

<sup>&</sup>lt;sup>19</sup>There are several reasons behind the missing matches. First, many borrowers were credit unions or savings and loans holding companies that did not file Y-9C reports. For example, US Central Federal Credit Union took out \$39,101 million in loans from the two facilities. Another example is Washington Mutual Inc. Even though it had an RSSD 2550581, it was an S&L holding company instead of a BHC. Therefore, it was regulated by the Office of Thrift Supervision and did not file a Y-9C report. Second, there are certain thresholds for reporting Y-9C. For example, banks with assets below \$1 billion did not have to report. Finally, there were several mergers and acquisitions during the crisis period. For example, Wachovia borrowed \$34,460 million from DW from 2007 Q3 to 2008 Q4, with the majority (\$29,000 million) borrowed in 2008 Q4. However, Wachovia was acquired by Wells Fargo in 2008 Q4, and thus did not file a Y-9C report that quarter.

**Did bank fundamentals predict LOLR borrowing decisions?** To explore how the BHCs' financial condition affects their borrowing from DW and TAF, we estimate the following specification:

$$\frac{DW_{it}}{DW_{it} + TAF_{it}} = \alpha + \beta_1 \cdot x_{it} + \Gamma \cdot [\text{Size}_{it}, ROA_{it}] + \gamma_i + Q_t + \varepsilon_{it},$$
(3)

where  $DW_{it}$  and  $TAF_{it}$  are bank *i*'s average daily outstanding balance from DW and TAF in quarter *t*. The left-hand side of Equation (3) therefore measures the use of DW relative to TAF. On the right-hand side,  $x_{it}$  is one of the proxies for BHC *i*'s financial condition in quarter *t*, including its core deposit to assets ratio, book leverage, tier-1 capital to risk-weighted asset ratio (T1RWA), unused commitment to assets, and short-term wholesale funding to assets. These variables are defined following Ellul and Yerramilli (2013) and Erel et al. (2014). In all regressions,  $\gamma_i$  is the bank fixed effect to take into account time-invariant conditions in the bank's fundamentals, and  $Q_t$  is the quarter fixed effect to incorporate variations in aggregate economic conditions. We include bank size and return to assets (ROA) as additional controls. Note that we use the *contemporaneous* measurement of banks' financial condition, for two reasons. First, the results are qualitatively unchanged if we control for lagged measurements  $x_{i,t-1}$ . Second, since these risk measurements were not available until at least 30 days after the quarter ended, we interpret the contemporaneous risk measurements as the part of banks' fundamentals that are not entirely observed by the public yet.

Table B2 reports the results if the above-mentioned bank fundamental measurements are included one by one; we use robust standard errors in all the regressions. Columns titles indicate the measurement used for bank fundamentals. Column (1) and (2) show that once a bank's core deposits to assets ratio goes up by 1%, the same bank borrows relatively 1% less from DW. The results are economically and statistically significant and also not driven by either time-varying aggregate conditions or the bank's time-invariant variables. Clearly, banks with more stable funding tried to avoid borrowing from DW. Column (3), (4), (5) and (6) confirm similar results if we measure a bank's fundamental through its capital adequacy. Banks with higher book leverage and lower tier-1 capital to risk-weighted assets tend to borrow more from DW. Moreover, Ivashina and Scharfstein (2010) show that borrowers heavily drew down their credit lines during the crisis, implying that banks with more unused loan commitments were more vulnerable and therefore had more urgent liquidity demand. Column (7) and (8) show that indeed, these banks tend to borrow relatively more from DW. Finally, it is widely acknowledged that the 2008 crisis was a run by short-term wholesale creditors (Shin, 2009). Our results in Column (9) and (10) show that banks relied more on short-term wholesale funding also borrowed relatively more from DW as well. Table B3 reports the regression results when we simultaneously control for all these bank

fundamental measurements.<sup>20</sup> Clearly, book leverage and tier-1 capital ratio still stand out as important predictors on a bank's relative use of DW.<sup>21</sup>

**Did LOLR borrowing decisions predict future bank fundamentals?** Did DW and TAF loans capture potentially unobservable risks in banks' fundamentals? In particular, did these loans predict changes in banks' fundamentals? To answer this question, we estimate the following specification:

$$x_{i,t+1} = \alpha + \beta_1 \cdot x_{it} + \beta_2 \cdot \frac{DW_{it}}{DW_{it} + TAF_{it}} + \Gamma \cdot [\text{Size}_{it}, ROA_{it}] + \gamma_i + Q_t + \varepsilon_{it},$$
(4)

where  $x_{i,t+1}$  is one of the previous proxies for BHC *i*'s financial condition in quarter t + 1. We control for the one-quarter lagged financial condition, size, ROA, as well as bank and quarter fixed effects.

Table B4 reports the results. Across all columns, the results show that the relative borrowing from DW could have additional predictive power regarding a bank's core deposits, book leverage, tier-1 capital ratio, unused loan commitment, and reliance on short-term whole sale funding in the next quarter. In particular, if a bank borrows relatively more from DW, all these measurements will imply that the bank becomes less healthy in the next quarter. In other words, the relative borrowing from DW can predict deterioration in a bank's future financial condition, controlling for the relevant financial condition this quarter. Therefore, a bank's reliance on DW captures certain financial condition that is not publicly observable.

The results also have strong economic significance. For example, if a bank switches from 0% to 100% DW borrowing (which is not rare in the sample), its book leverage increases by 0.2%–0.3% after controlling for either the quarter-specific fixed effects or the bank-specific fixed effects. Meanwhile, the unconditional standard deviation of the book leverage is merely 0.01% in our sample. Similarly, the standard deviation of core deposits over assets is 0.06%, whereas a bank that switched from 0% to 100% DW borrowing would reduce its core deposits to assets ratio by somewhere between 0.4% and 1.4%. In terms of the remaining proxies for financial strength, T1RWA has a standard deviation of 0.02%, unused commitment/assets 0.05%, and STWF/Assets 0.04%. All of them are small relative to the magnitude reported in Table B4.

 $<sup>^{20}</sup>$ Since tier-1 capital ratio and book leverage are highly correlated (correlation  $\approx -0.7$ ), we don't control for both in the same regression.

<sup>&</sup>lt;sup>21</sup>We have run additional robustness checks. In particular, the results are largely unchanged if 1) we only use the subsample before 2008 Q3; 2) if we eliminate banks that exclusively borrow from DW throughout the crisis; 3) if we use the lagged bank fundamental measurement x. Moreover, note that we have used the share of outstanding balance from DW as the left-hand-side variable. The results also stay unchanged if instead we use the share of new borrowing loans from DW.

### C.2.2 International Evidence

Specification (3) suffers from potential endogeneity issues. In particular, it does not control unobserved time-varying bank fundamental conditions. To address concerns about these omitted variables, we further employ a difference in differences (DID) approach and explore the international aspects of borrowing banks. In October 2008, leaders from the G7 countries met and established a plan of actions that aimed to stabilize financial markets, restore the flow of credit, and support global economic growth. Following the meeting, all of the G7 countries except Japan immediately announced to launch credit guarantee programs that effectively reduced the liquidity risk faced by domestic financial institutions (Yale Program on Financial Stability, 2019). Later on, many other countries also undertook similar credit guarantee programs to combat the potential crisis.<sup>22</sup> The operation dates of country-specific policies were staggered, however, as these policies could be largely driven by political obstacles through bargaining and renegotiation.<sup>23</sup> The staggered structure offers us an ideal setup to study the difference in these countries' banks' decisions to borrow from LOLR in the US.<sup>24</sup> Specifically, we compare the decisions to borrow from DW and TAF by banks from different countries before and after their country-specific credit guarantee programs. In particular, we focus on the auction held on October 20, 2008 and examine whether implementing (and also announcing) a credit guarantee program prior to that date affects banks' decisions to borrow from DW or TAF. The following equation is estimated a biweekly basis using data from 2008 Q3:

$$\frac{DW_{iw}}{DW_{iw} + TAF_{iw}} = \alpha + T_i + \lambda_w + \delta \cdot (T_i \times \lambda_w) + \varepsilon_{iw},$$
(5)

where  $DW_{iw}$  and  $TAF_{iw}$  are bank *i*'s outstanding balance from DW and TAF in the *w*'s bi-week, respectively. In the specification,  $T_i$  is a dummy variable for the treated group, which takes a value of 1 if the country's operation (announcement) date happens before October 20, 2008. The control group therefore includes countries with policies implemented (announced) after October 20, 2008, as well as countries that did not announce any policy.  $\lambda_w$  is the time trend, which equals one after October 20, 2008. We are mainly interested in the coefficient  $\delta$  before the interaction term, which estimates the DID effect.

We plot the dependent variable  $\frac{DW_{iw}}{DW_{iw}+TAF_{iw}}$  in Figure B3. The two dashed vertical lines mark the two TAF auctions held on October 6 and October 20. Clearly, there was a sharp decline by the treatment group on the relative usage of DW. Prior to Oct 6 and post Oct 20, 2008, the two

<sup>&</sup>lt;sup>22</sup>The details of these programs are available at https://newbagehot.yale.edu/find/all/credit-guarantee.

<sup>&</sup>lt;sup>23</sup>Table B5 lists announcement and operation dates.

<sup>&</sup>lt;sup>24</sup>Buch et al. (2018) show that access to TAF eased German banks financial stress.

groups have parallel trend in terms of the relative borrowing from DW and TAF.<sup>25</sup> A t-test on the difference in the growth rate of the dependent variable across the two groups shows the *t* statistic is only 0.1070 prior to October 6. By contrast, the same t-test during the post-treatment period has a *t*-statistic 1.7839. Table B6 presents the results to specification (5). Column (1) shows that after the policy shock, banks from treated countries, i.e., those countries with credit guarantee programs started before October 20, 2008 borrow about 11% less from DW. Note that these banks originally borrowed more from DW, compared with banks from the control groups. Column (2) conducts the same analysis, but using the announcement date of the credit guarantee program as the quasi-experiment. The results stay largely unchanged. Note that we do not further explore countries whose policies were implemented between the auctions held on Oct 20 and Nov 3, because only very few banks fall into the treatment group in this case.<sup>26</sup>

### C.3 Evidence from Bank Failure

Next, we study whether banks that borrowed more from DW were also more likely to fail subsequently. To do so, we manually collect data on whether a bank failed, was acquired, or got nationalized by the government by December 31, 2011. Our results are robust to the choice of this ending date. In the borrowing sample, 36 financial institutions failed by December 31, 2011. Of these, 11 failed in 2008, eight in 2009, seven in 2010, and 10 in 2011. We study whether banks that borrowed more from DW were more likely to fail from the following linear-probability specification.

$$\mathbb{1} \{ \text{bank } i \text{ fails in } t \} = \alpha + \beta_1 \cdot \frac{DW_{it}}{DW_{it} + TAF_{it}} + \gamma_i + Q_t + \varepsilon_{it}, \tag{6}$$

where  $\mathbb{1}$  {bank *i* fails in  $\tau$ } is an indicator function on whether bank *i* failed in quarter *t*, and  $\frac{DW_{it}}{DW_{it}+TAF_{it}}$  is the fraction of DW outstanding balance. We will also run the unconditional regression where the left-hand side variable is whether the bank failed during the crisis, and the right-hand side includes the aggregate borrowing during the entire sample period (2007Q3 to 2010Q2).

Table B7 reports the results. Column (1) shows that compared with a bank that only borrowed from TAF, a bank that solely borrowed from DW was more likely to fail within the same quarter

<sup>&</sup>lt;sup>25</sup>Note that the treatment group experiences a small upward jump in the week of Sep 23. This jump is statistically insignificant and possibly driven by the collapse of Lehman (15) and AIG (Sep 16).

<sup>&</sup>lt;sup>26</sup>Indeed, Table B5 shows only Austria, Germany, The Netherlands, Portugal, and Sweden fall into this treatment group. Among banks from these countries, only a total of eight banks were borrowing from both DW and TAF during the crisis.

by an additional probability of 1.1%. Column (2) confirms the result if we control for aggregate conditions by adding quarter fixed effects. Column (3) controls for bank fixed effects, where the result is no longer statistically significant. Finally, column(4) shows that if a bank borrows more from DW during the entire sample period, the chance that is fails during the crisis increases by 12.8%. Therefore, the borrowing from DW relative to TAF is associated with more bank failure, so that there are systematic differences between DW-borrowing banks and TAF-borrowing banks.

### C.4 Evidence from CDS Spreads

In this subsection, we take advantage of the high frequency of the Bloomberg data and match borrowing banks with their CDS spreads in the Markit database. Since only very large banks have CDS contracts outstanding, we could match 70 of them, which accounts for 24.8% of DW borrowing and 79.4% of TAF borrowing.

Figure B4 plots the level of 5-year CDS spreads around borrowing dates, after removing fixed effects of BHC, month, and CDS rating. Two observations are prominent. First, prior to the borrowing event, DW banks have persistently higher CDS spreads than TAF banks. The difference (about 0.05) is significant relative to the standard deviation (less than 0.002), implying that prior to the borrowing, DW banks have a higher probability of default as acknowledged by the CDS price. Second, following both borrowing events, BHCs' CDS spreads drop within the next 5 days, even though it seems that TAF banks drop slightly more than DW banks. Two reasons can potentially explain the difference in drop. First, TAF banks in general take out larger loans, and therefore their funding constraint is more relaxed. Second, if borrowing from DW and TAF has an identical probability of being detected, TAF borrowing suffers a lower level of stigma cost.

Formally, we estimate the following specification(s) at the daily frequency:

$$y_{it} = \alpha + \beta \cdot \text{CDS}_{i,t-1} + \gamma \cdot \text{CDS rating}_{i,t-1} + Q_m + \gamma_i + \varepsilon_{it}, \tag{7}$$

where  $y_{it}$  is a dummy variable for if a bank borrows from DW or TAF on date *t*. Table B8 reports the results. In Column (1),  $y_{it}$  equals 1 if BHC *i* borrows from DW on date *t* and 0 if BHC *i* borrows from TAF on date *t*. The coefficient shows that if the BHC's 5-year CDS spreads on date t - 1 increases by 100 basis points, its probability to borrow from DW, as opposed to TAF, increases by 0.1%. In Columns (2) and (3),  $y_{it} = 0$  if BHC *i* does not borrow from DW or TAF. In Column (2),  $y_{it} = 1$  if it borrows from DW, whereas in Column (3),  $y_{it} = 1$  if it borrows from TAF. Clearly, the results show that lagged CDS can predict DW borrowing but not TAF borrowing.



figure plots weakly borrowing amount This the total from DW (left panel) and from TAF (right panel), aggregated from the Bloomberg solid data (red line) and reported from the Fed (blue dashed).



#### Figure B3: Share of DW Borrowing in 2008 Q3 and Q4

This figure plots the average of the variable  $\frac{DW_{iw}}{DW_{iw}+TAF_{iw}}$  across different groups, where  $DW_{iw}$  and  $TAF_{iw}$  are bank *i*'s outstanding balance from DW and TAF in the two week indexed by *w*, respectively. The red solid line shows the average across all banks in the treated groups, i.e., banks from countries whose credit guarantee programs operating before October 20, 2008. The blue dashed line shows the average across all the banks in the remaining countries, i.e., the control group. The two dashed vertical lines mark the two subsequent TAF auctions held on October 6 and October 20.



### Figure B4: CDS Spreads around Borrowing Events

This figure plots an average bank's 5-year CDS spreads on date -5 and 5 surrounding a borrowing event, after removing BHC, month, and CDS-rating fixed effects. The blue solid line shows the spreads if a bank borrows from DW on date 0, whereas the red dashed line shows the spreads if it borrows from TAF on date 0.



	Ν	Mean	Max	Min	SD	$10^{th}$	$50^{th}$	90 <sup>th</sup>
Borrowers	407							
Banks	313							
<b>Diversified Financial Services</b>	24							
Insurance Companies	12							
Savings and Loans	30							
Market Cap on 8/1/07 (MM)		28525	399089	11	49876.8	107	7331	81813
Foreign Banks	92							
DW-only banks	18							
TAF-only banks	86							
borrow both	260							
Total DW events		12	242	0	28.7	0	2	35
Total TAF events		5	28	0	5.1	0	3	13
Total DW amount (MM)		1529	190155	0	10393.8	0	20	1809
Total TAF amount (MM)		3174	100167	0	10727.5	0	58	7250
Number of days in debt to Fed		323	814	28	196.8	85	306	606

### Table B1: Summary Statistics of Bloomberg Data

This table reports the summary statistics of borrowers in the Bloomberg data. The data cover institutions that borrowed from the Fed between August 1, 2007 and April 30, 2010. These data were released by the Fed on March 31, 2011 and subsequently collected by Bloomberg.

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ports. The columns differ in the measurement of financial strength: (1) and (2) use core deposits over assets; (3) and (4) use book leverage; (5) and (6) use T1RWA, (7) and (8) use unused commitment to assets, (9) and (10) use short-term wholesale fund-This table reports OLS and fixed-effect regression results in specification (3), where we put univariate proxy for financial health. The sample contains all BHCs (bank holding companies) that have borrowed in the Bloomberg sample and filed FR Y-9C re-

ing to assets.	All the regi	ressions con	trol tor bar	nk size and	KUA. Stan	dard errors	s in the pare	intheses are r	obust stanc	lard errors.
	Core Depc	osits/Assets	Book	t Lev	Tier-1 Cap	oital/RWA	Unused Co	mmit/Assets	STWF/	Assets
	(1)	(2)	(3)	(4)	(2)	(9)	(2)	(8)	(6)	(10)
x	-0.098 (0.116)	$-1.105^{***}$ (0.363)	$2.111^{**}$ (0.650)	$4.179^{***}$ (1.277)	-1.982*** (0.676)	-4.736*** (0.970)	0.066 (0.245)	$2.730^{***}$ (0.565)	0.227 (0.189)	$0.889^{**}$ (0.347)
ROA	0.443 (3.387)	17.959*** (4.287)	2.653 (3.437)	20.599*** (4.225)	2.740 (3.467)	17.195*** (4.220)	0.355 (3.437)	$13.573^{***}$ (4.613)	0.298 (3.377)	$18.121^{***}$ (4.308)
log(Size)	-0.045*** (0.008)	-0.752*** (0.160)	-0.037*** (0.007)	-0.770*** (0.160)	-0.042*** (0.007)	-0.668*** (0.159)	-0.045*** (0.008)	-0.508*** (0.172)	-0.041 <sup>***</sup> (0.007)	-0.775*** (0.160)
Constant	$1.050^{***}$ (0.167)	12.665*** (2.517)	-1.039* (0.622)	8.573*** (2.725)	$1.170^{**}$ (0.136)	$11.271^{***}$ (2.485)	$0.997^{***}$ (0.118)	7.816*** (2.745)	$0.897^{***}$ (0.121)	$12.254^{***}$ (2.516)
Fixed Effects N	Quarter 731	BHC 731	Quarter 731	BHC 731	Quarter 731	BHC 731	Quarter 674	BHC 674	Quarter 731	BHC 731
${ m R}^2$	0.19	0.53	0.20	0.53	0.19	0.54	0.19	0.54	0.19	0.53

Table B3: LOLR Bo	prrowing and	Multivariate	Bank F	undamentals
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This table reports OLS and fixed-effect regression results in the specification (3), where we include multiple proxies for financial health. Due to collinearity, we do not simultaneously include book leverage and T1RWA. The sample contains all BHCs (bank holding companies) that have borrowed in the Bloomberg sample and filed FR Y-9C reports. All the regressions control for bank size and ROA. Standard errors in the parentheses are robust standard errors.

	(1)	(2)	(3)	(4)
Core Deposits/Assets	-0.107	-1.325**	-0.013	-1.404***
	(0.155)	(0.533)	(0.155)	(0.536)
Tier 1 Capital/Risk-Weighted Assets	-2.212***	-4.246***		
	(0.740)	(1.150)		
Book Leverage			2.005***	4.751***
C			(0.714)	(1.449)
Unused Commitments/assets	0.117	2.087***	0.181	2.651***
	(0.267)	(0.587)	(0.268)	(0.581)
Short-Term Wholesale Fund/Assets	0.158	-0.683	0.107	-0.663
	(0.234)	(0.520)	(0.235)	(0.525)
ROA	3.256	12.300***	2.593	14.004***
	(3.549)	(4.558)	(3.511)	(4.591)
log(Size)	-0.051***	-0.473***	-0.043***	-0.521***
	(0.011)	(0.171)	(0.011)	(0.171)
Constant	1.331***	8.660***	-0.893	4.590
	(0.252)	(2.717)	(0.720)	(2.988)
Fixed Effects	Quarter	BHC	Quarter	BHC
Ν	674	674	674	674
$\mathbb{R}^2$	0.20	0.55	0.20	0.55

9C reports. The c book leverage; (5)	olumns dif and (6) us	fer in the mise T1RWA, (2	easurement $7$ ) and $(8)$ $u$	t of financi 1se unused	ial strength l commitm	i: (1) and (2 ent to asset	2) use core c ts, (9) and (1	leposits over 10) use short-	assets; (3) -term whol	and (4) use esale fund-
ing to assets. All	the regres	sions contro	I for bank	size and I	ROA. Stanc	lard errors	in the pareı	ntheses are r	obust stan	lard errors.
	Core dep	osits/assets	Book	Lev	Tier-1 Caj	pital/RWA	Unused co	mmit/assets	STWF/	assets
	(1)	(2)	(3)	(4)	(5)	(9)	(2)	(8)	(6)	(10)
DW/(DW+TAF)	-0.004	$-0.014^{***}$	$0.002^{***}$	$0.003^{**}$	-0.003**	-0.003**	0.001	$0.004^{**}$	0.008***	$0.012^{***}$
	(0.003)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.004)
$x_{it}$	$0.984^{***}$	$0.716^{***}$	$0.950^{***}$	$0.626^{***}$	$0.905^{***}$	$0.670^{***}$	$0.960^{***}$	$0.658^{***}$	$0.913^{***}$	$0.692^{***}$
	(0.00)	(0.033)	(0.016)	(0.035)	(0.019)	(0.032)	(0.012)	(0.030)	(0.015)	(0.031)
log(Size)	0.000	$0.061^{***}$	-0.000**	$-0.010^{**}$	0.000	$0.013^{**}$	$0.001^{***}$	0.002	-0.001	$-0.040^{***}$
	(0.001)	(0.015)	(0.00)	(0.004)	(0.000)	(0.005)	(0000)	(0.00)	(0.001)	(0.015)
ROA	0.080	-0.713*	-0.250***	-0.040	$0.204^{**}$	-0.225	$0.353^{**}$	$1.019^{***}$	$0.490^{*}$	$1.154^{***}$
	(0.260)	(0.390)	(0.085)	(0.116)	(0.097)	(0.137)	(0.178)	(0.242)	(0.266)	(0.394)
Constant	0.012	-0.804***	$0.051^{***}$	$0.503^{***}$	0.007*	-0.162**	-0.019***	0.018	$0.023^{**}$	0.677***
	(0.013)	(0.229)	(0.015)	(0.074)	(0.004)	(0.081)	(0.006)	(0.143)	(0.010)	(0.230)
Fixed Effects	Quarter	BHC	Quarter	BHC	Quarter	BHC	Quarter	BHC	Quarter	BHC
Ν	726	726	726	726	726	726	597	597	726	726
${ m R}^2$	0.96	0.97	0.85	0.89	0.81	0.86	0.94	0.96	0.85	0.89

Table B4: LOLR Borrowing and Future Bank Fundamentals

This table reports OLS and fixed-effect regression results in specification (4), where we put into proxies for future financial health one by one. The sample contains all BHCs (bank holding companies) that have borrowed in the Bloomberg sample and filed FR Y-

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Table B5: Announcement and Operation Dates of Credit Guarantee Programs

This table lists the announcement and operational dates of all the credit guarantee programs carried out by G7 countries and others that followed. The data are collected by Yale Program on Financial Stability (2019).

Country	Announcement Date	Operational Date
Australia	10/12/2008	11/28/2008
Austria	10/27/2008	10/27/2008
Belgium	10/15/2008	10/15/2008
UK	10/8/2008	10/13/2008
Canada	10/23/2008	2/25/2009
Denmark	10/10/2008	10/11/2008
France	10/12/2008	10/17/2008
Germany	10/13/2008	10/27/2008
Ireland	11/20/2009	12/9/2009
Italy	10/13/2008	12/4/2008
Netherlands	10/13/2008	10/23/2008
Portugal	10/12/2008	10/29/2008
South Korea	10/19/2008	10/20/2008
Spain	10/13/2008	11/21/2008
Sweden	10/20/2008	10/29/2008
US	10/14/2008	10/14/2008

This table reports DID regression results in the specification (5). The sample contains all in-
ternational BHCs (bank holding companies) that have borrowed in the Bloomberg sample be-
tween July 1, 2008 and Dec 31, 2008. All borrowings are aggregated at the bi-weekly fre-
quency. The treament group includes BHCs from countries whose credit guarantee program
happens before October 20, 2008. The control group includes countries with programs after
October 20, 2008, as well as countries that did not announce any policy. Column (1) uses the
operational dates for the credit guarantee programs at the cutoff, whereas column (2) uses an-
nouncement dates. Table B5 lists announcement and operation dates, collected by Yale Pro-
gram on Financial Stability (2019). Standard errors in the parentheses are robust standard errors.

	<b>Operational Dates</b>	Announcement Dates
Treated $\times$ after 10/20/2008	-0.112***	-0.172***
	(0.043)	(0.050)
Treated countries	0.364***	0.373***
	(0.032)	(0.035)
After 10/20/2008	0.029	0.095**
	(0.034)	(0.044)
Constant	0.150***	0.104***
	(0.025)	(0.030)
Observations	1844	1844
Adjusted <i>R</i> <sup>2</sup>	0.076	0.042

## Table B6: Credit Guarantee Programs and LOLR Borrowing

### Table B7: LOLR Borrowing and Bank Failure

Column (1)-(3) report the regression results in the specification (6) with and without BHC/quarter fixed effects. In Column (4), we report the results from the unconditional version of (6), where the dependent variable is whether a bank fails by the end of 2011, and the variable  $DW_{it}$  and  $TAF_{it}$  are respectively replaced by the aggregate borrowing DW and TAF between 2007Q3 and 2010Q2. The sample contains all U.S.-based and international BHCs (bank holding companies) that have borrowed in the Bloomberg sample between 2007Q3 and 2010Q2. We manually collect data on whether a bank failed, was acquired, or got nationalized by the government by December 31, 2011. Standard errors in the parentheses are robust standard errors.

	Fail	this quart	er	Fail during Crisis
DW/(DW+TAF)	0.011***	0.009**	0.006	0.128**
	(0.004)	(0.004)	(0.005)	(0.064)
Constant	0.002	0.002	0.003	0.070***
	(0.002)	(0.002)	(0.002)	(0.016)
<b>Fixed Effects</b>	No	Quarter	BHC	No
Ν	2025	2025	2025	364
$R^2$	0.00	0.01	0.19	0.02

#### Table B8: CDS Spreads and Borrowing Events

This table reports the regression results in the specification (7). The three columns differ in the dummy variable on the left-hand side of the specification. In column (1), the variable takes 1 if a bank borrows from DW on date t and 0 if it borrows from TAF on date t. In (2), the variable takes 1 if it borrows from DW on date t and 0 if it does not borrow on date t. Finally, in (3), the variable takes 1 if it borrows from TAF on date t and 0 if it does not borrow on date t. The sample contains BHCs (bank holding companies) with outstanding CDS data available in the Markit database. Standard errors in the parentheses are robust standard errors.

	(1)	(2)	(3)
	DW/TAF	DW/None	TAF/None
Lagged 5y CDS spread	0.129**	0.004***	0.001
	(0.058)	(0.001)	(0.002)
Constant	1.257***	0.030***	0.004
	(0.279)	(0.007)	(0.010)
N	707	33440	33617
$R^2$	0.466	0.043	0.016