The First Line of Defense: The Discount Window during the Early Stages of the Financial Crisis*

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Differences in stigma of borrowing from the discount window across banks caused federal funds rates to rise early in the 2007–09 financial crisis, even as the spread between the discount rate and the target rate narrowed. Low-stigma banks went to the discount window, leaving only high-stigma banks in the market, creating a separating equilibrium. A simple theoretical model illustrates this point, and its implications are evaluated using an empirical selection model. The results suggest the selection effect became stronger as the crisis intensified pre-Lehman, but faded once reserves ballooned.

JEL Codes: E52, E58, G28.

1. Introduction

The discount window's "lender-of-last-resort" function is one of the Federal Reserve's oldest tools to combat financial crises. It was also one of the first tools the Federal Reserve used at the start of the financial crisis in August 2007. About two weeks into the financial crisis, the Federal Reserve Board narrowed the spread between the rate on discount window loans (the "discount rate" or the "primary credit rate") and the Federal Open Market Committee's (FOMC's)

*The views expressed in this paper are those of the author and not necessarily those of the Board of Governors, other members of its staff, or the Federal Reserve System. Thanks to the editors and an anonymous referee for guidance, as well as Seth Carpenter, Huberto Ennis, Jane Ihrig, Ruth Judson, Ed Nelson, Viktors Stebunovs, and Shangwen Wang for helpful comments. Peter Andersen, Amanda McLean, and Ari Morse provided excellent research assistance. Author contact: Board of Governors of the Federal Reserve System, 20th and C Streets, Washington, DC 20551. Tel: (202) 721-4501. E-mail: elizabeth.c.klee@frb.gov.

policy rate (the target federal funds rate, or the "target rate") to promote the restoration of orderly conditions in financial markets.[1,2] On March 16, 2008, the spread was narrowed again, to "bolster market liquidity."[3] By narrowing the spread between the target rate and the primary credit rate,[4] the Federal Reserve aimed to provide ample liquidity to the federal funds market, the overnight U.S. interbank market for funds held in accounts by depository institutions at the Federal Reserve, and to keep rates in the federal funds market trading near the target rate.[5]

These actions were successful, as shown in figure 1: Lending in the Federal Reserve's main discount window program, the primary credit program, stepped up with each narrowing of the spread. (To see the figures in color, where the lines can more easily be differentiated, see the online version of the paper at http://www.ijcb.org.) However, volatility in the federal funds market picked up, and the spread between the highest federal funds rates banks paid and the target rate widened with each narrowing of the spread between the discount rate and the target rate.[6] In fact, on many days, the highest brokered rate was often above the discount rate. This was a puzzle, given that a bank could borrow directly from the Fed at the discount rate, and so the discount rate should have been a ceiling for rates in the federal funds market.[7]

Why did some federal funds trades occur at higher rates, even as the discount rate fell? One possible explanation is that banks borrowing federal funds differ according to their internal costs of using

[1]Federal Reserve Board Press Release, August 17, 2007.

[2]The primary credit program is the name of the principal Federal Reserve discount window program, and the primary credit rate is the rate at which funds are lent to sound depository institutions in that program. Since 2003, primary credit has been offered at a rate above the target federal funds rate.

[3]Federal Reserve Board Press Release, March 16, 2008.

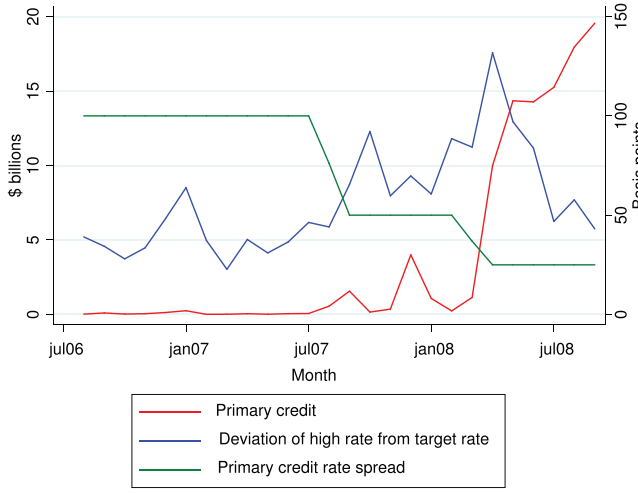
[4]The spread was narrowed by lowering the discount rate, not by raising the target rate.

[5]At that time, the Federal Reserve implemented monetary policy largely by influencing conditions in the federal funds market so that the average rate in that market (the "effective" federal funds rate) trades close to the target rate. For the rate definitions used in this paper, refer to table 1.

[6]In this paper, we use the term "banks" even in instances when the broader term "depository institutions" may apply.

[7]Although there were some instances of trading above the primary credit rate before the beginning of the financial crisis, the incidence was much less frequent.

Figure 1. Primary Credit and the Federal Funds Rate, Monthly Averages



Sources: H.4.1 Statistical Release, Federal Reserve Board; Federal Reserve Bank of New York.
Notes: This figure presents monthly average information on primary credit extensions ($billions), the deviation of the highest brokered federal funds rate from the target rate (basis points), and the spread between the primary credit rate and the target federal funds rate (basis points). The panel reflects data from August 2006 to September 2008.

the discount window as a funding source, over and above the rate charged by the Federal Reserve. These costs can be interpreted as a stigma of discount window borrowing.[8] Banks lending federal funds recognize that some borrowers might have an additional stigma cost of going to the discount window. Consequently, lenders charge borrowers higher rates than would be predicted simply by using the

[8] As described by Bernanke (2008):

> The efficacy of the discount window has been limited by the reluctance of depository institutions to use the window as a source of funding. The "stigma" associated with the discount window, which if anything intensifies during periods of crisis, arises primarily from banks' concerns that market participants will draw adverse inferences about their financial condition if their borrowing from the Federal Reserve were to become known.

spread between the primary credit rate and the target rate as a guide for the maximum rate in the market. In addition, federal funds market trading drops, as banks with lower stigma costs borrow from the discount window instead of paying high rates in the market.

This paper provides an analytical framework that captures characteristics of discount window borrowing and the federal funds market during the first year of the financial crisis, including (i) the narrowing of the spread between the discount rate and the target rate; (ii) the increased incidence of high-rate trading; and (iii) the decline in participation in the federal funds market. Lenders have imperfect information on the stigma costs of borrowers. These stigma costs can be interpreted as borrowers having different private costs of using the discount window as a funding source. The source of these costs could be something as simple as a manager of funding operations not wanting to fill out the necessary paperwork to execute a discount window loan, to a broader sentiment that banks do not want to be observed borrowing funds from the discount window during a financial crisis.[9] Differences in stigma across banks can cause both the federal funds rate to rise and discount window borrowing to increase when the spread between the discount rate and the target rate narrows. When the discount rate is high relative to the target rate, all banks stay in the funds market and few borrow from the discount window. Lenders cannot distinguish between different types of banks, and therefore all banks pay the same rate. By contrast, after the spread between the discount rate and the target rate narrows, banks that perceive a relatively lower stigma of going to the discount window ("lower-stigma" banks) do so, and exit the federal funds market. Concurrently, banks that perceive a higher stigma of going to the discount window ("higher-stigma" banks) refuse to borrow, and remain in the federal funds market. Lenders recognize that only high-stigma banks are left in the market, and so lenders can charge these banks high rates. This selection mechanism results in higher traded federal funds rates, lower federal funds market volume, and higher discount window borrowing. Moreover, any increases in

[9]Like other authors (Armantier and Copeland 2015), this paper is agnostic on the source and nature of this cost, but does suggest that some internal costs exist.

discount window stigma, which possibly could have occurred over the first year of the crisis, magnify these outcomes.[10]

After developing the framework, the paper explores its implications using federal funds market data. Both aggregate and bank-level data show how a possible increase in stigma and the resulting selection mechanism could contribute to higher observed rates in the federal funds market. The data suggest that, in aggregate, both federal funds volume brokered at rates above the primary credit rate and discount window increased during the first stages of the crisis. The empirical model results suggest that funds rates were correlated with some indicators of credit risk during the crisis in ways not evident during normal times. These indicators could be correlated with the stigma of going to the discount window, or be a proxy for the intensification of stigma as the crisis progressed. Bank-level data suggest some selection in the federal funds market, as banks that did not borrow from the discount window paid higher rates in the federal funds market than banks that did both. This selection became stronger as the spread between the primary credit rate and the target rate narrowed, coincident with the intensification of the financial crisis.

This paper is part of a long literature on discount window stigma. The literature suggests that there is a stigma associated with borrowing from the discount window that becomes more pronounced during financial crises. Friedman and Schwartz (1963) noted that such a stigma existed in the Great Depression, which may have impeded the Federal Reserve's ability to ease financial market conditions. Other stigma episodes stem from strains in the banking industry; Peristiani (1998) explored the rise in discount window stigma during the 1980s, which he attributed to worsening bank conditions. Similar to the analysis here, Ennis and Weinberg (2013) also model the effects of stigma on discount window borrowing during the recent financial crisis.[11] Finally, in recent empirical work, Armantier et al.

[10]Stigma is not the same as riskiness, and buying banks can experience a rise in stigma costs without an increase in riskiness. Still, this increase in stigma may be correlated with overall indicators of financial risk, as borrowers would be concerned that lenders would perceive banks as risky if they did go to the discount window.

[11]Calomiris (1994) empirically examines a related issue, the spreads on commercial paper as a result of the Fed's discount window lending during the Penn

(2015) also show that discount window stigma existed during the financial crisis, and banks substituted Term Auction Facility (TAF) borrowings as a result.

Still, other studies suggest a discount window stigma was present even in relatively normal times. In a theoretical model, Clouse and Dow (1999) pointed out that discount window stigma can lead to high rates in the federal funds market. Furfine (2003) concluded that stigma from borrowing at the discount window still existed even after the introduction of the primary credit program in 2003; by contrast to the previous discount window program, there was no "administration" from bank regulators in case of a borrowing.

This paper contributes to the literature in three ways. First, it provides a simple framework to illustrate how changes in the discount rate and increases in stigma can lead to selection in the federal funds market. Second, it evaluates how this stigma may have increased in aggregate in the federal funds market during the recent crisis by examining the correlation of trading at high rates and various indicators of market risk. And third, it confirms the existence of selection in the federal funds market during the financial crisis using bank-level data and panel estimation techniques to control for selection bias. Although previous literature has addressed different parts of the overall question, few studies have tied together both the theoretical implications of a simple model of a stigma with an illustration of its existence in the data.

2. Background

2.1 Monetary Policy Implementation

For many years, the discount window was one of the Federal Reserve's three main tools to implement monetary policy; the other two were open market operations and reserve requirements. Traditionally, the Federal Reserve implemented monetary policy by providing an appropriate level of reserve balances so that the federal funds rate would trade close to the target federal funds rate set

Central crisis. The lending in question, however, was to a nonbank and, in today's parlance, would have likely fallen under the auspices of the Commercial Paper Funding Facility (CPFF) or a direct loan to a nonbank counterparty, rather than the investigation of Fed lending to banks that is examined here.

by the FOMC. One way reserve balances are supplied is through open market operations. The other way that reserve balances can be supplied is through discount window borrowing.

As a result, in normal times, a bank had two ways to obtain funds to satisfy its reserve requirement, defined as an average level of funds required to be held in a bank's account at the Federal Reserve, and calculated as a percentage of a bank's total deposits. A bank could either buy funds in the federal funds market or borrow funds directly from the Federal Reserve at the discount window. Federal funds loans are unsecured advances of another bank's excess balances held in its account at the Federal Reserve. Federal funds loans are usually overnight, although some are for longer terms.

In some periods, discount window borrowing has been an integral part of monetary policy implementation, while in other times, its role has been less direct. For example, under the implementation regime in effect during the 1970s and 1980s, the FOMC declared a target for "borrowed" reserves, or those obtained from the discount window. The appropriate level of open market operations would be determined so that the level of "nonborrowed reserves" would induce the right amount of borrowing of "borrowed reserves." In turn, the level of "total reserves" would be such that funds would trade near the target federal funds rate. By contrast, through the 1990s and 2000s, discount window borrowing was not forecasted and was not an active part of the FOMC policy directive. This was the regime in place for the period studied in this paper as well.

2.2 The Discount Window

At its inception, one of the goals of the Federal Reserve System was to moderate the swings in deposits experienced by banks outside of the country's major banking centers. Loans outstanding would increase at the beginning of the growing season, while deposits would decline markedly, and after the harvest, loans would be repaid and deposits would increase. This led to a mismatch in timing between assets and liabilities for smaller banks outside of the major cities. While larger banks could provide funds to smaller ones, there were still banks with limited access to broader funding markets.

The discount window and the associated seasonal credit program were established in part because of this mismatch. In particular, the

discount window was viewed as a backstop funding facility to institutions with limited access to funds through other channels that would experience these swings in assets and liabilities. Although through the second half of the 20th century fewer banks were dependent strictly on an agrarian economy, the discount window remained available for institutions that lacked other access to funding.

While the function of the discount window has remained fairly constant over its history, its administration has not. According to Madigan and Nelson (2002), from the start of the Federal Reserve System through the mid-1960s, discount window loans were extended at rates equal to or higher than short-term market interest rates. This framework is known as a "penalty rate" regime. However, the regime changed subsequently, and from the mid-1960s through 2002, the rate paid on discount window loans was pegged 25 to 50 basis points below the target federal funds rate. The amount of funds lent through the discount window was controlled through Federal Reserve requirements that banks borrow only for short-term needs, exhaust other sources of funds, and refrain from arbitrage using funds borrowed from the discount window.[12] There were two major discount window programs. The first, adjustment credit, was for banks in sound financial condition, while the second, extended credit, was available for banks with lower credit ratings. In both cases, funds were offered at a below-market rate; however, there were restrictions on the use of the funds and there was significant administration attached to these borrowings. Limits on lending to at-risk institutions were established by the Federal Deposit Insurance Corporation (FDIC) so that discount window credit would not prop up a failing institution.

On January 9, 2003, the Federal Reserve returned to a penalty-rate regime for discount window loans. Two programs were established—primary credit and secondary credit. Primary credit is the principal safety valve for ensuring adequate liquidity in the banking system; it is a backup source of short-term funds for banks in sound financial condition. Normally, primary credit is granted on a "no-questions-asked" basis, with minimal administration and no

[12]The discouragement of longer-term borrowing has been evident for much of the discount window's history; this characteristic was not unique to the period discussed here.

restrictions on its use, including for arbitraging the federal funds market. Secondary credit is available to banks not eligible for primary credit, and entails a higher level of administration.[13] At the outset, the primary credit rate was 100 basis points above the target federal funds rate and secondary credit was 150 basis points above. Artuc and Demiralp (2010) find that this change in regime reduced discount window stigma in normal times.

2.3 The Crisis

The discount window changed quickly during the first year of the crisis. The Federal Reserve lowered the relative cost of borrowing at the discount window and increased the length of the term of borrowing on two separate occasions from its usual price of 100 basis points above the target federal funds rate for typically overnight loans. On August 17, 2007, a week or so after the suspension of redemptions from two mutual funds associated with BNP Paribas, the Federal Reserve Board voted to narrow the spread between the primary credit rate and the target rate to 50 basis points from 100 basis points, the spread that had been in effect since the start of the primary credit program in January 2003. At the same time, the allowable term for primary credit borrowing was increased to 30 days. Approximately seven months later, in the wake of the takeover of Bear Stearns by JPMorgan Chase, the Board narrowed the spread another 25 basis points.

Stigma for borrowing primary credit was reportedly a concern for some banks. To address this issue, at the end of August 2007, several large banks, including Bank of America, Citibank, JPMorgan Chase, and Wachovia, borrowed from the discount window in concert in an attempt to override any discount window stigma that could possibly exist (Sidel, Ip, and Bauerlein 2007). Nevertheless, total borrowing remained low and only a moderate additional amount in loans was extended.

Still, some stigma appeared to persist. As shown in table 1, the spread between the highest brokered rate and the target rate was typically 38 basis points before August 2007. This average spread

[13] For more details, refer to http://www.frbdiscountwindow.org/programs.cfm?hdrID=14.

Table 1. Rate Definitions

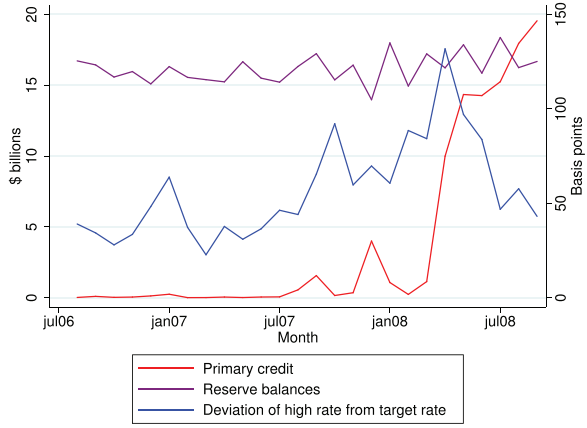
Effective Federal Funds Rate	Volume-weighted average of rates on federal funds transactions
Target Federal Funds Rate	Target rate set for trading in the federal funds market by the FOMC
High-Rate Trades	Trades on transactions late in the trading day well in excess of target rate
Primary Credit Rate	Rate on discount window borrowings from the Federal Reserve
r^{alt}	Alternative rate for federal funds lenders; usually zero

jumped to 69 basis points from August 2007 to March 14, 2008, and rose further to 82 basis points from March 17, 2008 to September 10, 2008. Moreover, the relative frequency of observing trades at wide spreads to the primary credit rate increased over the same period, as did the share of volume at high rates. During the baseline period from August 2006 to August 2007, trading occurred at rates 100 basis points above the target rate on 8 percent of the days. This share increased to 12 percent with the advent of the crisis. The share of days with trades in moderately high ranges is perhaps more striking: there were trades brokered at rates 25 to 50 basis points above the target rate on only 10 percent of the days in 2006 and 2007; this figure jumped to nearly half of the days with the beginning of the financial crisis.

Only once primary credit borrowing reached a threshold value of about $15 billion outstanding did the federal funds rate begin to fall. Notably, as shown in figure 2, this occurred around the time that primary credit equaled total Fed balances. The result was that, as shown in figure 3, federal funds market volume started to drop, and at the end of the sample period in September 2008, volume was considerably lower than it had been in March. Concurrently, the number of borrowers and lenders also fell, as shown in figure 4.

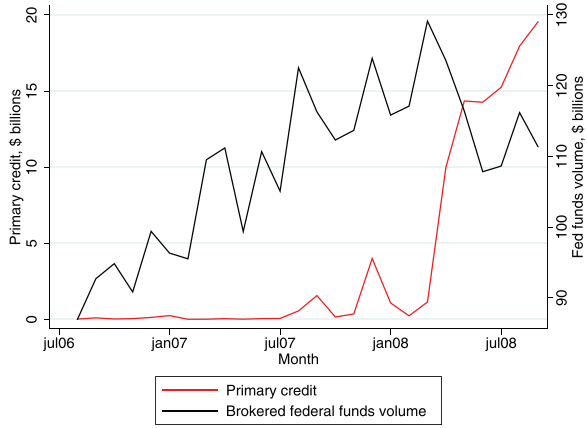
The summary statistics and distributions explored above present a few salient facts about discount window borrowing and the federal

Figure 2. Primary Credit, Reserve Balances, and the Federal Funds Rate, Monthly Averages



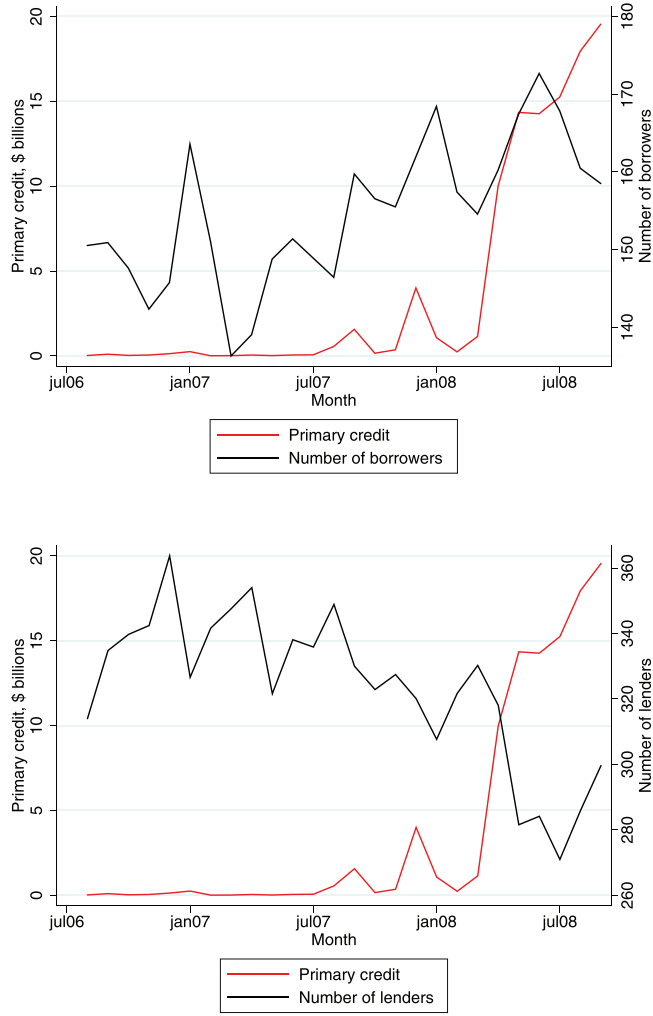
Sources: H.4.1 Statistical Release, Federal Reserve Board; Federal Reserve Bank of New York.
Notes: This figure presents monthly average information on primary credit extensions ($billions), reserve balances ($billions), and the deviation of the highest brokered federal funds rate from the target rate (basis points). The panel reflects data from August 2006 to September 2008.

Figure 3. Primary Credit and the Brokered Federal Funds Volume, Monthly Averages



Sources: H.4.1 Statistical Release, Federal Reserve Board; Federal Reserve Bank of New York.
Notes: This figure presents monthly average information on primary credit extensions ($billions) and brokered federal funds volumes ($billions). The panel reflects data from August 2006 to September 2008.

Figure 4. Primary Credit and the Federal Funds Market Participation



Sources: H.4.1 Statistical Release, Federal Reserve Board; Federal Reserve Bank of New York.

Notes: This figure presents monthly average information on primary credit extensions ($billions) and the number of borrowers and lenders in the brokered federal funds market (number). The panel reflects data from August 2006 to September 2008.

funds market over the first year of the crisis. As the spread between the primary credit rate and the target rate narrowed, (i) the overall distribution of rates on brokered federal funds trades shifted to the right; (ii) the level of primary credit borrowing increased substantially; and (iii) federal funds volume trended down. The framework described below illustrates how this might happen.

3. Framework

This section highlights the key determinants of trading above the primary credit rate. The model illustrates how reluctance to borrow from the discount window, or "stigma," can generate a selection bias in the federal funds market. The implications of the framework will be tested in the empirical sections that follow.

The model presented here uses methodology presented in Bech and Klee (2011), Ennis and Weinberg (2013), and Afonso and Lagos (2015) by assuming a search-and-bargaining structure for the federal funds market. The methodology assumes that the borrower and lender negotiate a rate for the federal funds transaction through a Nash bargaining framework. It focuses on the decision between borrowing in the federal funds market and borrowing from the discount window in a static setting. In particular, decisions to borrow from the discount window are usually made very late in the trading session. In most situations where borrowing from the discount window is considered as an option, it is unlikely that if the negotiation fails, either party would meet either each other or another counterparty from which to borrow or lend. As such, the most reasonable outside options are, for the borrower, the discount window, and, for the lender, to leave funds in an alternative instrument, most likely in its Federal Reserve account overnight. By contrast, if a lender and a borrower disagree earlier in the trading session, each could later meet other counterparties from which to borrow and lend. In this dynamic situation, the discount window would likely not need to be considered as an option. Because the analysis is restricted to the implications of the discount window for the federal funds market, the focus is on the late-day decision.

Against this backdrop, a Nash bargaining problem consists of a disagreement point $d = (d_b, d_l)$, where d is the payoff to the borrower or lender in the case of a disagreement. In this problem, lenders have

the option of lending federal funds in the market or investing in an alternative instrument. The rate earned on this alternative instrument is denoted by r^{alt}, which constitutes the disagreement point for the lender.

In addition to the posted rate paid for going to the discount window, there are other, possibly nonpecuniary costs of borrowing at the discount window.[14] We call these costs "stigma," and denote them by θ. This parameter is private information to the borrower. Moreover, while these costs may be nonpecuniary, we assume that there is a one-to-one mapping from the distribution of these costs to the real line and, as a result, we can model these costs as pecuniary.[15] This stigma cost could represent private information regarding the low quality of a bank's assets, or it could be concern that a bank's assets could be perceived as low quality if discount window borrowing is observed, as in Ennis and Weinberg (2013). More generally, it may be the case that these costs increase as general risk in financial markets climbs, as well as during a financial crisis. Taken together, these assumptions imply that $r^{dw}+\theta_k$ denotes the all-in cost of a type k bank in going to the discount window.

A solution to a Nash bargaining problem also has an agreement set A, a closed convex subset of $\mathbb{R}^2$. In our case, the agreement is an interest rate r, and an agreement is a pair $A = (-r, r)$, reflecting the fact that the trade involves a payment from the borrower to the lender. Characterizing this agreement point needs to reflect the environment surrounding the trade. The information setting for this problem is one of incomplete information. This information setting is consistent with brokered federal funds transactions, where both the borrower and the lender use a third-party intermediary to conduct the transaction. Although the lender knows its potential borrowers, it does not know exactly which one.[16]

Effectively, then, the reservation price of the borrower is unknown to the lender when bargaining. Results from Livne (1988) and others

[14]Goodfriend (1983) explored nonprice rationing at the discount window as a possible cost over and above the rate paid for borrowing.

[15]Other work, including Armantier et al. (2015), takes the view that rate spreads over the discount window rate can be viewed as a proxy for stigma; the analysis here also follows this reasoning.

[16]In particular, if a lender uses a broker, the lender will identify the names of potential borrowers and also the size of the loan that the lender is willing to

suggest that bargaining takes place with the disagreement point as the expected cost of borrowing from the discount window.

The setup of the game is as follows. There are two periods, with no discounting between. In period 1, a bank decides to borrow from the discount window or from the federal funds market. If the bank decides to borrow from the window, in period 2, it exits the federal funds market. If the bank decides to borrow in the federal funds market, in period 2, it meets a lender, and they bargain over the terms of trade.

This problem is solved backwards, starting in period 2. When discussing the trade with its broker, the lender attaches a probability of p_k that the borrower is of type θ_k, with p_k equal to zero if the bank does not participate in the market. Therefore, the expected disagreement point of the borrower is $-\left(r^{dw} + \sum_k p_k \theta_k\right)$. The disagreement point of the lender is the rate of return it would receive on its next best option, denoted by r^{alt}.

In addition, we posit that, given the level of funds left by the Desk in its morning open market operation, there is some bargaining power q that the borrower enjoys when bargaining with the lender. q is presumably increasing in the level of reserve balances; that is, banks pay less to borrow funds the more plentiful they are.

These assumptions imply the following form for the bargaining game:

$$\max_r \left(r - r^{alt}\right)^{1-q} \left(-r - \left(-r^{dw} - \sum_k p_k \theta_k\right)\right)^q. \tag{1}$$

During the first stages of the financial crisis, banks did not earn interest on funds kept overnight in their account at the Federal Reserve. As a result, r_{alt} may have been close to zero, particularly late in the

extend to a particular borrower. One this decision is made, the lender is generally required to accept trades with the pre-approved borrowers. As discussed in Stigum and Credenzi (2007, p. 516):

> In the fed funds market, whenever a buyer takes a seller's offering, the broker has to go back to the seller and tell her the name of the buyer and ask her if she will do the trade. The ethics of the game are such that the seller is supposed to do the trade unless she does not have a line to the buyer or her line to the buyer is filled.

day when most of these trades would have occurred.[17] q is the bargaining power of the borrower which is exogenous and, as explained above, likely a function of the level of reserve balances.[18] Finally, $\left(-r^{dw} - \theta_k\right)$ is the all-in cost of going to the discount window, the disagreement point for the borrower, should the negotiation fail.

Evaluating the Nash product gives the following expression:

$$r^* = qr^{alt} + (1-q)\left(r^{dw} + \sum_k p_k\theta_k\right), \tag{2}$$

where r^* indicates the equilibrium interest rate.

The solution to the second stage informs the participation decision in the first stage. A bank j exits the federal funds market and borrows from the discount window in period 1 if

$$r^{dw} + \theta_j \leq qr^{alt} + (1-q)\left(r^{dw} + \sum_k p_k\theta_k\right). \tag{3}$$

Rearranging a bit shows that for this to be true,

$$\theta_j \leq \frac{q\left(r^{alt} - r^{dw}\right) + (1-q)\sum_{k\neq j} p_k\theta_k}{1 - p_j(1-q)}. \tag{4}$$

Let θ^* denote the critical value of θ such that (4) holds with equality. Intuitively, this says that a bank will exit the federal funds market and go to the discount window if its cost of going to the discount window is sufficiently below that of other borrowing banks in the market, controlling for the amount of surplus captured by the borrower and lender from the bargaining problem. As a result, the critical value θ^* is a function of r^{alt}, r^{dw}, and the weighted average stigma of all other borrowing banks, $\sum_{k\neq j} p_k\theta_k$.

[17] Federal funds trading often took place after the close of other financial markets.

[18] Extensions to this model might plausibly make this an endogenous parameter that depended on the level of Fed balances.

It is fairly easy to see that this critical value increases with a step-up in stigma. For illustrative purposes, let θ_h denote a high-stigma bank. We then see that

$$\frac{d\theta^*}{d\theta_h} = \frac{p_h\,(1-q)}{1-(1-p_h)\,(1-q)} > 0. \tag{5}$$

It is then possible to see how the decision to go to the discount window changes with respect to the discount window rate. Interestingly, we see that

$$\frac{d\theta^*}{dr^{dw}} = -\frac{q}{1-(1-p_h)\,(1-q)} < 0. \tag{6}$$

If the discount window rate moves up, the critical value for staying in the market goes down. Note also that the absolute value of this effect ranges between 0 and 1, and moreover, it equals 0 only if lenders have all of the market power and equals 1 only if borrowers hold all of the bargaining power, or $q = 1$. In this way, a change in the discount window rate can generate selection among banks, where if there is a high discount window rate relative to general market rates, then all banks stay in the federal funds market; but if the discount window rate falls, then those banks with the lowest stigma cost of going to the discount window do so, and only those with higher stigma costs stay in the market. Taken together, a fall in the discount window rate leads to a decline in the number of federal funds market participants and an increase in discount window borrowing.

There are a couple of points worth discussing that are not explicitly modeled. First, discount window borrowing increases reserve balances. This change in the level of reserve balances likely affects bargaining power, q. If low-cost types borrow from the discount window and drop out of the market, then there are two opposing effects on the bargaining power of the remaining banks. At first, the increase in balances due to the discount window borrowing lowers the bargaining power of the sellers. However, at the same time, the existence of only the high-cost types in the market raises the bargaining power of the lenders. Still, it can be shown that, with reasonable parameter values, even though the cost of borrowing increases for the high-stigma types, the overall cost of funding goes down with

the decrease in the discount window rate. As such, it is likely that lowering the primary credit rate is the correct policy response, in terms of providing liquidity at the least cost.

Second, the model does not explicitly account for TAF borrowing, which in principle can affect bargaining power, as it is a complementary source of liquidity. However, because TAF borrowing is for a fixed, forward-settling term, discount window borrowing and TAF borrowing cannot be perfect substitutes. That said, this imperfect substitutability is put to good use in the empirical sections that follow.

4. Empirical Findings—Aggregate Data

As presented above, there are likely two factors that boost federal funds trading volume above the primary credit rate. The first factor is increased stigma. Theoretical models and casual observation suggest that stigma could climb if bank health deteriorates, leading banks to become more reluctant to borrow from the discount window. As a result, for any given spread of trading to the target rate, as stigma increases, one would expect to see less discount window borrowing and more federal funds purchases. The second factor is selection. Holding the distribution of stigma costs constant, one would still expect to see increased trading above the primary credit rate as the spread between the primary credit rate and the target rate is narrowed, if some portion of the distribution of costs is above the primary credit rate.

In order to explore increased stigma and selection more closely, this section investigates the daily distributions of rates on brokered federal funds trades to determine whether trading at relatively higher rates is correlated with indicators of aggregate credit risk, including a bank-based credit default swap (CDS) index and the LIBOR-overnight indexed swap (OIS) spread. While these results cannot identify directly the factors modeled above, they can document correlations implied by the model.

The data used are aggregate data on federal funds trading that the Federal Reserve Bank of New York collected from federal funds brokers to construct the effective federal funds rate. The daily data cover 2006 to 2008 and consist of the rates at which trades were brokered and the volumes of trades at those rates. The analysis focuses

on three ranges for federal funds trading: trading that occurs at rates more than 100 basis points above the target rate; greater than 50 basis points up to 100 basis points above the target rate; and greater than 25 basis points up to 50 basis points. These series are plotted as a share of daily volume in figure 5. As is evident from the figure, high-rate trading at all spreads to the primary credit rate increased as the crisis intensified.

The specification tests whether the effects of aggregate risk indicators change with the spread of the primary credit rate to the target rate. To this end, the sample is split into three periods: (i) the 100 basis point regime from August 2006 to August 14, 2007, the day before the narrowing of the spread between the target and the primary credit rate; (ii) the 50 basis point regime from August 17 and March 14, 2008, the day before the second spread narrowing; and (iii) the 25 basis point regime March 17, 2008 to September 10, 2008. See table 2. The sample has 529 daily observations.

4.1 Specification

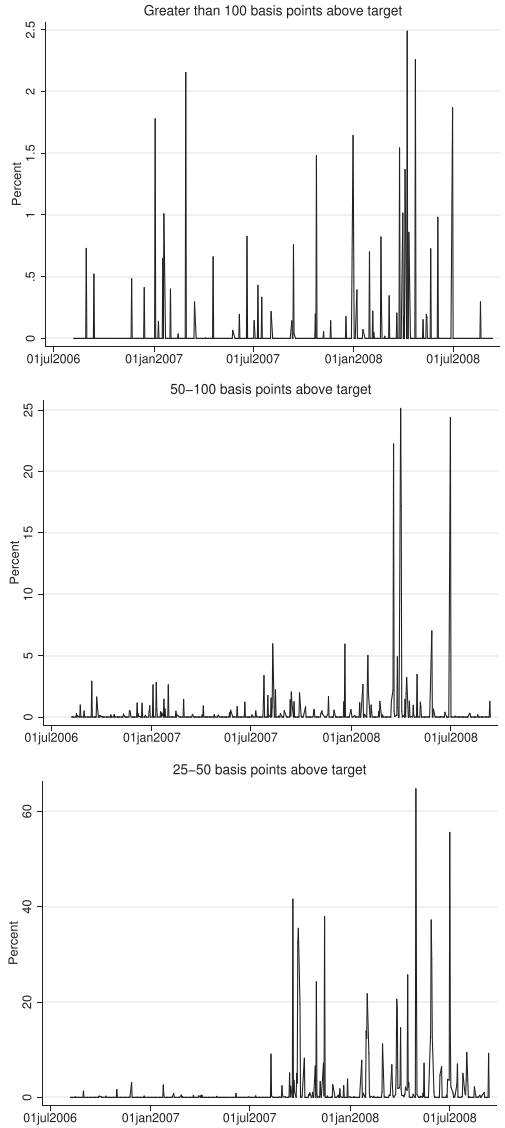
To investigate the determinants of trading at selected spreads to the target rate, let V_{it} represent volume brokered at selected ranges to the target rate, denoted by i. Furthermore, let $E\ (V_{it}) = \mu_{it}$, the mean volume brokered at a particular spread to the target federal funds rate. μ_{it} is specified as

$$\mu_{it} = x_t\beta_i = \beta_0 + \beta_{1ij}risk_t + \beta_{2i}calendar_t. \tag{7}$$

The mean volume brokered at a particular spread to the target rate depends on a number of factors, including $risk_t$, which is a vector of indicators of general financial risk; $fftar_t$ is the target federal funds rate, and $calendar_t$ is a vector of calendar effects. The β coefficients are allowed to vary both by the spread to the target for the trading volume, i, as well as the primary credit spread in effect, j, at time t.

There are three characteristics of the dependent variable that influence the chosen functional form. First, the dependent variable is strictly non-negative, suggesting that a transformation of the variable is appropriate. Second, there are a number of observations with the value of zero for which there is significant economic meaning, ruling out the usual log transformation. And third, the observation of

Figure 5. Trading above the Target Rate



Source: Federal Reserve Bank of New York.
Note: The graphs display the share of federal funds volume brokered at selected spreads to the target federal funds rate.

Table 2. Trading at High Rates in the Federal Funds Market (percent)

	Average Spread between High and Target Rate	Percent of Days			Percent of Brokered Volume		
		> 100	50–100	25–50	> 100	50–100	25–50
Aug. 1, 2006 to Aug. 14, 2007	38	8	19	10	0.04	0.14	0.06
Aug. 17, 2007 to March 14, 2008	69	12	29	42	0.05	0.30	1.76
March 17, 2008 to Sep. 10, 2008	82	12	25	56	0.12	0.79	3.10

Source: Federal Reserve Bank of New York.
Notes: This table presents summary statistics for trading at high rates in the federal funds market over three daily sample periods. Percent of days is the percent of trading days on which nonzero volume was brokered at rates within or above selected spreads to the target federal funds rate. Percent of volume is percent of dollar volume brokered at rates within or above selected spreads to the target federal funds rate.

significant volume above the primary credit rate is generally rare. To address these three issues, we use a generalized linear model with the functional form $E\left(V_{it}|x_t, V_t\right) = V_t \Pr\left(x_t\beta_i\right)$, where V_t is total daily transaction volume and Pr() is the probability of a transaction occurring in rate range i.

The functional form of Pr() is chosen to be a Gompertz distribution, appropriate for modeling an infrequent event at the higher ranges of the support of a distribution. As federal funds trades at relatively high spreads to the primary credit rate are infrequent, this distribution is appropriate. It has the functional form

$$\Pr(x_t\beta_i) = 1 - \exp(-\exp(x_t\beta_i - 1)). \tag{8}$$

Combining this distributional assumption with the mean specification outlined above, the final specification is

$$E\left(V_{it}|x_t, V_t\right) = V_t \Pr\left(x_t\beta_i\right) = V_t\left(1 - \exp(-\exp(x_t\beta_i - 1))\right). \tag{9}$$

In addition, Newey-West errors that are corrected for heteroskedasticity and autocorrelation are used, as the dependent variable is nonlinear and these are time-series data.

4.2 Results

Table 3 shows three sets of results, each reflecting how various factors are correlated with federal funds volume brokered at rates at selected spreads above the target federal funds rate ("high-rate funds market trading"). The first set of results displays information for rates 100 basis points or more above the target rate (columns 1 and 2); the second, 50 to 100 basis points above (columns 3 and 4); and the third, 25 to 50 basis points above (columns 5 and 6). Two specifications are highlighted in each set, and the results are presented in terms of marginal effects for ease of interpretation.

Overall, high-rate funds market trading and measures of perceived bank risk are significantly correlated, and this correlation deepened as the crisis wore on. Moreover, the sign of the correlation is perhaps consistent with some form of selection in the federal funds market. These results are evident in two specifications that use different indicators of bank risk: the CDS index (labeled A) and the LIBOR-OIS spread (labeled B). In the 100 basis point discount

Table 3. Federal Funds Trading at Selected Spreads above Target Rate

	Above 100 bp		50–100 bp		25–50 bp	
	(1)	(2)	(3)	(4)	(5)	(6)
A. CDS Index						
100 bp Regime	−0.836**		4.759**		26.260**	
	(0.27)		(0.42)		(1.00)	
50 bp Regime	0.719**		−5.448**		−32.668**	
	(0.27)		(0.44)		(1.41)	
25 bp Regime	0.734**		−3.629**		−28.614**	
	(0.27)		(0.59)		(1.02)	
B. LIBOR-OIS Spread						
100 bp Regime		−1.972**		3.611**		19.004**
		(0.49)		(0.21)		(0.71)
50 bp Regime		1.810**		−3.766**		−23.748**
		(0.49)		(0.31)		(0.87)
25 bp Regime		2.024**		−10.494**		−20.330**
		(0.49)		(0.85)		(1.45)
C. Spread of Repo Rate to Target Rate						
100 bp Regime	0.063	0.222**	2.233**	1.388**	46.912**	30.200**
	(0.06)	(0.09)	(0.30)	(0.20)	(8.31)	(5.69)
50 bp Regime	−0.102	−0.275**	−2.242**	−1.396**	−45.750**	−29.693**
	(0.06)	(0.09)	(0.28)	(0.17)	(8.30)	(5.68)
25 bp Regime	−0.060	−0.200*	−2.074**	−0.507*	−46.717**	−28.974**
	(0.07)	(0.10)	(0.36)	(0.20)	(8.32)	(5.73)

(*continued*)

Table 3. (Continued)

	Above 100 bp		50–100 bp		25–50 bp	
	(1)	(2)	(3)	(4)	(5)	(6)
D. TAF						
50 bp Regime	0.001**	−0.000	0.010**	0.004**	0.045**	−0.025**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
25 bp Regime	−0.002**	−0.002**	−0.019**	−0.042**	−0.021**	−0.038**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
E. Calendar Effects						
Month End	0.110**	0.117**	1.190**	1.405**	3.649**	3.633**
	(0.01)	(0.01)	(0.12)	(0.19)	(0.22)	(0.22)
P&I Day	0.026	0.021	0.076	0.213**	1.427**	1.338**
	(0.02)	(0.02)	(0.15)	(0.07)	(0.20)	(0.21)
50 bp Regime	−0.194**	−0.115**	1.670**	0.484**	15.402**	9.653**
	(0.07)	(0.04)	(0.16)	(0.11)	(0.80)	(0.48)
25 bp Regime	0.226**	0.154**	2.949**	10.031**	18.104**	13.609**
	(0.07)	(0.06)	(0.30)	(0.89)	(0.64)	(2.13)
Observations	529	528	529	528	529	528

Notes: This table presents estimated marginal effects for the regression $E(V_{it}|x_t,\ V_t) = V_t \Pr(x_t\beta_i)$, where $\Pr(x_t\beta_i) = 1 - \exp(-\exp(x_t\beta_i - 1))$ and $x_t\beta_i = \beta_0 + \beta_{1ij} risk_t + \beta_{2i} calendar_t$. Dependent variable is daily brokered volume in $billions. Financial series are in percentage points. TAF is in $billion. Calendar effects are 0/1 indicators. Newey-West heteroskedastic-autocorrelated corrected errors are in parentheses. ** denotes significance at the 5 percent level.

window regime, as these measures of bank risk increased, volumes at the highest rates actually fell, while trading at more moderate spreads to the target rose. Evaluated at the means of the variables, the coefficients imply that a 1 percentage point increase in the CDS index is associated with an 83 basis point decrease in the volume of trades 100 basis points above the target rate, and a 26 percentage point increase in the volume of federal funds trades brokered at rates 25 to 50 basis points above the target rate. Results using the LIBOR-OIS spread instead of the CDS index are qualitatively similar, suggesting a reasonably robust result. Even though market strains may have been appearing, borrowing banks with low stigma pooled with borrowing banks with high stigma, leading to some increase in rates, but not to extremes.

Once the crisis began and the primary credit spread narrowed, high-rate funds market trading at rates more than 100 basis points above the target rate increased as these measures of bank risk climbed. At the same time, high-rate trading at rates between 25 and 100 basis points above the target fell somewhat. The differential effects according to selected ranges above the target rate suggest that there could be some selection in observed trades. That is, banks with low stigma costs went to the discount window, but banks that had high stigma costs remained in the market and were forced to borrow funds at higher rates. Taken together, these results suggest that as banks were perceived as more risky, and the discount window spread narrowed, rates in the federal funds market went up, not down. These empirical results are consistent with the Bernanke (2008) observation discussed in the introduction; namely, banks may become reluctant to borrow at the discount window as financial strains intensify.

One caveat to the estimated coefficients for these bank-risk results is that there may be some endogeneity issues. That is, the high-rate trading in the federal funds market may boost measures of bank risk, including the LIBOR-OIS spread as well as the CDS index. As a result, lenders may be unwilling to extend federal funds loans to banks that exhibit high risk. This is, of course, a weakness of this type of aggregate specification. That said, as discussed in the model section, the institutional norm in the market was that if a credit line was available, lenders were obligated to extend loans to borrowers. Moreover, even if lenders did want to cut credit lines,

they usually did so on a case-by-case basis, and did not do so very frequently. Taken together, these results suggest that selection on the borrowing side could be driving the results. However, this issue will be investigated more completely in the bank-level analysis below.

The next set of results (labeled C) explores the correlation of high-rate funds market trading with the demand for safe collateral. While the demand for safe collateral suggests overall market risk, it is not specific to banks. During the 100 basis point primary credit regime, the Treasury GC repo rate and high-rate funds trading tended to co-move, reflecting the more general behavior of short-term money market rates in normal times. As the first year of the crisis wore on, however, the correlation between high-rate trading and the Treasury GC repo rate became negative. The Treasury GC repo rate tends to fall with heightened demand for safe collateral, which occurs during periods of market stress. Evaluating the marginal effects at the mean of the variables suggest that for every percentage point decrease in the Treasury GC repo rate below the target rate, the share of funds brokered within the 50 to 100 basis point range above the target increases by about 2 percentage points relative to normal times. The effect for more modest ranges above the target is larger: for every percentage point decrease in the repo rate below the target rate, the share of volume brokered in the 25 to 50 basis point range above the target increases by about 35 percentage points relative to the baseline period. Taken together, then, the coefficient suggests that high-rate federal funds trading increased concurrently with elevated demand for safe collateral, with no specific selection effects related to widespread collateral demand.

Correlations of high-rate federal funds market trading with TAF borrowing are displayed in the rows labeled D. While there is some variation, the results generally suggest that increased TAF borrowing was associated with more higher-rate trading under the 50 basis point primary credit regime, but with less under the 25 basis point regime. Dollar for dollar, the effect appears to be largest on volume brokered at rates 25 to 100 basis points above the target rate. TAF borrowings can provide some certainty regarding a bank's level of reserve balances. Because TAF funds were auctioned two days before settlement, endogeneity concerns are likely minimal.

The final set of rows control for various calendar effects (labeled E). High-rate trading was somewhat more evident on month-end

and on days when Fannie Mae and Freddie Mac made principal and interest (P&I) payments on their mortgage-backed securities (MBS). The marginal effects for these suggest the share of trading at relatively elevated ranges to the target rate increased a percentage point or so on those days. The last couple of lines of the table show the level of high-rate trading during the 50 basis point and 25 basis point primary credit regimes, independent of bank credit risk or demand for safe collateral. Overall, high-rate funds market trading became more prevalent as the crisis intensified.

To summarize, the results presented here suggest that some pickup in high-rate trading was due to overall increases in financial risk. At the same time, the effects of increases in bank-specific financial risk appear consistent with selection in the funds market. In addition, TAF borrowings appear to dampen high-rate trading in the federal funds market. These results inform the bank-level results, which are discussed below.

5. Empirical Findings—Bank-Level Data

This section uses bank-level data to evaluate the connection between high-rate funds market trading, primary credit, and various bank characteristics. However, a simple panel regression will not be appropriate, as the model illustrates that rates and borrowing are endogenously determined. Also, the aggregate empirical results suggest that funds market participation exhibits selection that is correlated with overall bank risk. Against this backdrop, the empirical strategy follows a framework outlined by Semykina and Wooldridge (2010) to control for endogeneity of primary credit borrowing and selection bias in the federal funds market.

5.1 Data Construction

The data are constructed by combining bank-level daily data, market-level daily data, and bank-level quarterly data.

The bank-level daily data on federal funds rates is constructed using proprietary transaction-level data from the Fedwire Funds Service, using an algorithm pioneered by Furfine (1999) to match and form plausible overnight funding transactions, likely related to

the federal funds market.[19] However, because there is no independent way to verify if these are actual federal funds transactions, identified trades and characteristics of these trades are subject to error.[20] These errors potentially include correspondent transactions (transactions done by one bank on behalf of another bank), capturing funding transactions outside of the federal funds market, or coincidence. Although these are possible weaknesses, they may not be critical for this analysis. If the high-rate trade reflects a correspondent relationship, it still reflects an unwillingness to go to the discount window. In addition, if banks are obtaining funding outside of the federal funds market at rates higher than the primary credit rate, then there is still aversion to using the discount window; the actual funding source is less critical. And finally, while trades could be simply coincidence, this likelihood is minimized by using trades that match rates observed in the brokered data. Specifically, the high-rate data critical to the analysis below were cross-validated with brokered data for many sample days.

The data cover August 1, 2006 to September 11, 2008. The transaction data contain information on the amount of the transaction, the implied interest rate of the identified transaction, and the lender and borrower in the trade. From there, these data are summarized on a daily basis, and the high rate on the day and the total funds bought are calculated.

Other bank-account activity variables are also generated from proprietary Federal Reserve databases. The data on reserve account balances are constructed from the Federal Reserve's database of banks that report reserve balance and related information on the weekly "Report of Transaction Accounts, Other Deposits, and Vault

[19]The algorithm matches an outgoing Fedwire funds transfer sent from one account and received by another with a corresponding incoming transfer on the next business day sent by the previous day's receiver and received by the previous day's sender. This pair of transfers is considered a federal funds transaction if the amount of the incoming transfer is equal to the amount of the outgoing transfer plus interest at a rate consistent with the rates reported by major federal funds brokers. Similar data were used by Demiralp, Preslopsky, and Whitesell (2006), Bartolini, Hilton, and McAndrews (2010), and Afonso, Kovner, and Schoar (2011).

[20]Armantier and Copeland (2015) discuss some of the important shortcomings of the data.

Cash."[21] Information on primary credit and TAF borrowings is from internal databases; current borrowings are available on the Board's public website.[22] The daylight overdraft information is calculated from the same database used to construct the federal funds transactions. Peak daylight overdrafts is the maximum amount a bank overdrafts its Fed account on a particular day.

The daily data are then paired with bank-level information from the Call Report and other regulatory reports that are issued on a less frequent basis, to capture key balance sheet and reserves-related items. Also included are some of the daily financial market indicators studied in section 4 to control for overall market conditions on the day.

After the combination of all data sets, the data are summarized by week. For the purposes of testing for selection, the sample is split into the three regimes described above: August 2006 to August 2007, the 100 basis point primary credit regime; August 2007 to March 2008, the 50 basis point regime; and March 2008 to September 2008, the 25 basis point regime. The sample ends at September 11, 2008, immediately before the failure of Lehman Brothers.

5.2 Estimation Framework for Testing and Correction

As described in the model and illustrated in the aggregate empirical results, a regression that explores the dependence of high-rate trading on discount window borrowing likely suffers from both selection and endogeneity problems.

Semykina and Wooldridge (2010) develop a panel data estimator that controls for both selection bias and endogenous regressors. In the spirit of a traditional Heckman selection model, the diagnostic and estimation procedure is in three steps. Using the notation in Semykina and Wooldridge, in the first step, a probit model is estimated for each time period:

$$Pr\left(s_{it} = 1 | z_i\right) = \Phi\left(z_{it}\delta_t^a + \bar{z}_i\xi_t^a\right) \tag{10}$$

[21] Reporting form FR2900, http://www.federalreserve.gov/apps/reportforms/default.aspx.

[22] http://www.federalreserve.gov/newsevents/reform_discount_window.htm.

for each bank i during week t. s_{it} equals 1 if bank i borrowed from the discount window in week t, z_{it} is a vector of exogenous variables, and $\bar{z}_i$ is the mean of these variables for each i over all t. Importantly, the z_{it} should be observed for all i, regardless of whether the bank borrowed from the discount window. The means of exogenous variables $\bar{z}_i$ control for unobserved fixed effects and are used to correct for possible selection bias.

The inverse Mills ratios are then calculated for each t, which take the form

$$\hat{\lambda}_{it} = \lambda\left(z_{it}\hat{\delta}_t^a + \bar{z}_i\hat{\xi}_t^a\right), \tag{11}$$

where $\hat{\delta}_t^a$ and $\hat{\xi}_t^a$ are the estimated coefficients from equation (10). With these Mills ratios, the selection bias test can now be executed. A fixed-effects two-stage least squares model is estimated only on the sample of institutions that borrowed from the discount window,

$$\begin{aligned} ffhighdev_{it} = c_i + \alpha primary_{it} + x_{it}\beta + \gamma pcspread_t \\ + \ \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}. \end{aligned} \tag{12}$$

The coefficients ρ differ according to primary credit regime to capture changes in selection as the spread between the primary credit rate and the target rate narrowed. Selection bias is indicated by significant coefficients on the $\hat{\lambda}_{it}$ terms.

To control for endogeneity, a subset $z_{it1} \subset z_{it}$ is used as instruments in the estimation, and to control for the selection, one variable is excluded from z_{it1} but included in z_{it}. This construct conforms to the Semykina and Wooldridge (2010) requirements that one instrumental variable is necessary to control for the endogenous regressor, and another is necessary to control for the selection.

If selection is present and endogeneity is suspected, pooled two-stage least squares is run on the following specification, which controls for both selection and endogeneity:

$$\begin{aligned} ffhighdev_{it} = c_i + \alpha \widehat{primary}_{it} + x_{it}\beta + \gamma pcspread_t \\ + \ \bar{z}_i\eta + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}, \end{aligned} \tag{13}$$

where $\widehat{primary}$ indicates that primary credit is instrumented. With this construction, the α coefficient on the $primary$ term should indicate the true relationship between rate paid on federal funds and the level of discount window borrowing, while the ρ_{spread} coefficients indicate the degree of selection according to time period.

$$primary_{it} = x_{it}\beta + z_{it1}\gamma + \bar{z}_i\eta + \rho_{spread}\hat{\lambda}_{it} + \mu_{it} \qquad (14)$$

A key factor in the success of this approach is identifying appropriate instruments. The specification uses TAF borrowing to control for selection bias, and daylight overdrafts to instrument for primary credit. The operational framework surrounding each of these forms of Federal Reserve credit make them good candidates to help identify the effects of discount window stigma on high-rate federal funds trades.

Turning first to correcting for selection bias, it is important to identify a factor that is correlated with the probability of borrowing from the discount window, but not correlated with high-rate federal funds market trading that is a function of stigma. TAF borrowing likely affects the probability of borrowing from the discount window in a given week, but is uncorrelated with unexpected account shortfalls and was generally free from stigma. In particular, if a bank has sufficient funds in its account from TAF borrowing, it may not need to borrow primary credit. Alternatively, if a bank had a general need for funds, it may choose to borrow at either facility. However, the two forms of reserve bank credit were not perfect substitutes. Because TAF auctions occurred at predetermined intervals (funds were usually auctioned on Tuesdays, and settled on Thursdays) banks could not borrow from the TAF to cover unexpected daily funding needs. Moreover, in part because of this settlement structure, TAF borrowing was generally free from stigma.

Turning next to correcting for endogeneity, it is important to identify a factor uncorrelated with unobserved stigma and indirectly related to federal funds rates. Daylight overdrafts likely satisfy these requirements. Specifically, they are a byproduct of the thousands of payments banks make each day. These payments use funds in a bank's Fed account. During this sample period, banks with insufficient funds could still make payments, but would incur a "daylight overdraft," to be repaid before the end of the banking day. If a bank

Table 4. Bank-Level TAF and Daylight Overdraft Summary Statistics, $Billions

	Mean	Median	Std. Dev.	Obs.
TAF Borrowings				
Borrowed Primary Credit	1.053	0	6.599	2,421
Did Not Borrow Primary Credit	0.114	0	1.571	123,640
Peak Daylight Overdrafts				
Borrowed Primary Credit	1.213	0.004	6.409	2,421
Did Not Borrow Primary Credit	0.273	0.002	2.612	123,640

Source: Federal Reserve Board.
Note: This table reports summary statistics for the variables used to identify selection and to control for endogeneity.

was short, they would need to borrow funds, either in the federal funds market or from the discount window. Failure to do so meant a bank incurred an overnight overdraft, with a hefty fee of 400 basis points above the effective federal funds rate.

Daylight overdrafts had two important qualities that make them suitable as an instrument. First, any individual bank's daylight overdraft was presumably private information: while a counterparty would likely have some idea of the amount of payments or loans it sent to any one bank, it would likely not have information on that bank's payment activity with other institutions. Second, demand for federal funds as a result of daylight overdrafts was likely independent of credit risk, market stress, or stigma. Rather, daylight overdrafts independently shift a bank's demand curve for reserve balances; these balances could be obtained in the federal funds market or at the discount window. Presumably, banks in need of funds late in the day in order to cover a daylight overdraft were willing to pay high rates in the federal funds market or take out a discount window loan, as both of these options had lower costs than the 400 basis point overnight overdraft fee.

Summary statistics on TAF borrowing and daylight overdrafts corroborate the usefulness of these indicators as instrumental variables. Table 4 displays basic summary statistics on TAF borrowings

and peak daylight overdrafts at an institution-week level according to whether primary credit borrowing was also observed. TAF borrowings are substantially higher for those institutions that borrowed primary credit relative to those that did not. While most institutions did not borrow from the TAF, the standard deviation of borrowings for those that borrowed primary credit is much higher than that for those that did not.

Turning to daylight credit, mean peak daylight credit is substantially higher for those banks that borrowed primary credit, by about $1 billion on average. In addition, the median peak overdraft is substantially higher for banks that also borrowed primary credit. Similar to TAF borrowings, the standard deviation of peak daylight overdrafts is also higher for the banks that borrowed primary credit than those that did not.

5.3 Baseline Panel Estimates and Results

Before proceeding to the selection tests, it is instructive to have baseline panel regression results as a comparison. This is specified as

$$ffhighdev_{it} = c_i + \alpha_t^1 primary_{it} + \alpha^2 daylight_{it} + \alpha_t^3 TAF_{it} + x_{it}\delta + c_i + q_{pc}\zeta + \epsilon_{it}. \quad (15)$$

Table 5 displays summary statistics for the variables in the specification. The dependent variable $ffhighdev_{it}$ is the average of daily deviations of the highest observed rate for funds bought from the effective rate for bank i during week t. Because the discount window generally served as a marginal source of funds in the sample period, the highest rate paid is a close proxy to an actual reservation price. Furthermore, comparing the highest rate paid with the effective rate gives an idea of rates paid relative to the market average.

The first set of independent variables reflect borrowings and account activity at the Federal Reserve. $primary_{it}$ is the sum of primary credit borrowing by the bank over the week. The coefficient on this factor is permitted to vary over primary credit regimes. According to the model presented above, rates paid by banks that borrowed primary credit should be lower than those for banks that did not. The second set of variables are daylight overdrafts and TAF

Table 5. Bank-Level Summary Statistics

	Mean	Std. Dev.	Min.	Max.
Regime Probability				
100 bp Regime	0.50	0.50	0	1
50 bp Regime	0.28	0.45	0	1
25 bp Regime	0.23	0.42	0	1
Primary Credit ($Billions)	0.01	0.34	0	17.5
100 bp Regime	0.00	0.01	0	1.16
50 bp Regime	0.00	0.09	0	15
25 bp Regime	0.01	0.33	0	17.5
Daily Total Balances ($Billions)	0.01	0.08	0	7.18
Days in Market	0.62	1.48	0	5
Funds Bought ($Millions)	0.31	2.82	0	92.92
Assets ($Billions)	1.42	23.42	0	1,392.27
Required Reserves ($Billions)	0.03	0.25	0	7.89
N	120,464			

Sources: Federal Reserve Board; Bloomberg; Federal Reserve Bank of New York.
Notes: This table reports descriptive statistics for the variables used in the panel regressions. The sample includes bank-week observations from October 2006 to September 2008.

borrowings. As discussed above, these will be used as instruments in the selection and correction specifications. Both vary at the bank-week level.

The next set of factors control for bank characteristics, denoted x_{it}. One control variable is the number of days bank i participated in the federal funds market during week t. More frequent participation can indicate that the bank is generally a "market maker" in the federal funds market, while infrequent participation suggests transacting to satisfy short-term liquidity needs. The vector also contains bank-specific information, including the assets of the bank, weekly average amount borrowed in the federal funds market, reserve requirements, and average reserve balance holdings over a week.

A Hausman test rejects the hypothesis that a random effects model is sufficient to control for individual-level effects. As a result, fixed effects are assumed in the estimation, denoted by c_i. We include time period controls as well, indicated by q_{pc}, which correspond to the primary credit regime. The error term ϵ_{it} captures all other unobserved factors.

The first column of table 6 presents the results. Primary credit borrowing does not appear to be significantly correlated with rates paid on federal funds. By contrast, daylight overdraft activity is correlated with higher federal funds rates, suggesting that banks with elevated funding demands are forced to pay more to obtain funds. Very roughly, the estimated coefficient on the daylight overdraft term suggests that for each one standard deviation of peak overdrafts, the spread on the high-rate trading above the effective rate increases about 5 to 6 basis points. TAF borrowing in the 50 basis point spread primary credit regime is not statistically significantly associated with higher rates paid in the federal funds market, but in the 25 basis point regime, the effect is positive and significant. This result suggests that the TAF may have offset the need to buy high-rate funds in the market early in the program, but later in the program, TAF borrowers paid significantly higher rates in the federal funds market than other borrowers.

Turning next to bank-level factors, neither the number of days in the market nor the amount of funds borrowed appear to be significantly correlated with high rates paid in the federal funds market. Asset size does not significantly predict high rates. Also, required reserves and total reserve balances are not associated with higher rates paid.

Some of the broad financial market variables are significantly correlated with rates paid in the federal funds market. Although the CDS index is somewhat surprisingly negatively correlated with trading in the federal funds market, it could be a result of selection in the federal funds market. At the same time, the spread of the repo rate to the target rate has an intuitive sign, with a more negative spread associated with higher-rate trading.

The intercept terms, reported in the last three lines of the table, suggest that rates rose as time wore on. On average, high rates were about 12 basis points higher in the 25 basis point regime than in the 100 basis point regime, after controlling for the factors listed above.

5.4 Controlling for Selection and Endogeneity

With the baseline panel results in mind, the next columns present results that test and control for selection and endogeneity.

Table 6. Controlling for Selection Bias in and Endogeneity of Discount Window Borrowing

	Panel (1)	Selection (2)	Corrected (3)	Corrected (FHLB) (4)	Corrected (90^{th}) (5)
Primary Credit	2.053	−30.20**	−2.262*	−1.388	−0.00977
	(4.987)	(10.67)	(0.998)	(0.897)	(0.00608)
50 bp Regime	−1.240				
	(5.161)				
25 bp Regime	−1.607				
	(4.921)				
Peak Daylight Overdrafts	0.742***				
	(0.205)				
TAF Borrowing	−0.0438				
	(0.0525)				
25 bp Regime	0.276*				
	(0.138)				
Number of Days in Market	−0.183	3.787	0.119	0.105	0.00657
	(0.106)	(2.912)	(0.588)	(0.586)	(0.00551)
Amount Borrowed	0.202	−2.767*	0.296	0.861	−0.00172
	(0.166)	(1.381)	(0.481)	(0.552)	(0.00264)
Total Assets	−0.00111	−0.0972	−0.00674	−0.00134	−0.0000762
	(0.00124)	(0.0665)	(0.0230)	(0.0240)	(0.000176)
Required Reserves	1.423	34.95	14.17	13.04	0.106
	(1.933)	(21.75)	(9.873)	(10.40)	(0.0725)
Total Reserve Balances	−1.839	−33.67	−12.22	−9.890	−0.00477
	(2.007)	(19.86)	(14.40)	(13.11)	(0.0609)
FHLB Borrowings				−489.0	
				(357.6)	
CDS Index	−3.203***	−15.56	−4.723	−3.610	−0.0371
	(0.401)	(10.45)	(2.831)	(2.804)	(0.0262)
Repo-Target Spread	−0.0602***	0.114	−0.0451	−0.0401	−0.000873***
	(0.00405)	(0.0907)	(0.0277)	(0.0247)	(0.000232)
Selection					
100 bp Regime		31.82*	1.459	1.141	−0.0125
		(12.55)	(1.474)	(1.760)	(0.0145)
50 bp Regime		1.086	−4.594	−2.422	−0.0754**
		(6.914)	(3.389)	(3.081)	(0.0258)
25 bp Regime		−26.49*	−9.434***	−8.331***	−0.0607**
		(10.48)	(2.748)	(2.144)	(0.0199)
Constant	9.317***	−33.35	4.838	5.278	0.132***
	(0.602)	(22.21)	(3.863)	(4.247)	(0.0357)
50 bp Regime	9.232***	92.35**	25.87***	21.03***	0.254***
	(0.411)	(30.32)	(6.318)	(5.793)	(0.0643)
25 bp Regime	12.53***	149.6**	36.83***	32.61***	0.260***
	(0.638)	(47.48)	(8.742)	(8.017)	(0.0727)
N	21,390	642	642	642	643
Number of Banks	547	129	129	129	129
Adj. R-sq.	0.1574	0.0052	0.269	0.324	0.176

Notes: Dependent variable is the deviation of the average observed high rate paid for federal funds from the effective rate. Specifications include Mundlak-Chamberlain fixed effects.
Column 1 presents estimated coefficients for the baseline panel regression:
$ffhighdev_{it} = c_i + \alpha_t^1 primary_{it} + \alpha^2 daylight_{it} + \alpha_t^3 TAF_{it} + \gamma days_{it} + x_{it}\delta + c_i + q_{pc}\zeta + \epsilon_{it}$.
Column 2 presents estimated coefficients for the selection test:
$ffhighdev_{it} = c_i + \alpha primary_{it} + x_{it}\beta_t + \gamma pcspread_t + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}$.
Columns 3–6 present estimated coefficients that control for selection and endogeneity:
$ffhighdev_{it} = c_i + \alpha\widehat{primary}_{it} + x_{it}\beta_t + \gamma pcspread_t + \bar{z}_i\eta + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}$.
Cluster-robust standard errors are in parentheses on panel and selection estimates. Bootstrapped standard errors on corrected estimates. *, **, and *** denote significance at the 5 percent, 1 percent, and 0.1 percent level, respectively.

As shown in column 2 of table 6, selection in the federal funds market intensified as the spread between the primary credit rate and the target rate narrowed. The coefficient on the ρ_{25} term implies that an unobserved factor suggesting a higher propensity to borrow from the discount window is correlated with lower rates paid in the federal funds market. If this factor is "stigma," then lower stigma leads to lower federal funds rates paid. Consistent with the model's predictions, then, banks that were willing to borrow from the discount window did not pay as high rates for funds. The coefficient suggests that borrowing from the discount window was associated with about a 25 basis point decrease in the average high rate paid. In addition, there appears to be positive selection in the federal funds market when the spread is 100 basis points. Because this was the spread in a period of relative calm, it may be the case that borrowing from the window occurred on days with specific pressures in the funds market, such as quarter-end reporting dates. The magnitude of the coefficient suggests that banks paid an average of about 30 basis points higher for high-rate funds if going to the discount window during normal times. During the 50 basis point regime, the correlation between borrowing from the discount window on high rates paid was not significant.

However, examining the selection terms by themselves does not give a complete picture. As indicated by the coefficient on primary credit, borrowing $1 billion in primary credit is associated with a 30 basis point lower peak federal funds rate. Taken with the selection terms, the results suggest that borrowing from the discount window substantially reduced funding costs during the 25 basis point regime, somewhat damped them during the 50 basis point regime, and probably had a minimal net effect in the 100 basis point regime.

The final step of the estimation procedure corrects for both the endogeneity of primary credit and the selection for federal funds rates. These results are presented in the third through fifth columns of table 6. The coefficient on the primary credit term is negative and significant, suggesting that banks that borrowed primary credit paid lower federal funds rates. The point estimate suggests that for each $1 billion borrowed, peak rates fell by about 2 basis points. Taken with the highly statistically significant and negative coefficients on the selection terms, rates appear to be substantially lower for banks willing to go to the discount window. Indeed, during the 25 basis

point regime, the net effect of borrowing $1 billion from the discount window was a peak funds rate that was about 10 basis points lower. Overall, the results are consistent with the model and suggest that banks that borrowed from the discount window paid lower rates in the federal funds market, and this phenomenon became stronger as the primary credit rate spread narrowed and the crisis intensified.

One caveat is that banks may have been using another source of funding, other than the discount window, and that our results might mask the effect of this other source. In particular, as discussed in Ashcraft, Bech, and Frame (2010), many institutions substituted Federal Home Loan Bank loans for discount window loans, as the FHLB loans generally had lower interest rates. As a robustness check, column 4 of table 6 tests if there was any influence on rates paid in the federal funds market that depended on FHLB borrowings; we use the level of FHLB borrowings as reported quarterly on the Call Report as a control variable in our specification. Interestingly, the level of FHLB borrowings is not correlated with paying lower rates in the federal funds market. Controlling for FHLB borrowings shows that primary credit borrowings are still weakly correlated with lower rates paid in the federal funds market; each $1 billion borrowed is associated with a 1 basis point lower rate paid in the market; selection-term coefficients are roughly the same as in column 3. More generally, even if rates only weakly fall for each dollar borrowed (the intensive margin), rates do fall with a willingness to go to the discount window (the extensive margin).

Finally, some may question the choice of dependent variable. Although the high rate paid on the day is a metric that is consistent with the model presented above, there may be some biases due to data limitations and also to using an extreme value of a distribution. Other plausible suggestions include the 90th percentile of trades, expressed as a deviation from the effective rate and measured over a week. Results with this dependent variable are shown in the final column of table 6. Specifically, while the coefficients on the selection terms remain significant, the magnitude is far less. The coefficients suggest that borrowing from the discount window depressed a wide range of rates, but the most dramatic effect was on the highest rates paid.

Across all specifications, the adjusted R-squared statistics suggest a reasonable amount of variation is explained by these

variables. In particular, the specifications in columns 3–5 center around explaining roughly 25 percent of overall variation, consistent with meaningful impact of these factors on trading in the federal funds market.

6. Robustness and Diagnostics

Two-stage estimation procedures with selection can be plagued by a number of weaknesses. This section discusses potential weaknesses of our results related to weak instruments, failure to satisfy overidentifying restrictions, or overly restrictive selection parameters. The section also presents some results from the later crisis period to gauge how federal funds rates were related to discount window borrowing as the crisis wore on.

6.1 First-Stage Results

The selection and endogeneity first-stage results are shown in columns 1 and 2 of table 7. Column 1 displays the results of estimating the first-stage equation described in equation (10), which is the probability of borrowing at the discount window. The two instrumental variables are daylight overdrafts and TAF borrowing; there are also fixed-effect terms for each of these variables. In addition, all exogenous variables from the second stage are also included in the first-stage specification. Looking at the individual coefficients, daylight overdrafts do not appear to be statistically significantly correlated with discount window borrowing. At the same time, TAF borrowing is positively correlated with the probability of borrowing from the discount window. This latter result suggests some complementarity between funding sources during the early stages of the crisis. The result is also consistent with our interpretation of TAF borrowing as an instrument for the probability of borrowing from the discount window, but perhaps uncorrelated with unexpected account shortfalls. For the exogenous factors, the number of days in the market is positively correlated with the probability of borrowing at the discount window, while total assets, required reserve balances, and holdings of reserve balances are negatively correlated. Column 2 presents results from the first-stage specification used to

Table 7. First-Stage Results and Robustness Checks

	First Stage		Cubic Spline		
	Pr(Borrow) (1)	**Amount Borrowed (2)**	**Probit (3)**	**Logit (4)**	**Hazard Ratio (5)**
Peak Daylight Overdrafts	0.00264	−0.0338			
	(0.00929)	(0.0335)			
TAF Borrowing	0.00584*	0.159***			
	(0.00291)	(0.0215)			
Primary Credit			−2.432**	−2.381**	−2.303**
			(0.861)	(0.845)	(0.841)
Number of Days in Market	0.0286*	0.0435	0.219	0.166	0.191
	(0.0113)	(0.0523)	(0.589)	(0.588)	(0.580)
Amount Borrowed	0.0169*	−0.0524	0.231	0.248	0.268
	(0.00824)	(0.0345)	(0.441)	(0.444)	(0.436)
Assets	−0.000721*	−0.00763***	−0.0102	−0.0119	−0.00731
	(0.000280)	(0.00197)	(0.0188)	(0.0197)	(0.0180)
Required Reserves	−0.634***	0.589	15.28	15.34	15.39
	(0.162)	(0.721)	(8.175)	(8.245)	(8.126)
Total Reserve Balances	−0.746***	0.0579	−12.57	−12.21	−12.27
	(0.199)	(0.630)	(11.96)	(11.96)	(12.28)
CDS Index		−0.446	−3.360	−3.607	−4.891
		(0.308)	(2.662)	(2.679)	(2.774)
Repo-Target Spread		0.00419*	−0.0404	−0.0415	−0.0506*
		(0.00209)	(0.0234)	(0.0233)	(0.0251)
Selection					
100 bp Regime		0.434*	3.847	4.806	79.12*
		(0.171)	(3.505)	(4.440)	(34.65)
50 bp Regime		−0.397	−13.75	−16.86	−241.8
		(0.229)	(7.440)	(9.789)	(205.2)
25 bp Regime		−0.908**	−24.40***	−32.20***	−9.640***
		(0.324)	(7.048)	(8.885)	(2.775)
Hazard Spline					
100 bp Regime					−76.55*
					(33.56)
50 bp Regime					234.9
					(204.5)
25 bp Regime					−11.66
					(71.85)
N	124,403	642	642	642	642
Number of Banks	1,238	129	129	129	129
R^2	0.100	0.292	0.289	0.290	0.298
F-statistic		29.81			
Hansen J Statistic		3.617			
P-value		0.06			
Endogeneity χ^2 Statistic		5.67			
P-value		0.02			

Notes: Specifications include Mundlak-Chamberlain fixed effects and indicators for discount window regime.
Column 1 presents estimated coefficients for the selection equation $Pr(s_{it} = 1|z_i) = \Phi(z_{it}\delta_t^a + \bar{z}_i\xi_t^a)$.
Column 2 presents estimated coefficients for the first-stage equation $primary_{it} = c_i + z_{it1}\alpha + x_{it}\beta_t + \gamma pcspread_t + \bar{z}_i\eta + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}$.
Columns 3–6 present estimated coefficients that control for selection and endogeneity: $f\,highdev_{it} = c_i + \alpha\widehat{primary}_{it} + x_{it}\beta_t + \gamma pcspread_t + \bar{z}_i\eta + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}$.
Robust standard errors are in parentheses. *, **, and *** denote significance at the 5 percent, 1 percent, and 0.1 percent level, respectively.

instrument the amount of primary credit. Coefficients for both the probability of borrowing and the amount borrowed are similar.

Despite the individual insignificance of the daylight overdraft result, a battery of first-stage diagnostics suggest that the TAF and daylight overdraft instruments are both sufficiently strong and satisfy overidentifying restrictions. The statistics for these are presented in the bottom lines of the table in column 2. The F-statistics are significantly higher than the critical values suggested by Stock and Yogo (2005). In addition, the Hansen J-statistic does not reject the hypothesis that overidentifying restrictions are satisfied.

6.2 Other Functional Forms

An issue that arises with selection estimators is the degree to which results depend on the form of the control function. This issue was raised by Newey (2009) and addressed by Semykina and Wooldridge (2010) within the context of their model. Columns 3–6 report results from specifications using a range of control functions. These include three cubic spline estimators: probit, logit, and a hazard function, as in Semykina and Wooldridge (2010).

The results in the rows marked "Selection" and "Hazard Spline" imply similar selection and endogeneity results to the baseline. For the probit and logit spline specifications, banks that opt to use the discount window pay a few basis points less for their highest-rate trades than banks that remain in the market. In addition, all other coefficients on included variables in the specification are qualitatively and quantitatively similar to those presented in the baseline. The hazard rate model does suggest slightly different magnitudes of selection than the probit and logit models spline models. However, the results are still qualitatively similar and there may be some functional form effects that should be accounted for more generally.

6.3 Later Crisis Period

The focus of this paper is on the early stages of the crisis. For robustness, it is important to explore how stigma and sample selection shifted after the collapse of Lehman Brothers in the fall of 2008. To do so, the baseline specification is evaluated on a sample with data

from September 2008 to April 2010, which marked the conclusion of the TAF program.

There are some caveats with this exercise. Not only did the collapse of Lehman Brothers signal the acute stage of the financial crisis, but it was also met with a substantial change in the Federal Reserve's monetary policy operating framework. Specifically, as a result of a wide range of lending programs and the first rounds of quantitative easing, reserve balances ballooned, from an average level of roughly $25 billion before September 2008 to 100 times that level afterwards. In turn, the level of daylight overdrafts cratered, as banks generally had substantial funds in their reserve accounts to cover payments without incurring overdrafts.

Against that backdrop, table 8 reports the results of estimating equation (13). Comparing the baseline panel specifications shown in column 1 of table 8 with the baseline specification in column 1 of table 6, there are some key differences in the interplay between borrowing and rates paid. Specifically, the coefficient on primary credit borrowing is positive, not insignificant or negative. Still, TAF borrowing is also negatively correlated with higher rates paid, and the coefficient on peak daylight overdrafts is positive and significant. Taken together, these coefficients suggest that banks that borrowed from the TAF paid lower rates and banks with overdrafts paid higher rates than those that did not, similar to what our early crisis hypothesis would suggest.

That said, evidence in columns 2 and 3 implies that high-rate trading may have become somewhat decoupled from primary credit as the crisis continued and the Federal Reserve's balance sheet ballooned. Column 2 suggests that there was no selection evident in high rates paid in the federal funds market. As such, the results in columns 2 and 3 are not remarkably different. Moreover, as shown in the bottom lines of column 3, first-stage tests suggest that primary credit was no longer endogenous to rates paid in the federal funds market. Importantly, federal funds market participation declined dramatically as reserve balances climbed and counterparty credit risk intensified. Moreover, only the best credits remained in the market. While lenders were wiling to extend credit at higher rates to borrowers during the early stages of the crisis, after Lehman, overnight unsecured credit became scarce and rates became less dispersed, with many banks turning to the TAF for funding.

Table 8. Later Crisis Period

	Panel (1)	Selection (2)	Corrected (3)
Primary Credit	−0.000562	−0.334	0.193
	(0.00200)	(0.566)	(0.618)
Target = 2 Percent	0.0294**		
	(0.00977)		
Target = 1.5 Percent	0.0116***		
	(0.00310)		
Target = 1 Percent	0.00676*		
	(0.00319)		
Peak Daylight Overdrafts	0.0142***		
	(0.00170)		
TAF Borrowing	−0.000938***		
	(0.000221)		
Target = 2 Percent	0.0110**		
	(0.00344)		
Target = 1.5 Percent	0.00174		
	(0.00212)		
Target = 1 Percent	−0.000137		
	(0.000609)		
Number of Days in Market	0.00754*	0.178	−0.0541
	(0.00305)	(0.326)	(0.150)
Amount Borrowed	0.000788	0.00151	0.133
	(0.00102)	(0.192)	(0.147)
Assets	0.000224	−0.206	−0.0697
	(0.000134)	(0.377)	(0.270)
Required Reserves	−0.0421	−39.13	13.04
	(0.0236)	(64.19)	(43.63)
Reserve Balances	−0.00346***	−0.0515	−0.111
	(0.000974)	(0.0587)	(0.197)
CDS Index	0.0123**	−0.328	0.126
	(0.00444)	(0.565)	(0.389)
Repo-Target Spread	−0.244***	−0.653	−0.138
	(0.0258)	(0.722)	(0.235)
Selection			
Target = 2 Percent		0.288	0.0713
		(0.728)	(0.463)
Target = 1.5 Percent		0.365	0.174
		(0.695)	(0.908)
Target = 1 Percent		0.0473	0.0218
		(0.362)	(0.364)
Target = 25 bp		0.149	−0.0214
		(0.273)	(0.301)
N	9,301	503	503
Number of Banks	395	121	121
Adj. R-sq.	0.277	0.046	
Endogeneity χ^2 Statistic			3.233
P-value			0.07

Notes: Dependent variable is the deviation of the average observed high rate paid for federal funds from the effective rate. Specifications include Mundlak-Chamberlain fixed effects.
Column 1 presents estimated coefficients for the baseline panel regression:
$ffhighdev_{it} = c_i + \alpha_t^1 primary_{it} + \alpha^2 daylight_{it} + \alpha_t^3 TAF_{it} + \gamma days_{it} + x_{it}\delta + c_i + q_{pc}\zeta + \epsilon_{it}$.
Column 2 presents estimated coefficients for the selection test:
$ffhighdev_{it} = c_i + \alpha primary_{it} + x_{it}\beta_t + \gamma pcspread_t + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}$.
Columns 3–6 present estimated coefficients that control for selection and endogeneity:
$ffhighdev_{it} = c_i + \alpha \widehat{primary}_{it} + x_{it}\beta_t + \gamma pcspread_t + \bar{z}_i\eta + \rho_{spread}\hat{\lambda}_{it} + \epsilon_{it1}$.
Cluster-robust standard errors are in parentheses. *, **, and *** denote significance at the 5 percent, 1 percent, and 0.1 percent level, respectively.

7. Conclusion

This paper presents a theoretical framework and empirical results that can explain the interaction of the Fed's liquidity provision and the federal funds market in the first stages of the recent financial crisis. If aversion to obtaining funds from the discount window differs across banks, a lower spread of the primary credit rate over the target rate can help lenders price discriminate in a way that is impossible with a wider spread. And, although this price discrimination may lead to higher market rates, overall funding costs may still be lower as a result of the narrowing of the spread between the primary credit rate and the target rate.

Furthermore, the lowering of the primary credit rate may have supported trading in the federal funds market to continue despite the financial crisis, as lenders were more able to price discriminate. Three salient empirical facts help to show this point: (i) as the spread between the primary credit rate and the target rate narrowed, the number of primary credit borrowers and the level of primary credit increased, while the number of participants in the federal funds market decreased; (ii) on an aggregate level, trading above the primary credit rate is correlated with various measures of banking industry stress; and (iii) on an institution level, there is evidence of selection in the federal funds market—as the spread between the primary credit rate and the target rate narrowed, banks that did not go to the discount window paid significantly higher rates in the federal funds market.

By and large, most of the time federal funds were brokered below the primary credit rate and occasions where funds were brokered above the primary credit rate were infrequent. But it is still instructive to study these episodes of above-rate trading to understand the interaction between unsecured interbank markets and central bank liquidity provision in the early days of a financial crisis.

Appendix. Comparative Statics

This appendix reviews some basic comparative statics from the model.

- If q decreases, the equilibrium rate rises.

Taking the total differential of (2) shows

$$\frac{dr^*}{dq} = r^{alt} - \left(r^{dw} + \sum_k p_k \theta_k \right). \tag{A.1}$$

Since $r^{alt} < r^{dw}$ and $sum_k p_k \theta_k \geq 0$ by assumption, this statement is necessarily true. This result intuitively makes sense: as the bargaining power of the buyer falls, the equilibrium rate necessarily rises. During the beginning stages of the financial crisis, as banks were increasingly under scrutiny for their safety and soundness, one might suspect that their bargaining power might fall a bit.

- If stigma increases, the equilibrium rate rises.

There are two ways stigma can increase: either the stigma parameter θ_k or the share of banks with a high stigma p_k can increase. For the first case, taking the total differential of (2) shows

$$\frac{dr^*}{d\theta_k} = p_k, \tag{A.2}$$

which is necessarily positive.

For the second, we assume that an increase in p_k causes the shares p_j to decrease equally, $j \neq k$. Thus, if dp_k is the change in type $k's$ share, we have $dp_j = -\frac{dp_k}{n-1}$ for all $j \neq k$. As a result, we see that

$$\frac{dr^*}{dp_k} = \theta_k - \frac{1}{n-1} \sum_{j \neq k} \theta_j \Longrightarrow \tag{A.3}$$

$$\frac{dr^*}{dp_k} = \theta_k - \bar{\theta}_{-k}, \tag{A.4}$$

where n is the number of banks in the federal funds market and $\bar{\theta}_{-k}$ is the average stigma of institutions not of type k. This simply implies that the effective rate goes up if banks with above-average stigma increase in share.

- If the discount window rate decreases, the equilibrium rate can rise or fall.

This is a result of the direct effect of the discount window rate on pricing in the federal funds market, as well as the indirect effect on participation. Taking the total differential of (2) shows

$$\frac{dr^*}{dr^{dw}} = (1-q) + (1-q)\left(\frac{d}{dr^{dw}}\left(\sum_k p_k\theta_k\right)\right). \tag{A.5}$$

The direct effect of a decrease in the discount window rate on the equilibrium rate is a fall in the rate, as shown by the first term, $(1-q)$. However, note that $\frac{d}{dr^{dw}}(\sum_k p_k\theta_k)$ increases with a decrease in the discount window rate—that is, while there are fewer buyers if the primary credit rate falls, those with lower stigma drop out, because of selection. Consequently, the average level of stigma increases. If this effect is sufficiently positive, then overall, the equilibrium rate will rise. Empirically, we will show that there are instances where this selection effect dominates and the lowering of the primary credit rate resulted in higher federal funds rates.

Of course, the same factors that could lead policymakers to narrow the spread between the primary credit rate and the target rate could also cause some of the parameters of this equilibrium condition to shift. For example, these factors could lead to an increase in the average level of stigma. As a result, the term $\frac{d}{dr^{dw}}(\sum_k p_k\theta_k)$ could be boosted, and the equilibrium rate could rise coincident with the primary credit rate.

Another item to note is how this affect adjusts with a change in the bargaining power parameter, q. If conditions are such that the discount window rate would be lowered, this could also be reflected as a fall in the bargaining parameter, q. This could serve to boost the direct effect of lowering the discount window rate. However, the same factors that could lead to a reduction in the discount rate could also lead to an increase in the average level of stigma, and therefore, boost $\frac{d}{dr^{dw}}(\sum_k p_k\theta_k)$, and cause the equilibrium rate to increase more with the discount rate.

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