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FIGHTING CRISES

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ABSTRACT

In fighting a financial crisis, opacity (keeping the names of banks borrowing at emergency lending facilities secret) and stigma (the cost of having a bank's name revealed) are desirable to restore confidence. Lending facilities raise the perceived average quality of all banks' assets. Opacity reduces the costs of these facilities, creating an information externality that prevents runs even on banks not participating in lending facilities. Stigma is costly but keeps banks from revealing their participation, making opacity sustainable. The key tool for implementing optimal opacity while fine tuning stigma is the haircut for bonds offered as collateral in lending facilities.

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1 Introduction

During the financial crisis of 2007-2008 the Federal Reserve introduced a number of new emergency lending programs, including the Term Auction Facility, the Term Securities Lending Facility, and the Primary Dealers Credit Facility, which provide public funds to financial intermediaries in exchange for private assets. Also as part of their Emergency Economic Stabilization Act, the U.S. Treasury implemented similar programs, such as the Troubled Asset Relief Program (TARP). These facilities were specifically designed to hide borrowers' identities.[1] Secrecy was also integral to the special crisis lending programs of the Bank of England and the European Central Bank.[2] Plenderleith (2012), asked by the Bank of England to review their Emergency Lending Facilities (ELA) during the financial crisis, wrote: "Was secrecy appropriate in 2008? In light of the fragility of the markets at the time . . . it was right to endeavor to keep ELA operations covert. . . in conditions of more systemic disturbance, as in 2008, ELA is likely to be more effective if provided covertly" (p. 70). Even before the Federal Reserve came into existence, private bank clearinghouses would also open an emergency lending facility during banking panics keeping the identities of borrowing banks secret. See Gorton and Tallman (2016).

The secrecy of all these lending facilities has been widely criticized for hiding the identities of weak or insolvent banks, resulting in fierce calls for transparency. During the recent crisis, for instance, Bloomberg and Fox News sued the Fed (under the Freedom of Information Act) to obtain the identities of borrowers.[3] In this paper, however, we show that lending facilities that replace "bad private assets" with "good public bonds" in secret are indeed optimal. Secrecy creates an information externality by raising the average quality of assets in the banking system without replacing all bad assets, mitigating the desire of depositors to examine banks' assets, thereby avoiding a withdrawal of funds (*runs* hereafter) from those banks that are found to have less than average asset quality. A crisis here is an information event, as in Dang,

[1] Bernanke (2010): ". . . [because of] the competitive format of the auctions, the TAF [Term Auction Facility] has not suffered the stigma of the conventional discount window" (p.2). Also, see Armantier et al. (2015). In the case of TARP there were fierce criticisms after their implementation by the Senate Congressional Oversight Panel about its lack of transparency. See `http://www.jec.senate.gov/public/index.cfm/2009/3/03.1.09`.

[2] For an overview see Bank for International Settlements (BIS) Committee on the Global Financial System (2008).

[3] Bloomberg L.P. v. Board of Governors of the Federal Reserve System, 649 Supp 2d 263. Fox News Network v. Board of Governors of the Federal Reserve System, 639 F. Supp 2d 388. See Karlson (2010).

Gorton, and Holmström (2013) and Gorton and Ordonez (2014a). Lending facilities recreate confidence and avoid inefficient examination of banks' portfolios. Secrecy minimizes the cost of those facilities.

Our view of a bank run is in contrast to the more standard view of run as coordination failures and captures both depositors seeking to withdraw from banks and repo lenders wanting to withdraw via higher haircuts on the collateral or not rolling over their loans at all. As these runs are motivated by suspicion about the bank's backing collateral, the Central Bank may lend cash against collateral using an emergency lending facility, or lend Treasury bonds against collateral as in the Term Securities Lending Facility (TSLF) to raise the perceived average quality of the backing collateral. Our arguments below apply in either case, but we will, for consistency, speak throughout of a facility like the TSLF where government bonds are lent against private collateral. Additionally, we will speak of the "Central Bank", but we also think of that as including fiscal authorities' facilities, as with TARP.

Bonds are "good assets" because they are backed by taxation, but this is costly as taxation is usually distortionary.[4] Then, to minimize the cost of issuing bonds these have to be pooled with private assets, but this is only feasible if there is secrecy that allows the pooling.

In our model, for simplicity, households are born with endowments already deposited in a bank which they can withdraw immediately to consume or keep in the bank. A bank is an institution with proprietary access to a productive investment opportunity, or a "project" hereafter, and needs funds to invest. Each bank also has a legacy asset (hereafter simply an "asset") that is used to back deposits. We assume the quality of the asset is unknown unless costly (private) information is produced. If no information is produced, even banks with a bad asset can avoid early withdrawals and invest in the project. The underlying problem in the economy is a scarcity of good assets ("safe debt" to back repo, for example). When good assets are scarce, an efficient substitute is ignorance about which assets are good and which are bad. In that case, good and bad assets are pooled in an informational sense. When this pooling results in a high enough perceived average value of banks' portfolios, depositors do

[4] The distortionary taxation may be in the form of inflation if the Central Bank is lending cash against collateral via emergency lending facilities. Sometimes the Central Bank can sterilize the outflow of cash, and sometimes the result is inflation or compromised monetary policy more generally. See Sinclair (2000).

not examine their own bank's portfolio (no run), maintain their deposits in the bank and banks efficiently invest in their projects.

A crisis happens when an (exogenous) event occurs (a fall in home prices, for instance) causing depositors to run, examining the bank's portfolio and withdrawing if the bank has a bad asset. If this happens, banks can react by reducing the investment scale to avoid information acquisition, or give in to the run, be examined by depositors and hope those depositors find out that the asset is good so it can invest at the optimal scale. In either case, absent government intervention, aggregate consumption falls during a crisis.

The government's goal is to prevent runs, which means avoiding information acquisition about banks' portfolios. How does a Central Bank end a crisis? First, the Central Bank opens an emergency lending facility (called the *discount window* throughout the paper). As banks have heterogeneous collateral, which banks go to the discount window depends on their private information about their asset quality and on the haircut (*discount* throughout the paper) on the assets they deliver as collateral at the discount window in exchange for government bonds.

The choice of the haircut on assets controls which banks participate in the discount window and by doing so determines the perceived average quality of private assets remaining in the economy. But, banks which go to the discount window might be tempted to reveal that they have exchanged bad private assets for good government bonds, so that they can maintain their deposits. But, this reveals information about their own asset quality which will affect them next period. If by revealing that they went to the borrowing facility banks are perceived as having low quality assets (because they exchanged low quality assets for high quality government backed assets), then they may be stigmatized. "Stigma" is the cost, in terms of future fund raising, of revealing that the bank borrowed from the emergency facility. We show how the stigma costs arise endogenously and are necessary for the policy of opacity to work, as banks participating in lending facilities do not have incentives to reveal this information. Stigma aligns the secrecy incentives of the government with those of individual banks.

In contrast to the standard view that opacity prevents stigma, in our paper stigma prevents transparency. Stigma plays an important role in sustaining secrecy, allowing the Central Bank to generate an information externality. If the Central Bank is successful, the result is a high enough perceived average value of banks' assets in the economy such that runs do not occur. The threat of stigma is critical for opacity to be sustainable in equilibrium. The optimal haircut is given by the point at which there are enough banks participating at the lending facility to avoid runs, and no bank faces stigma in equilibrium.

A prominent branch of the literature has studied the effects of lending facilities in helping the economy during crises. Most of this work is based on the premise that a crisis is given by an exogenous tightening in credit constraints and lending facilities step in to provide loans directly (increasing the role of governments as credit providers), open a discount window (mostly to improve inter-banking operations) and injecting equity (to increase the net worth of banks). These interventions are conditional on the exogenous tightening of credit conditions (see Gertler and Kiyotaki (2010) for a discussion). In our model the tightening of credit constraints is endogenous and created by an informational reaction in credit markets to changes in fundamentals, and then we emphasize the role of lending facilities in relaxing the tightening of credit conditions.

There is also a large literature on the lender-of-last-resort summarized by Freixas, Giannini, Hoggarth and Soussa (1999 and 2000) and by Bignon, Flandreau, and Ugolini (2009).[5] Recent historical work also includes Flandreau and Ugolini (2011) and Bignon, Flandreau, and Ugolini (2009) who document the development of the lender-of-last-resort role at the Bank of England and at the Bank of France. Unlike the existing literature, we focus on why secrecy surrounds interventions during crises, the roles of stigma, and a determination of how haircuts are set during a crisis.

The paper proceeds as follows. In Section 2 we specify the model, including the households' choice to run or not to run, and the role of the Central Bank. Section 3 concerns the equilibrium when the economy is in a crisis and the Central Bank opens a lending facility. First, we determine the equilibrium for a fixed collateral haircut and a disclosure policy, and second, the Central Bank maximizes welfare by choosing the haircut and the disclosure policy. Section 4 concludes.

[5] See also Flannery (1996), Freeman (1996), Rochet and Vives (2004), Castiglionesi and Wagner (2012) and Ponce and Rennert (2012).

2 Model

2.1 Environment

We study a two-period economy composed of a Central Bank, a mass 1 of risk-neutral banks that live in both periods and two generations (with mass 1 each) of risk-neutral households that live for a single period. Each household has endowment D of consumption good (numeraire) deposited in a bank at the beginning of each period. Accordingly we refer to households as *depositors*. The consumption good can be stored within a period but not across periods. Depositors are indifferent between consuming at the beginning or the end of each period and can choose to withdraw deposits at the start of each period at no cost.

At the beginning of each period, each bank holds a unit of a legacy asset (in what follows we refer to it simply as the *asset*). This is a fixed-income asset that delivers C units of numeraire at the end of each period with probability p_i (the *type of the asset is good*) and no numeraire with probability $1 - p_i$ (the *type of the asset is bad*). We assume the asset type is drawn every period.[6] We refer to p_i as the *quality of the asset* held by bank i. Further, $p_i = \overline{p} + \eta_i$. The element $\overline{p}$ represents an aggregate component of the quality of assets in the economy, which is public information and can vary over time. Later, when we discuss a crisis, $\overline{p}$ will take a lower value than in non-crisis times. The element $\eta_i \sim F[-\overline{\eta}, \overline{\eta}]$, with $E(\eta_i) = 0$ and $\overline{\eta}$ (such that $p_i \in [0, 1]$) represents a bank i's idiosyncratic component, which is private information (only bank i observes η_i) and is persistent over time (bank i has the same η_i in both periods).

Finally we assume that depositors do not know the realization of the asset's type at the beginning of a period, but depositors can privately learn about it at a cost γ in terms of numeraire. Later, when discussing crises, we will introduce government bonds as another possible asset that banks can hold.

At the beginning of each period, each bank can finance an investment opportunity (in what follows we refer to it simply as the *project*). The project pays $A \min\{K, K^*\}$ with probability q and 0 otherwise. We assume $qA > 1$, so it is ex-ante optimal to finance the project up to an optimal scale K^*. We also assume that $D > K^*$ so there are enough resources for a bank to finance projects to optimal scale. For simplicity we assume that if a bank fails in the first period, it does not operate in the second period.

[6] This is just a convenient simplification that allows us to analyze the two periods separately.

At the beginning of each period a bank is able to invest in the project only if depositors are willing to keep their funds in the bank. Otherwise, since the asset pays off at the end of the period, the bank does not have funds to finance the project at the beginning of the period. If the realization of the project was verifiable, banks could promise depositors a return for their funds that was conditional on the realization, implementing the unconstrained first-best allocation, regardless of the quality of the asset. We assume, however, that the bank can abscond with the numeraire good but cannot abscond with the asset. To fix ideas think of the numeraire good as like cash and the asset as like land, a building or a mortgage. Further we assume $\overline{p}C - K^* > 0$, so the asset generates enough funds in expectation to finance the project to optimal scale, but the bank gets those funds at the end of the period, not at the beginning.

2.2 Withdrawal and Investment Choices

In this setting depositors choose whether to withdraw and consume the funds at the beginning of each period or to leave the funds at the bank and consume at the end of each period. This is a relevant decision as it determines whether the bank is able to finance the project or not. It is also relevant to the household as it determines whether it consumes a known amount at the beginning of the period or an uncertain amount at the end of the period. As households are risk-neutral, they only compare expected consumption levels.

In making this choice depositors decide whether to examine the bank's asset at the beginning of the period or not. Examination is costly, so the depositor may choose not to examine the bank's asset. In what follows we say there is a *run* on a bank when depositors examine the bank's asset at the beginning of the period, and withdraw the funds when they find out that the asset is bad. In our setting we have a single depositor per bank and a run is not triggered by coordination failures. In other words, in our interpretation of a run the depositor does not say "give me the money!" but instead he says "show me the money!"

Next we compare the bank's profits when the depositors examine the bank's asset before deciding whether to withdraw or not (*run*), and the case in which the depositors keep the deposits in the bank without examining the bank's asset (*no run*). Then, we analyze the bank's investment choice (how much to invest in the project) under the shadow of a possible run.

While the bank knows its own p_i, households just have an expectation about the probability that a particular bank's asset is good, which we denote as $E(p_i|\mathcal{I})$, where $\mathcal{I}$ is the information set of depositors at the time of deciding whether to withdraw at the beginning of the period. In this section we focus on a single bank, so we dispense with the subindex i.

2.2.1 Run

Depositors can learn the bank's asset type at the beginning of the period by spending γ of numeraire.[7] We assume information acquisition (and hence information itself) is private immediately after being obtained but becomes public at the end of the period. Still, the depositor can credibly disclose his private information immediately upon acquisition if it is beneficial to do so. This introduces incentives for depositors to obtain information about the bank's asset type privately before deciding to keep their funds in the bank, and thus take advantage of such private information before it becomes common knowledge. Depositors are indifferent between running (examining the bank's portfolio before deciding whether to withdraw) and withdrawing at the beginning of the period without producing any information when

$$D = (1 - E^r(p))D + E^r(p)R_r - \gamma,$$

where D is the amount of deposits in the bank and $E^r(p) \equiv E(p|run)$ is the expected quality of assets among banks suffering runs (being examined) and R_r is the deposit rate promised by banks in case the asset turns out to be good. This implies that

$$R_r = D + \frac{\gamma}{E^r(p)},$$

which is independent of q. If the asset turns out to be bad, the bank would not be able to retain the deposit to finance the project.[8]

Total expected per-period profits for a bank that knows its asset is good with probability p are $p(D + qAK^* - K^* - R_r) + pC$. Substituting R_r in equilibrium, *expected*

[7]Assuming that banks can also learn the bank's asset type does not modify the main insights. See Gorton and Ordonez (2014b) for such extension in a model without banks.

[8]To simplify notation we further assume that $C - K^* > \frac{\gamma}{\overline{p}-\overline{\eta}}$. This guarantees that a good asset generates enough funds to cover the promise to depositors even if the project fails.

period net profits (net of the asset expected value pC) from facing a run are:

$$E_r(\pi|p, E^r(p)) = \max\{pK^*(qA - 1) - \frac{p}{E^r(p)}\gamma, 0\}. \tag{1}$$

The expected profits of a bank in case of a run with depositors examining its assets not only depends on the probability that the bank's asset is good, p, but also on the average quality of the assets of all other banks facing a run. This implies that there is cross-subsidization among banks that face a run: banks with $p > E^r(p)$ end up paying more to compensate depositors for the information costs in expectation, as $\frac{p}{E^r(p)} > 1$. The opposite happens for banks with $p < E^r(p)$.

2.2.2 No-Run

Another possibility is that depositors do not run and keep their deposits at the bank without examining the bank's asset.

Depositors are indifferent between withdrawing at the beginning or at the end of the period if

$$D = qR^R_{nr} + (1 - q)R^D_{nr},$$

where R^R_{nr} is the deposit rate in case the bank repays at the end of the period and R^D_{nr} is the expected return in case the bank defaults, such that

$$R^D_{nr} = D - K + xE^{nr}(p)C.$$

If the bank defaults, then the depositor obtains the endowment not invested in the project and a fraction x of the bank's asset, which has an expected value of $E^{nr}(p)C$, where $E^{nr}(p) \equiv E(p|no\ run)$ is the expected quality of the asset among banks that did not suffer a run.

In equilibrium it should be the case that $R^R_{nr} = R^D_{nr}$. Otherwise, if $R^R_{nr} < R^D_{nr}$ the bank would always liquidate its assets in case the project fails to pay the deposit rate, while if $R^R_{nr} > R^D_{nr}$ the bank would always default on the depositors. Imposing this truth-telling restriction and substituting the definition of R^D_{nr} into the break-even condition,

$$x = \frac{K}{E^{nr}(p)C} \leq 1. \tag{2}$$

For a no-run outcome to be sustainable in equilibrium we have to guarantee that no depositor has incentives to deviate and examine the bank's asset privately at the beginning of the period. Depositors want to deviate because they can maintain deposits at an expected gain if they know the asset is good and withdraw if the asset is bad. Then, depositors want to deviate if the expected gains from acquiring information, evaluated at R^R_{nr} (and then at x), are greater than the gains from not acquiring information. This is

$$(1 - E^{nr}(p))D + E^{nr}(p)\left[qR^R_{nr} + (1-q)[D - K + xC]\right] - \gamma > D.$$

Substituting in the definitions of R^R_{nr} (and then x) in the no-run situation, there are incentives to privately deviate and acquire information about the bank's asset if

$$(1 - E^{nr}(p))\,(1-q)K > \gamma.$$

Intuitively, by acquiring information the depositor only keeps his deposits in the bank if the asset is good, which happens with probability $E^{nr}(p)$. If there is default, which occurs with probability $(1-q)$, the depositor gets xC for a unit of asset that was obtained at a price $E^{nr}(p)xC = K$, making a net gain of $(1 - E^{nr}(p))\,xC = (1 - E^{nr}(p))\,\frac{K}{E^{nr}(p)}$ with probability $E^{nr}(p)(1-q)$. In other words, when deviating and examining the asset, the depositor withdraws at the beginning of the period if the asset is bad and keeps the funds at the bank until the end of the period if the asset is good.

The condition that guarantees that depositors do not want to produce information about the bank's asset can then be expressed in terms of the size of the project, K,

$$K < \frac{\gamma}{(1 - E^{nr}(p))\,(1-q)}. \tag{3}$$

When the bank downsizes the project, depositors have less of an incentive to acquire information about the bank's asset.

Imposing constraints (2) and (3), the investment size that is consistent with a no-run equilibrium is

$$K_{nr}(E^{nr}(p)) = \min\left\{K^*, \frac{\gamma}{(1 - E^{nr}(p))\,(1-q)}, E^{nr}(p)C\right\}, \tag{4}$$

and the bank's expected profits, net of the asset's expected value pC, are

$$E(\pi|E^{nr}(p)) = K_{nr}(E^{nr}(p))(qA - 1). \tag{5}$$

2.2.3 Investment

The size of the investment under which a bank with an asset of quality p results in a run or not depends on the choices of all other banks. In particular, the expected profits of a bank suffering a run depends both on p and $E^r(p)$, and then on the expected quality of the assets among those banks suffering a run and the results of the examination of their portfolios. Similarly, the expected profits of a bank without a run depends on $E^{nr}(p)$, and then on the expected quality of the assets among those banks not suffering a run. The optimal decision of how much to invest in the project is isomorphic to the bank announcing an investment strategy that either invests the deposits at optimal scale (then triggering a run) or restricting the investment size (to avoid a run), and all banks' decisions should be consistent in the aggregate.

In order to solve for the equilibrium, notice first that $E_r(\pi)$ increases in p while $E_{nr}(\pi)$ is independent of p. This implies that, conditional on the strategies of all other banks, if a bank with asset of quality p invests and then faces a run, then all $p' > p$ also prefer to invest and face a run. Similarly, if a bank with an asset of quality p invests to avoid facing a run, then all $p' < p$ also prefer to invest to avoid a run. This implies that the optimal investment strategy is given by a cutoff rule under which all banks with $p < p^*$ restrict their investments and do not face runs and all banks with $p > p^*$ invest at the optimal scale and open themselves to a run (asset examination), where p^* is determined by

$$E_r(\pi|p^*, E^r(p)) = E_{nr}(\pi|E^{nr}(p)),$$

where $E^r(p) = E(p|p > p^*)$ and $E^{nr}(p) = E(p|p < p^*)$.

More formally, allowing for corner solutions in which all banks either face a run or not, the equilibrium cutoff is such that

$$p^* = \begin{cases} \overline{p} + \overline{\eta} & \texttt{if} \quad E_r(\pi|\overline{p} + \overline{\eta}, \overline{p} + \overline{\eta}) < E_{nr}(\pi|\overline{p}) \\ p^* & \texttt{s.t.} \quad E_r(\pi|p^*, E(p|p > p^*)) = E_{nr}(\pi|E(p|p < p^*)). \\ \overline{p} - \overline{\eta} & \texttt{if} \quad E_r(\pi|\overline{p} - \overline{\eta}, \overline{p}) > E_{nr}(\pi|\overline{p} - \overline{\eta}) \end{cases} \tag{6}$$

Notice that when the solution is at a corner the expected quality of the asset of a bank following a strategy that is not assumed to be followed is not well-defined. More formally, if $p^* = \overline{p} + \overline{\eta}$ no bank faces a run and then $E^r(p)$ is not well-defined as it is an off-equilibrium strategy. The same is the case for $E^{nr}(p)$ if $p^* = \overline{p} - \overline{\eta}$ and all banks face a run.

Following the Cho and Kreps (1987) criterion, we assume that if a bank follows a strategy that is not supposed to be followed in equilibrium, depositors believe the bank holds an asset that maximizes its incentives to deviate from the expected strategy. This is, if $p^* = \overline{p} + \overline{\eta}$ and a depositor observes a bank investing in a large project and faces a run, then the depositor believes that the bank has the highest available quality, $E^r(p) = \overline{p} + \overline{\eta}$. Similarly, if $p^* = \overline{p} - \overline{\eta}$ and a depositor observes a bank investing in a project that discourages examination of the asset, then the household believes that the bank has the lowest available quality, $E^{nr}(p) = \overline{p} - \overline{\eta}$.

As both $E^r(\pi|p^*, E(p|p > p^*))$ and $E^{nr}(\pi|E(p|p < p^*))$ increase with p^* there may be multiple p^* in equilibrium. In what follows we will focus on the largest p^* as this represents the *best equilibrium*, the one that guarantees the highest sustainable output.

The next Proposition characterizes the threshold p^* and shows that the fraction of banks facing a run, depends on the average quality of assets, $\overline{p}$ in the best equilibrium. In other words, the next proposition shows that an increase in the average quality of assets in the economy reduces the fraction of banks facing runs.

Proposition 1 *In the best equilibrium, the threshold p^* is increasing in $\overline{p}$. There are beliefs $p^H > p^L$ such that if $\overline{p} > p^H$ no bank faces a run and if $\overline{p} < p^L$ all banks face runs.*

Proof

We first characterize p^H. The maximum profits that a bank with the highest asset quality $\overline{p} + \overline{\eta}$ can get when causing a run when no other bank faces a run (that is, when $E^r(p) = \overline{p} + \overline{\eta}$), is:

$$E_r(\pi|\overline{p} + \overline{\eta}, \overline{p} + \overline{\eta}) = (\overline{p} + \overline{\eta})K^*(qA - 1) - \gamma.$$

This bank does not induce a run if these profits are lower than the profits from not inducing a run conditional on no other bank facing a run, which are

$$E_{nr}(\pi|\overline{p}) = K_{nr}(\overline{p})(qA - 1)$$

where

$$K_{nr}(\overline{p}) = \min\left\{K^*, \frac{\gamma}{(1-q)(1-\overline{p})}\right\}.$$

If there is always a $\overline{p}$ large enough such that $K^* < \frac{\gamma}{(1-q)(1-\overline{p})}$ and $K_{nr}(\overline{p}) = K^*$. Then a bank with asset quality $\overline{p} + \overline{\eta}$ (and all other banks) would never face a run. All banks invest without runs for all $\overline{p} > p^H$, where p^H is defined by $E_r(\pi|p^H + \overline{\eta}, p^H + \overline{\eta}) = E_{nr}(\pi|p^H)$, or

$$(p^H + \overline{\eta})K^*(qA-1) - \gamma = \frac{\gamma}{(1-q)(1-p^H)}(qA-1).$$

In this region, $p^* = \overline{p} + \overline{\eta}$, which trivially increases one for one with $\overline{p}$.

We now characterize p^L. The maximum profits that a bank with the lowest asset quality $\overline{p} - \overline{\eta}$ can obtain when not causing a run when all other banks face runs (that is, $E^{nr}(p) = \overline{p} - \overline{\eta}$) are

$$E_{nr}(\pi|\overline{p} - \overline{\eta}) = K_{nr}(\overline{p} - \overline{\eta})(qA-1)$$

where

$$K_{nr}(\overline{p} - \overline{\eta}) = \min\left\{K^*, \frac{\gamma}{(1-q)(1-(\overline{p} - \overline{\eta}))}\right\}.$$

This bank does not prevent a run if these profits are lower than the profits from causing a run when all other banks face a run, which are

$$E_r(\pi|\overline{p} - \overline{\eta}, \overline{p}) = (\overline{p} - \overline{\eta})\left[K^*(qA-1) - \frac{\gamma}{\overline{p}}\right].$$

Defining p^L by the point at which $E_r(\pi|p^L - \overline{\eta}, p^L) = E_{nr}(\pi|p^L - \overline{\eta})$, such that

$$(p^L - \overline{\eta})\left[K^*(qA-1) - \frac{\gamma}{p^L}\right] > \frac{\gamma}{(1-q)(1-(p^L - \overline{\eta}))}(qA-1),$$

then when $\overline{p} < p_L$ all banks invest such that there is examination of their assets. In this region, $p^* = \overline{p} - \overline{\eta}$, which also trivially increases one for one with $\overline{p}$.

In the best equilibrium and by monotonicity, in the intermediate region of $\overline{p}$ the threshold p^* also increases with $\overline{p}$. Q.E.D.

2.3 Crises and Interventions

We assume that $\overline{p}$ can only take one of two values in the first period. During *normal times*, $\overline{p} = p_H > p^H$ such that there are no runs on the banks. During *crises*, $\overline{p} = p_L < p^L$, such that all banks face runs. In the second period the economy is always in normal times.

If in the first period the economy is in normal times, the economy achieves the maximum potential consumption: households consume D and all banks invest at the optimal scale and produce an additional amount $K^*(qA-1)$ of numeraire. Consumption in the first period during normal times is then

$$W_{1,N} = D + p_H C + K^*(qA-1).$$

During crises, absent government intervention, all banks face runs in terms of depositors examining the banks' assets and only a fraction p_L of banks retain their deposits, at an informational cost γ, and produce at the optimal scale, while the remaining fraction $(1-p_L)$ of banks face withdrawals at the beginning of the period and are not able to finance the project. In this case, first period consumption is,

$$W_{1,C} = D + p_L C + p_L K^*(qA-1) - \gamma.$$

In crises, absent government intervention, consumption is clearly lower than consumption in normal times.

In the second period, as times go back to normal, consumption is

$$W_2 = D + p_H C + qK^*(qA-1).$$

Notice that only q banks are successful in the first period and they are able to produce in the second period, regardless of whether the economy was in normal times or crisis during the first period. Also, regardless of whether information about the asset type was generated in the first period or not, in the second period only the bank knows its own quality (its own η) while its asset type is reset.

Lending Facilities: We model the timing of Central Bank interventions through lending facilities during crises in the first period as follows

1. The Central Bank opens a *discount window* where it will exchange government bonds (hereafter "bonds" for short) that pay at the end of the period for assets, specifically B bonds per unit of asset. It also announces whether it will reveal the identities of banks participating at the discount window (a policy of *transparency*) or whether these identities will be secret (a policy of *opacity*). The Central Bank can commit to its announced policy.[9]

2. Banks choose whether to go to the discount window or not. Even if the Central Bank announces a policy of opacity, still a bank may choose to reveal its participation to its depositors. In that case, it becomes public knowledge that the bank has bonds in its portfolio. But, this will result in an endogenously determined stigma cost, denoted χ, as discussed below.[10] Further, we assume that a bank that does not borrow from the discount window has a probability ε of *information leakage* about the quality of its asset during a crisis.

3. At the end of the first period, discount window borrowers with successful projects repay deposits using the proceeds from production and retain their bonds to redeem at end of the period. Failing banks lose their bonds to depositors, who redeem them at the end of the period. Successful banks that did not borrow from the discount window, repay their deposits and retain their assets. Unsuccessful banks default and hand over their assets to the depositors, who consume them at the end of the period.

4. The Central Bank can liquidate the assets left in its possession by defaulting banks but only imperfectly. The Central Bank can only extract a fraction ϕ of the value of the banks' asset in its possession at the end of the period. Then the numeraire generated by the asset in possession of the Central Bank plus distortionary taxes (transfers) are used to redeem the bonds.

Our focus will be on whether the optimal policy of the Central Bank is one of transparency or one of opacity. This decision of the Central Bank will take into account the

[9]Borrowing a Treasury bond, posting assets as collateral, corresponds to using the Fed's Term Securities Lending Facility; see Hrung and Seligman (2011). But, bonds could also be thought of as cash or reserves.

[10]See Armantier et al. (2015), Anbil (2015), Ennis and Weinberg (2010) and Furfine (2003) for other ways to model stigma costs.

strategies of banks and depositors.[11] Importantly, the Central Bank does not produce information about the assets it receives through the discount window; just avoids private production of information.

Step 2 is the critical step for banks if the Central Bank chooses the opacity policy. If neither the Central Bank nor the bank reveals participation at the window, the deposit is backed by a portfolio with uncertain composition. Depositors only know that a fraction y of banks participated at the discount window in equilibrium. But, under opacity, discount window borrowers may still wish to reveal that they borrowed so that they can display that their portfolio consists of bonds guaranteed by the government instead of an asset of uncertain type. But, this makes them vulnerable to stigma. We will show how this stigma is determined and how it keeps borrowing banks from revealing that they borrowed so that the pooling of collateral that the Central Bank seeks can be accomplished.

Step 4 is also important because it concerns the costs of intervention. As the Central Bank is less efficient than private agents at extracting value from assets, the extra resources that are needed to redeem bonds come from distortionary taxation or transfers. With no costs there would be no trade-off faced by the Central Bank in determining the optimal policy.

3 The Roles of Opacity and Stigma in Fighting Crises

We solve the Central Bank's problem in two steps. First, we compute the equilibrium and welfare in the economy under *opacity* and then under *transparency*, as a function of the bonds B that the Central Bank exchanges per unit of asset through the discount window. Then we allow the Central Bank to choose the disclosure policy and the optimal B^* that maximizes welfare in equilibrium.

[11]We are interested in the optimal disclosure policy within the realm of a lending facility intervention. The intervention corresponding to the solution of an optimal mechanism is outside the scope of this paper, but certainly an interesting problem for further research.

3.1 Ending a Crisis with Opacity

3.1.1 Preliminaries

In any equilibrium in which the Central Bank successfully maintains the anonymity of participating banks, banks make the same investment decisions regardless of their participation at the discount window as long as they do not face runs. Still the banks' expected payoffs differ according to whether they go to the discount window or not. The cost of no participation is given by the probability that information about the bank's asset type leaks and that the bank faces a run. This cost decreases with the quality of the bank's asset p. The cost of participation is the *discount* imposed by the government (defined by the difference $pC - B$), which increases with the quality of the bank's asset. We can also define the *haircut* by the ratio $1 - \frac{B}{pC}$. We use the terms discount and haircut interchangeably.

As the cost of participation increases with p and the cost of not participating decreases with p, banks tend to participate more when they have lower p. In other words, if a bank with asset p borrows from the discount window, then all other banks with $p' < p$ will do the same. In contrast, if a bank with asset p does not borrow from the discount window, then no bank with $p' > p$ will borrow. Hence, there is a threshold p_w^* in equilibrium such that all banks $p < p_w^*$ participate and all banks $p > p_w^*$ do not. We can redefine the fraction of banks participating at the discount window as

$$y(p_w^*) = Pr(p < p_w^*).$$

The expected asset quality of banks participating at the discount windows is

$$E^w(p) = E(p|p < p_w^*)$$

and the expected asset quality of banks not participating is

$$E^{nw}(p) = E(p|p > p_w^*).$$

Depositors know that with probability $y(p_w^*)$ the bank has borrowed from the discount window and obtained B bonds, and then the expected value of the bank's portfolio is

$$y(p_w^*)B + (1 - y(p_w^*))E^{nw}(p)C.$$

Given this expectation, depositors are indifferent between withdrawing or not withdrawing at the beginning of a period when

$$D = qR^R_{nr} + (1-q)R^D_{nr},$$

where R^D_{nr} is now given by the expected return in case the bank defaults, such that

$$R^D_{nr} = D - K + x[yB + (1-y)E^{nw}(p)C].$$

In equilibrium the bank should promise in expectation the same in case of repayment or default (for the same reasons as in the previous section), $R^R_{nr} = D - K + x[yB + (1-y)E^{nw}(p)C] = D$. We can then obtain the fraction of assets in the portfolio that go to the depositors in case of default,

$$x = \min\left\{\frac{K}{yB + (1-y)E^{nw}(p)C}, 1\right\}.$$

Now we can compute the incentives of depositors to privately acquire information about the portfolio of the bank. At a cost γ the depositor can privately learn whether the bank has bonds or the asset in its portfolio, and in case the bank has an asset, whether the asset is of good or bad type.

The benefits of acquiring information are as follows: with probability $y(p^*_w)$ the bank has bonds and the depositor that examines the portfolio does not withdraw his deposits because he did not find out anything bad about the bank, getting a payoff of:

$$qR^R_{nr} + (1-q)[D - K + xB] - \gamma.$$

With probability $(1-y)(1-E^{nw}(p))$ the bank has a bad asset and the depositor withdraws at the beginning of the period, getting a payoff of $D - \gamma$. Finally, with probability $(1-y)E^{nw}(p)$ the bank has a good asset, and the depositor keeps his deposits in the bank, getting a payoff of

$$qR^R_{nr} + (1-q)[D - K + xC] - \gamma.$$

As $R^R_{nr} = D$, and adding the previous payoffs weighted by the respective probabilities, there are no incentives to acquire information as long as:

$$D + y(1-q)[xB - K] + (1-y)E^{nw}(p)(1-q)[xC - K] - \gamma \leq D.$$

Rearranging

$$(1-q)x(yB + (1-y)E^{nw}(p)C) - (1-q)[y + (1-y)E^{nw}(p)]K \leq \gamma.$$

Since $x(yB + (1-y)E^{nw}(p)C) = K$, there is no information acquisition as long as

$$K \leq \frac{\gamma}{(1-q)(1-y)(1-E^{nw}(p))}. \tag{7}$$

Proposition 2 *Runs are less likely with intervention when there are many banks participating at the discount window (i.e., high p_w^* and then high y).*

This Proposition arises trivially from comparing the condition for no information acquisition in the absence of intervention (equation 3) and in the presence of intervention (equation 7). It is also straightforward to check that condition (7) is more likely to hold when y is higher.

Define

$$B \equiv \widetilde{p}C,$$

such that the Central Bank choosing $\widetilde{p}$ implicitly chooses how many bonds B to offer per unit of asset with quality p, or the haircut $1 - \frac{\widetilde{p}}{p}$. This will be clearer when we analyze comparative statics in terms of $\widetilde{p}$ based on this one-to-one mapping between $\widetilde{p}$ and B.

3.1.2 Equilibrium under Opacity

Now we solve for the equilibrium strategies of depositors (in terms of running to acquire information) and of banks (in terms of participating at the discount window) as a function of $\widetilde{p} = \frac{B}{C}$.

Define $\sigma(\widetilde{p})$ as the probability of a run, in which depositors privately acquire information about a bank's portfolio before choosing whether to withdraw

$$\sigma(\widetilde{p}) = \begin{cases} 0 & \texttt{if} \quad K < \frac{\gamma}{(1-q)(1-y(\widetilde{p}))(1-E^{nw}(p|\widetilde{p}))} \\ [0,1] & \texttt{if} \quad K = \frac{\gamma}{(1-q)(1-y(\widetilde{p}))(1-E^{nw}(p|\widetilde{p}))} \\ 1 & \texttt{if} \quad K > \frac{\gamma}{(1-q)(1-y(\widetilde{p}))(1-E^{nw}(p|\widetilde{p}))}. \end{cases} \tag{8}$$

First, define

$$L(p, \widetilde{p}) \equiv pK^*(qA-1) - \frac{p}{E^{nw}(p|\widetilde{p})}\gamma$$

as the "relatively (L)ow" bank's expected gains in case of a run when the bank did not participate at the discount window and holds an asset. Second, define

$$H(K) \equiv K(\widetilde{p})(qA-1)$$

as the "relatively (H)igh" bank's expected gains from raising funds $K(\widetilde{p})$ without a run. Third, define stigma, $\chi(p, \widetilde{p})$, as the cost in terms of a higher probability of a run in the second period coming from information that the bank participated at the discount window in the first period, and so has revealed that the quality of its asset is lower than average. We will derive this value endogenously later.[12] Finally, define $d(p, \widetilde{p}) \equiv (p - \widetilde{p})C$ as the bank's discount when borrowing from the discount window.

We can express the payoffs of a bank p when not borrowing from the discount window when the discount is $\widetilde{p}$ as

$$E^{nw}(\pi) = \sigma(\widetilde{p})L(p, \widetilde{p}) + (1 - \sigma(\widetilde{p}))[(1-\varepsilon)H(K) + \varepsilon L(p, \widetilde{p})] \tag{9}$$

and when borrowing from the discount window as

$$E^{w}(\pi) = \sigma(\widetilde{p})[H(K) - d(p, \widetilde{p}) - \chi(p, \widetilde{p})] + (1 - \sigma(\widetilde{p}))[H(K) - d(p, \widetilde{p})]. \tag{10}$$

The next four lemmas characterize the optimal depositors' run (examinations) strategies and banks' participation strategies, as a function of $\widetilde{p}$, under opacity.

Lemma 1 *Very low discount region.*

[12]There is in principle a symmetric *positive stigma*, a benefit in terms of reducing bank runs from the revelation that a firm has not participated in the discount window, then having asset with quality above the average. We do not introduce any notation for this, as later we show it is zero.

There exists a cutoff $\widetilde{p}_h < p_L+\overline{\eta}$ such that, for all $\widetilde{p} \in [\widetilde{p}_h, p_L+\overline{\eta})$ ("very low discount region"), no depositor runs (that is, $\sigma(\widetilde{p}) = 0$) and all banks borrow from the discount window (that is, $y(\widetilde{p}) = 1$).

Proof Assume first that the Central Bank chooses the haircut such that $\widetilde{p} = p_L + \overline{\eta}$. In this case there is no discount for the bank with the highest asset quality, this is $d(p_L + \overline{\eta}, \widetilde{p}) = 0$. As this high level of $\widetilde{p}$ implies there is a subsidy for all banks with $p < p_L + \overline{\eta}$, the analysis is reinforced for all haircuts such that $\widetilde{p} > p_L + \overline{\eta}$. Compare equations (9) and (10) for $p = p_L + \overline{\eta}$. It is optimal for a bank with $p = p_L + \overline{\eta}$ to borrow from the discount window (and then all banks borrow from the discount window, $y = 1$) and there is no stigma (i.e., $\chi = 0$), confirming that this is indeed the best sustainable equilibrium.[13] Hence, for $\widetilde{p} \geq p_L + \overline{\eta}$, a fraction $y(\widetilde{p}) = 1$ of banks participate, from equation (8), $\sigma(\widetilde{p}) = 0$ and from equation (7) $K(\widetilde{p}) = K^*$.

For lower levels of $\widetilde{p}$, this is still an equilibrium as long as the bank with the highest asset quality finds it optimal to participate. The critical level $\widetilde{p}_h$ is determined by the point at which

$$H(K^*) - d(p_L + \overline{\eta}, \widetilde{p}_h) = (1 - \varepsilon)H(K^*) + \varepsilon L(p_L + \overline{\eta}, \widetilde{p}_h),$$

such that $p^*_w(\widetilde{p}_h) = p_L + \overline{\eta}$ and then $E^{nw}(p|\widetilde{p}_h) = p_L + \overline{\eta}$. Then,

$$\widetilde{p}_h = (p_L + \overline{\eta}) - \frac{\varepsilon}{C}\left[(1 - p_L - \overline{\eta})K^*(qA - 1) + \gamma\right].$$

Q.E.D.

Lemma 2 *Low discount region.*

There exists a cutoff $\widetilde{p}_m < \widetilde{p}_h$ such that, for all $\widetilde{p} \in [\widetilde{p}_m, \widetilde{p}_h)$ ("low discount region"), no depositor runs (that is, $\sigma(\widetilde{p}) = 0$) and fewer banks borrow from the discount window as the discount increases (that is, $y(\widetilde{p})$ increases with $\widetilde{p}$).

[13] Notice that this is only one possible equilibrium. If everybody believes that some banks did not borrow from the discount window, $\chi > 0$, it may be indeed optimal for those banks not to borrow from the window. This shows how endogenous stigma may induce equilibrium multiplicity and may generate self-confirming collapses in the use of discount windows. Here we focus on the best equilibrium based on intervention, and show its limitations.

Proof Assume first the extreme case in which $\widetilde{p} = \widetilde{p}_h$. From the previous proposition, $y(\widetilde{p}_h) = 1$ and $\sigma(\widetilde{p}_h) = 0$. For $\widetilde{p} = \widetilde{p}_h - \epsilon$ (from the definition of $\widetilde{p}_h$),

$$H(K^*) - d(p_L + \overline{\eta}, \widetilde{p}_h - \epsilon) < (1-\varepsilon)H(K^*) + \varepsilon L(p_L + \overline{\eta}, \widetilde{p}_h - \epsilon),$$

and then banks with asset quality $p_L + \overline{\eta}$ strictly prefer to not participate at the discount window. This implies that $y(\widetilde{p}_h - \epsilon) \equiv Pr(p < p^*_w(\widetilde{p}_h - \epsilon)) < 1$ where $p^*_w(\widetilde{p}_h - \epsilon)$ is given by the indifference condition

$$H(K^*) - d(p^*_w, \widetilde{p}_h - \epsilon) = (1-\varepsilon)H(K^*) + \varepsilon L(p^*_w, \widetilde{p}_h - \epsilon),$$

or

$$d(p^*_w, \widetilde{p}_h - \epsilon) = \varepsilon[H(K^*) - L(p^*_w, \widetilde{p}_h - \epsilon)],$$

where p^*_w declines monotonically as we reduce $\widetilde{p}$. Notice that this construction relies on the conjecture that $\sigma(\widetilde{p}_h - \epsilon) = 0$, but for relatively low ϵ this is the case as long as $y(\widetilde{p}_h - \epsilon)$ and $E^{nw}(p|\widetilde{p}_h - \epsilon)$ are such that

$$K^* < \frac{\gamma}{(1-q)(1-y)(1-E^{nw}(p))}.$$

Define by $\overline{p}^*_w$ the threshold such that $\overline{y}(\overline{p}^*_w)$ is the fraction of banks borrowing from the discount window and $\overline{E}^{nw}(p|\overline{p}^*_w)$ is the expected quality of the non-participating banks' assets, such that

$$K^* = \frac{\gamma}{(1-q)(1-\overline{y})(1-\overline{E}^{nw}(p))}.$$

The bank with the marginal asset quality $\overline{p}^*_w(\widetilde{p}_m)$ is determined by

$$H(K^*) - d(\overline{p}^*_w, \widetilde{p}_m) = (1-\varepsilon)H(K^*) + \varepsilon L(\overline{p}^*_w, \widetilde{p}_m),$$

such that

$$\overline{y} = Pr(p < \overline{p}^*_w(\widetilde{p}_m)) \qquad \texttt{and} \qquad \overline{E}^{nw}(p) = E(p|p > \overline{p}^*_w(\widetilde{p}_m)).$$

Finally, the threshold $\overline{p}^*_w$ is well-defined, as both y and $E^{nw}(p)$ monotonically increase in p^*_w, which monotonically decreases in $\widetilde{p}$. Q.E.D.

Intuitively, when the discount is low ($\widetilde{p}$ is large), many banks choose to borrow at the discount window because the cost in terms of exchanging assets for bonds at a low haircut more than compensates for the risk of a run and information about the asset being revealed. Given this, depositors do not have incentives to run and examine the bank's portfolio.

The next lemma characterizes the equilibrium for an intermediate discount region.

Lemma 3 *Intermediate discount region.*

There exists a cutoff $\widetilde{p}_l < \widetilde{p}_m$ such that, for all $\widetilde{p} \in [\widetilde{p}_l, \widetilde{p}_m)$ ("intermediate discount region"), depositors run with positive probability but not always (that is, $\sigma(\widetilde{p}) \in (0,1)$) and a constant fraction $\overline{y}$ of banks go to the discount window (that is, $y(\widetilde{p}) = \overline{y}(\widetilde{p}_m)$).

Proof

Assume first the extreme case where $\widetilde{p} = \widetilde{p}_m$. From the previous lemma, $y(\widetilde{p}_m) = \overline{y}$ and $\sigma(\widetilde{p}_h) = 0$. For $\widetilde{p} = \widetilde{p}_m - \epsilon$, the bank that is indifferent about borrowing from the discount window is $p^*_w(\widetilde{p}_m - \epsilon) < p^*_w(\widetilde{p}_m)$. Then $y(\widetilde{p}_m - \epsilon) < \overline{y}$ and $E^{nw}(p|\widetilde{p}_m - \epsilon) < \overline{E}^{nw}(p)$. We will show that this is an equilibrium.

From the information acquisition condition

$$K^* > \frac{\gamma}{(1-q)(1-y(\widetilde{p}_m - \epsilon))(1 - E^{nw}(p|\widetilde{p}_m - \epsilon))},$$

and there are incentives to run when the bank invests K^* in the project, as there are relatively few participants at the discount windows (low y) and the assets of those not participating at the discount windows are worse in expectation (low $E^{nw}(p)$).

One possibility for banks to prevent runs, $\sigma(\widetilde{p}) = 0$, is to reduce the investment in the project to $K(p^*_w) < K^*$, to avoid information acquisition. The size of the deposit K, however, also determines y, as $p^*_w(\widetilde{p}_m - \epsilon)$ is pinned down by the condition

$$d(p^*_w, \widetilde{p}_m - \epsilon) = \varepsilon[H(K(p^*_w)) - L(p^*_w, \widetilde{p}_m - \epsilon)].$$

A lower K relaxes the constraint and reduces the incentives to run, but at the same time reduces p^*_w for a given $\widetilde{p}$, increasing the incentives to run. Intuitively, for a given discount, a reduction in the gains from borrowing from the discount window (from lower $H(K)$) reduces the p of the marginal bank which is indifferent between borrowing or not, i.e., reducing p_w^* further.

If $H(K(p_w^*))$ declines faster than $L(p_w^*)$, then no participant will go to the discount window if, at the lowest possible p, which is $p_L - \overline{\eta}$,

$$H(K(p_L - \overline{\eta})) - L(p_L - \overline{\eta}, p_L) < 0$$

which we have assumed in the definition of a crisis.

In words, banks cannot discourage runs by reducing the size of their investments in the project, which is in contrast to what happens in the absence of intervention. Our result here comes from the endogenous participation of banks at the discount window. By reducing K, the effect of a lower y in inducing information acquisition is stronger than the effect of a lower K in discouraging information acquisition, thus increasing on net the incentives for depositors to examine a bank's asset as K declines.

Under these conditions, the equilibrium involves either the discount window sustaining a deposit of K^* (when a fraction $\overline{y}$ of banks borrows from the discount window) or no participation in the discount window at all, which replicates the allocation without intervention. To maintain the fraction $\overline{y}$ constant in this region as $\widetilde{p}$ declines, the marginal bank with asset quality $p_w^*(\widetilde{p}_m)$ should always be indifferent about borrowing from the discount window or not. This is achievable only if depositors choose to run and examine the portfolio of banks with higher probability as $\widetilde{p}$ declines, as this increases the incentives to have bonds in the portfolio.

With positive information acquisition ($\sigma(\widetilde{p}) > 0$) there is stigma when the depositor discovers participation at the discount window. The reason there is stigma is that those banks borrowing from the discount window are the ones with relatively low asset quality (relatively low η_i). Once a bank is stigmatized, it may face withdrawals during normal times in the second period.

To be more precise about the endogeneity of stigma, once back in normal times, the bank will face a run when investing at the optimal scale of production if

$$K^* > \frac{\gamma}{(1-q)(1-E^w(p))},$$

and the bank will not suffer a run in the second period based on an indifference condition that pins down p_2^* in the second period where

$$E_r(\pi|p_2^*, E^r(p|p < p_w^*)) = E_r(\pi|E^{nr}(p|p < p_w^*)).$$

We denote by $K^w(p, \widetilde{p})$ the investment size that a bank with an asset of quality p can obtain in the second period conditional on having borrowed from the discount window in the first period.

Then, we define stigma as

$$\chi(p, \widetilde{p}) = [K^* - K^w(p, \widetilde{p})](qA - 1),$$

where χ is an increasing function of the discount (a decreasing function of $\widetilde{p}$). As the discount increases, p_w^* decreases, $y(p_w^*)$ decreases and $E^w(p)$ decreases. This leads to a decline in K^w and then an increase in stigma from going to the discount window.

Given $\overline{p}_w^*$, to maintain the investment size K^* without triggering information, the indifference of the marginal bank $\overline{p}_w^*$ pins down the probability the depositor runs. This is $E^{nw}(\pi|p_w^*) = E^w(\pi|p_w^*)$, which implies

$$\sigma L(\overline{p}_w^*, \widetilde{p}) + (1-\sigma)[(1-\varepsilon)H(K^*) + \varepsilon L(\overline{p}_w^*, \widetilde{p})] = [H(K^*) - d(\overline{p}_w^*, \widetilde{p})] - \sigma\chi(\overline{p}_w^*, \widetilde{p})$$

and then

$$\sigma(\widetilde{p}) = \frac{d(\overline{p}_w^*, \widetilde{p}) - \varepsilon[H(K^*) - L(\overline{p}_w^*, \widetilde{p})]}{(1-\varepsilon)[H(K^*) - L(\overline{p}_w^*, \widetilde{p})] - \chi(\overline{p}_w^*, \widetilde{p})}. \tag{11}$$

Finally, depositors randomize between running and not given the bank investing K^* in the project, and a bank with asset quality $\overline{p}_w^*$ is indifferent between borrowing from the discount window or not. Q.E.D.

When the intermediate discount range exists, the equilibrium cannot involve pure strategies by depositors. Since participation at the discount window when depositors do not run is low, depositors have incentives to run. In contrast, if depositors run, banks have more incentives to borrow from the discount window, which discourages runs. Depositors have to be indifferent between running or not. As the discount increases in this range, banks incentives to borrow from the discount window have to be compensated for by an increase in the probability of runs.

Finally, the next lemma characterizes the case with very large discount levels.

Lemma 4 *High discount region.*

There exists a cutoff $\widetilde{p}_l > 0$ *such that, for all* $\widetilde{p} \in (0, \widetilde{p}_l]$ *("high discount region"), banks do not borrow from the discount window (that is* $y(\widetilde{p}) = 0$*) and depositors always run (that is,* $\sigma(\widetilde{p}) = 1$*).*

Proof

From equation (11), $\sigma(p_w^*) = 1$ for $d(\overline{p}_w^*, \widetilde{p}) \geq H(K^*) - L(\overline{p}_w^*, \widetilde{p}) - \chi(\overline{p}_w^*, \widetilde{p})$. We define $\widetilde{p}_l$ as the discount that solves this condition with equality. Evaluating $E^{nw}(\pi)$ and $E^w(\pi)$ at $\sigma(\widetilde{p}) = 1$ given a project of size K^* and at the threshold $\overline{p}_w^*$ a bank with asset p_w^* goes to the discount window whenever

$$H(K^*) - d(\overline{p}_w^*, \widetilde{p}) - \chi(\overline{p}_w^*, \widetilde{p}) > L(\overline{p}_w^*, \widetilde{p})$$

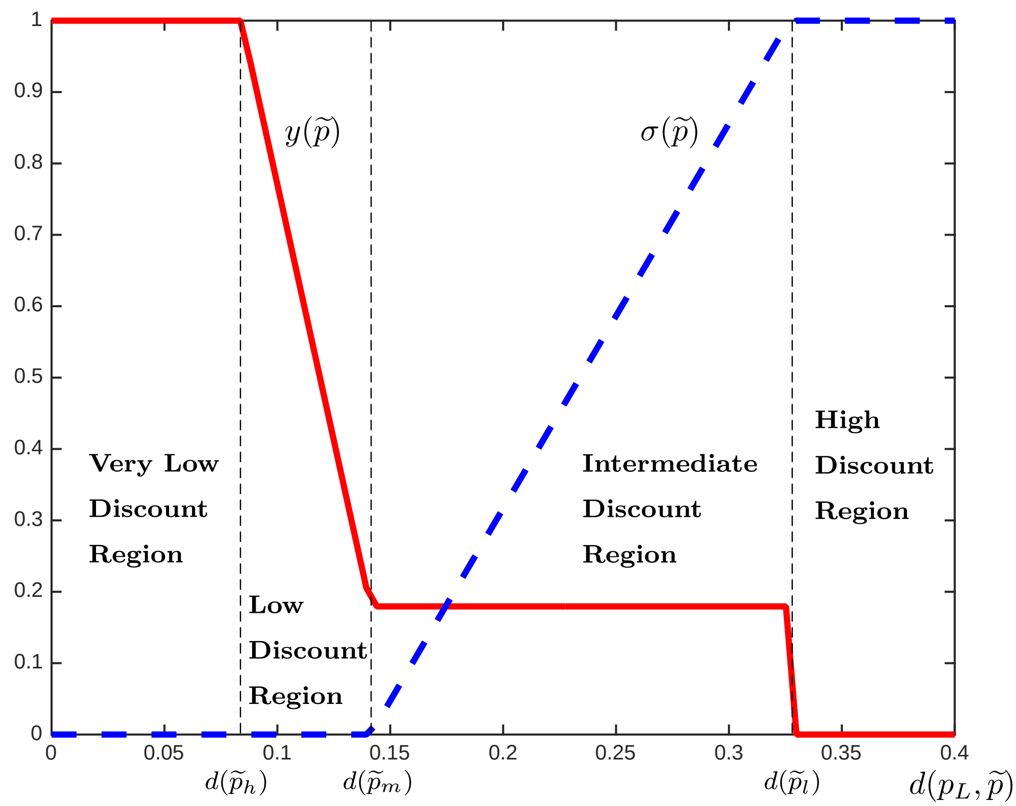
which is never the case in this region by the previous condition. Then $y(\widetilde{p}) = 0$ and then it is indeed optimal that $\sigma(\widetilde{p}) = 1$. Q.E.D.

Intuitively, when the discount is high ($\widetilde{p}$ is low), no bank chooses to borrow from the discount window, even when depositors are running. Given this reaction, depositors always run. The economy generates the same consumption as in the case of a crisis without intervention.

It is straightforward to check that no bank would like to deviate from the opaque policy of the Central Bank in terms of disclosing its participation, or lack thereof, at the discount window. Banks borrowing from the discount window do not want to reveal their participation, otherwise they have to pay the stigma cost without getting any benefit (by preventing a run the bank still extends a loan by K^* to invest in the project, exactly as it can do in case the depositor runs and learns that the bank has bonds in its portfolio as collateral). Similarly, banks not borrowing from the discount window do not want to reveal their lack of participation, otherwise they have a higher chance of suffering a run (depositors will always try to examine the bank's portfolio once they know for sure that they hold an asset in the portfolio).

The equilibrium strategies derived in Lemmas 2-4 are illustrated in Figure 1. On the horizontal axis we show the average discount $d(p_L, \widetilde{p})$, the red solid function shows the fraction of depositors who run, $\sigma(\widetilde{p})$, and the black dashed function shows the fraction of banks that borrow from the discount window, $y(\widetilde{p})$. We use the average discount instead of $\widetilde{p}$ as it is more intuitive to think of the discount as the cost of participation. The strategies in the "very low discount region" $[0, d(p_L, \widetilde{p}_h)]$ are shown in Lemma 1, in the "low discount region" $[d(p_L, \widetilde{p}_h), d(p_L, \widetilde{p}_m)]$ are shown in Lemma 2, in the "intermediate discount region" $[d(p_L, \widetilde{p}_m), d(p_L, \widetilde{p}_l)]$ in Lemma 3 and in the "high discount region" $[d(p_L, \widetilde{p}_l), C]$ in Lemma 4.

Figure 1: Equilibrium Strategies under Opacity



3.2 Ending a Crisis with Transparency

When the Central Bank discloses information about the identity of banks participating at the discount window, the information acquisition strategy of depositors is conditional on this information. More specifically, when depositors know a bank has borrowed from the discount window, they never run on it, as they know the bank uses government bonds as collateral. Then $\sigma(\widetilde{p}) = 0$ for all $\widetilde{p}$, conditional on participation at the discount window, and $E^w(\pi) = H(K^*) - d(p, \widetilde{p}) - \chi(p, \widetilde{p})$. In contrast, when depositors know a bank has not participated at the discount window, they always run on it, as they know the bank has an asset in its portfolio. Then $\sigma(\widetilde{p}) = 1$ for all $\widetilde{p}$, conditional on no participation in the discount window, and $E^{nw}(\pi) = L(p, \widetilde{p})$.[14]

This implies that the borrower p_w^* that is indifferent about borrowing from the discount window, when the discount is given by $\widetilde{p}$, is determined by

$$H(K^*) - d(p_w^*, \widetilde{p}) - \chi(p, \widetilde{p}) = L(p_w^*, \widetilde{p}).$$

Notice that this is the same condition that determines $p_w^*(\widetilde{p}_l)$ in Lemma 4. Still this does not imply that policies of opacity and transparency coincide at $\widetilde{p}_l$. While the best equilibrium with opacity is given by a fraction $\bar{y} < 1$, the best equilibrium with transparency may have all banks participating. The latter is sustainable with transparency and not with opacity because transparency eliminates the strategic incentive of banks to avoid paying the discount and still being able to invest at the optimal scale without triggering a run.

Proposition 3 *In the best equilibrium under transparency, all banks borrow from the discount window $y_T(\widetilde{p}) = 1$ for $\widetilde{p} \in [\widetilde{p}_T, \overline{p} + \overline{\eta}]$ such that $\widetilde{p}_T < \widetilde{p}_h$.*

Proof Define $\widetilde{p}_T$ by

$$H(K^*) - d(p_L + \overline{\eta}, \widetilde{p}_T) = L(p_L + \overline{\eta}, \widetilde{p}_T)$$

as for all $\widetilde{p} > \widetilde{p}_T$

$$H(K^*) - d(p_L + \overline{\eta}, \widetilde{p}) > L(p_L + \overline{\eta}, \widetilde{p})$$

and the bank with asset of quality $p_L + \overline{\eta}$ strictly prefers to borrow from the discount window. Notice that as all banks participate, $\chi = 0$.

The condition that pins down $\widetilde{p}_h$ in Lemma 1 is

$$H(K^*) - d(p_L + \overline{\eta}, \widetilde{p}_h) = (1 - \varepsilon)H(K^*) + \varepsilon L(p_L + \overline{\eta}, \widetilde{p}_h).$$

As the right-hand side is larger than in the condition above that pins down $\widetilde{p}_T$, the discount has to be smaller and $\widetilde{p}_T < \widetilde{p}_h$. Q.E.D.

[14]Note that we have defined crises by a $\bar{p} = p_L$, such that depositors run for all banks if they only hold private assets, even those with $p_i = p_L + \overline{\eta}$. This assumption is not restrictive but allows us to bypass the issue of signaling. If not participating in the lending facility is a good signal of the bank's quality, strong enough to prevent a bank run, then banks with bad quality would rather not participate in the discount window. Then this proposed situation is not an equilibrium.

Intuitively, when all banks participate under a policy of transparency, the alternative of not participating results in suffering a run for sure. This is in stark contrast to the opacity policy, in which if all banks participate, and the alternative of not participating has only a slight chance ε of an information leak and a run.

There is nothing that prevents $\widetilde{p}_T$ from being smaller than $\widetilde{p}_l$, such that $\widetilde{p}_T < \widetilde{p} < \widetilde{p}_l$, so that under transparency all banks participate while under opacity none do. The reason is that at $\widetilde{p}_l$ depositors always run conditional on there being $\bar{y}$ banks participating. If all banks were participating, depositors would not run and then the alternative gains from not participating under opacity are very large, inducing individuals to deviate, making this equilibrium unsustainable. This is not the case under transparency in which the alternative to not participating always leads to runs.

3.3 Opacity or Transparency?

Given the equilibrium strategies for each $\widetilde{p}$ under both opacity and transparency, we can compute the total production (or welfare in our setting) for each $\widetilde{p}$ under each disclosure policy. Welfare is given by

$$\begin{aligned}
W(\widetilde{p}) \;\; = \;\; & \int_p \left[\mathbb{I}_w[H+B-pC] + (1-\mathbb{I}_w)[\sigma L(p) + (1-\sigma)((1-\varepsilon)H + \varepsilon L(p))]\right] dF(p) \\
& + \int_p \mathbb{I}_w[q(pC-B) + (1-q)(\phi pC - B)] dF(p) \\
& + \int_p \left[\mathbb{I}_w[q(H-\sigma\chi(p)) - (1-q)\delta(1-\phi)pC] + (1-\mathbb{I}_w)qH\right] dF(p),
\end{aligned}$$

where $\mathbb{I}_w$ is an indicator function that takes the value 1 if the bank participates at the discount window and 0 otherwise.

Taking integrals and rewriting the expression, we can write welfare in simpler terms as

$$\begin{aligned}
W(\widetilde{p}) \;\; = \;\; & y(H+B-E^w(p)C) + (1-y)[\sigma\widehat{L} + (1-\sigma)((1-\varepsilon)H + \varepsilon\widehat{L})] \\
& + y[q(E^w(p)C-B) + (1-q)(\phi E^w(p)C - B)] \\
& + y[q(H-\sigma\widehat{\chi}) - (1-q)\delta(1-\phi)E^w(p)C] + (1-y)qH.
\end{aligned}$$

where $H \equiv H(K^*)$, $\widehat{L} \equiv \int_p L(p)dp$ and $\widehat{\chi} \equiv \int_p \chi(p)dp$.

The first two terms (the first line) represent the welfare of banks in the crisis period. A fraction y of banks borrow from the discount window leading to a production of H and exchanging asset for bonds at an average discount of $B - E^w(p)C$. A fraction $1-y$ of banks do not participate and their investments lead to a production level that depends on whether they suffered a run or if there was an informational leak. The first line can be rewritten as

$$H - y(E^w(p)C - B) - (1-y)(\varepsilon + \sigma(1-\varepsilon))(H - \widehat{L}).$$

The third term (the second line) represents the welfare for the government. From the fraction y of banks borrowing from the discount window, a fraction q has their asset seized, which delivers $E^w(p)C$ in expectation while a fraction $1-y$ defaults and the asset has to be liquidated, recovering just $\phi E^w(p)C$. Still in both cases the government has to repay B for the bonds. The second line can be rewritten as

$$y(E^w(p)C - B) - y(1-q)(1-\phi)E^w(p)C.$$

The last term (the third line) captures the investments of the q successful banks in the second period (no discount). Those banks that did not borrow from the discount window and those that did without their participation being revealed can borrow without triggering a run in the second period (then leading to production level H). Those banks that participated and were known to participate can potentially suffer a run (captured by L). Finally, the government has to repay (facing inefficiency costs $1-\phi$ and distortionary taxation costs δ) the bonds that could not be covered by liquidating assets in the previous period. The third line can then be rewritten as

$$qH - y[q\sigma\widehat{\chi} + (1-q)\delta(1-\phi)E^w(p)C].$$

Adding (and canceling) terms, total welfare is

$$W(\widetilde{p}) = (1+q)H - (1-y)(\varepsilon+\sigma(1-\varepsilon))(H-\widehat{L}) - y[(1-q)(1+\delta)(1-\phi)E^w(p)C - q\sigma\widehat{\chi}].$$

Since the unconstrained welfare is $(1+q)H$, we can denote the distortion from the crisis as

$$Dist(\widetilde{p}) = (1-y)(\varepsilon+\sigma(1-\varepsilon))(H-\widehat{L}) + y[(1-q)(1+\delta)(1-\phi)E^w(p)C + q\sigma\widehat{\chi}]. \quad (12)$$

The first component shows the distortion that comes from lower output from those banks which did not participate at the discount window, either due to information leaks or because they suffered a run. The second component shows the costs of the distortionary taxation that is needed to cover deposits from defaulting banks, and that cannot be covered by liquidating the asset. Finally, the third component shows the lower production in the second period that arises from stigma – banks who were discovered borrowing from the discount window and then were revealed to have collateral of relatively lower quality, being more likely to suffer a run.

Now, we can compare the welfare levels of distortions for each $\widetilde{p}$ under opacity and under transparency, following the Ramsey strategy of choosing the one that maximizes welfare. The next Proposition characterizes the optimal policy

Proposition 4 *Opacity with a discount rate of $\widetilde{p}_m$ dominates transparency.*

Proof Here we compare the distortions for different levels of discount $\widetilde{p}$ (in the different regions that we characterized in the previous section) for different disclosure policies, for simplicity maintaining the assumption that $\widetilde{p}_T < \widetilde{p}_l$.

In all the identified regions, under transparency all banks participate, which implies that $y = 1$, $\chi = 0$ and $E^w(p) = p_L$. Distortions with transparency are then

$$Dist(\widetilde{p}|Tr) = (1 + \delta)(1 - q)(1 - \phi)p_L C.$$

With opacity, in the "very low" discount region all banks also participate, then $y = 1$ and $\chi = 0$ introducing the same level of distortion as under transparency.

In the "low" discount region, $y < 1$ but still $\sigma = 0$, then

$$Dist(\widetilde{p}|Op) = (1 - y)(H - \widehat{L})\varepsilon + y(1 + \delta)(1 - q)(1 - \phi)E^w(p|Op)C.$$

With small ε these distortions are lower than under transparency. Even though a fraction ε of non-participating banks produce less, there are fewer banks that participate and need to be covered by distortionary taxation in case they default.

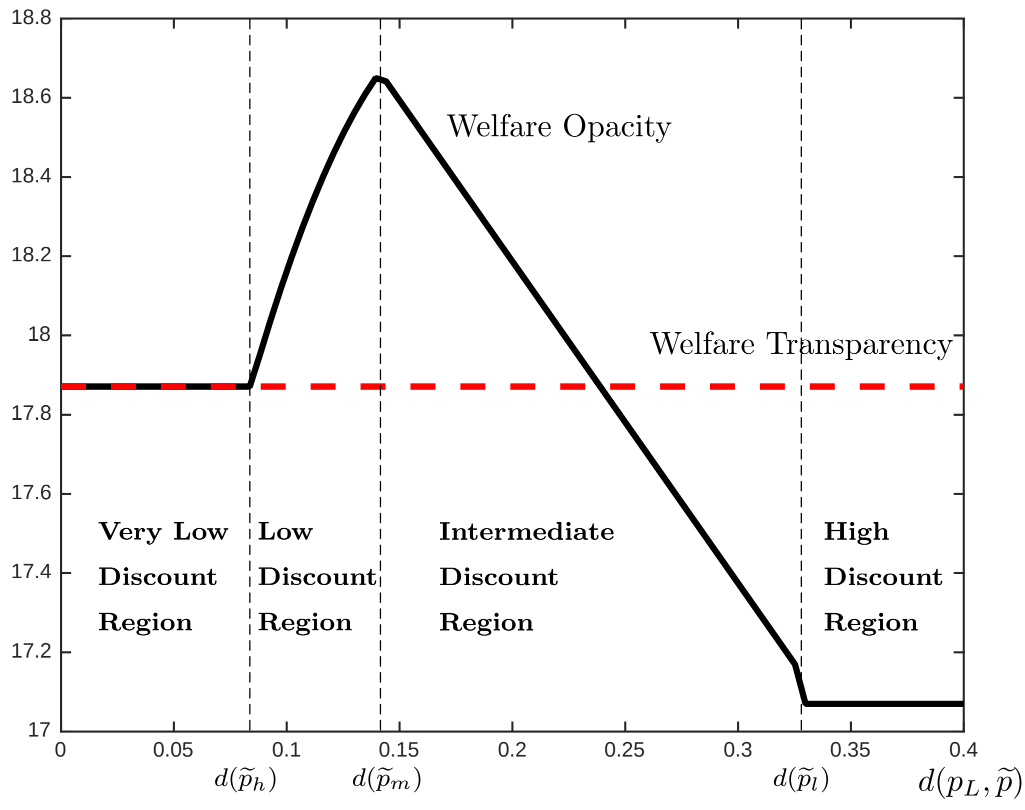
In the "intermediate" discount region, $y = \overline{y}$, but $\sigma > 0$ increases with the discount, with the distortion expressed by equation (12). In this region as the average discount increases the distortions also do. While the fraction of banks participating is fixed, there are more runs and then more banks not participating end producing less, both in the first period (less deposits) and the second period (more stigma).

Finally, in the "high" discount region, the discount windows collapse under opacity, so the distortion is naturally $H - \widehat{L}$.

Distortions under opacity are fixed in the very low discount region, increase in the low discount region, decrease in the intermediate discount region and reach the maximum in the high discount region. In contrast, distortions under transparency are fixed in all these regions and are the same as under opacity in the very low discount region. This implies the optimal discount is $\widetilde{p}_m$ under opacity. Q.E.D.

Figure 2 shows welfare under both disclosure policies (dashed red for transparency and solid black for opacity) for all discount rates, using a set of parameters for the illustration such that $d(p_L, \widetilde{p}_l) < 0.4 < d(p_L, \widetilde{p}_T)$.

Figure 2: Welfare Comparison



Notice that the welfare implemented with a transparent intervention is the same for all discounts in the range of this illustration, as we have assumed the discount that induces some banks not to participate is larger than 0.4. This level of welfare under transparency is lower than the unconstrained first best because the government has to use distortionary taxation to meet the deposits of insolvent banks.

Under opacity, welfare depends on the discount. In the very low discount region all banks participate at the discount window, which implies that welfare is the same as that obtained under transparency. In the low discount region, some banks prefer to take advantage of pooling and not participate. In this region welfare increases with the discount as no depositor runs, and then the government needs to rely less on distortionary taxation. In the intermediate discount region, only a fraction of banks ($\overline{y}$) borrow from the discount window but more and more depositors run as the discount increases. This reduces welfare because the level of distortionary taxation is lower than under transparency but more and more banks face stigma that reduces their production in the second period. In this region a discount level above which the "stigma" effect dominates the "less distortion" effect and welfare under opacity is lower than welfare under transparency. Finally, in the high discount region, the level of the discount is so high that there is no participation in equilibrium under opacity, with welfare reaching a no intervention level.

As is clear, the policy that maximizes welfare is opaque and imposes an average discount of $d(\widetilde{p}_m)$. At this discount the participation of banks in the discount window is minimized, without triggering any runs.

Remarks on Securitization and Deposit Insurance In our setting, if all banks were able to sign contracts that perfectly eliminate the idiosyncratic risk of individual portfolios no depositor would have an incentive to acquire information about a bank's asset. In other words, if idiosyncratic risk were eliminated by pooling all assets in the economy, there are no runs and no role for intervention. Indeed, given the assumption that $p_L C > K^*$, not only would there be no crisis but all banks would be able to invest at the optimal scale.

Even though we have assumed that banks cannot diversify their individual portfolio risk, there could be in principle two institutions that allow for such diversification: *securitization* (sustained by private contracts) and *deposit insurance* (imposed by public regulation).

In the case of securitization, a bank can sign a contract at the beginning of the period, selling shares of its own asset and buying shares of the assets of other banks, eliminating the idiosyncratic risk as the value of its portfolio would be deterministic and equal to $p_L C$. This contract discourages depositors in the bank from acquiring information about its portfolio, which is now irrelevant for the probabilities of recovering the deposit. There are no runs and no crisis. These private contracts are difficult to sustain, however. Banks with high η subsidize banks with low η and may not have incentives to enter into these contracts as a way to signal their high η. Studying the sustainability of these contracts is interesting to understand the effects of securitization as a stabilizing innovation, but it is outside the scope of this paper.

Assuming securitization is not feasible, the government may have incentives to impose diversification in the form of deposit insurance. In the standard view of bank runs, under which they are triggered by a collective action problem, deposit insurance prevents panics and then it is not used in equilibrium. In our setting a run is not driven by lack of coordination among depositors but instead by individual incentives to investigate the bank's portfolio, withdrawing the funds if it is found that the portfolio is of low value. The government can prevent the examination of a bank's portfolio by forcing banks to pay a premium, ex-post, in case their assets are good and to receive insurance in case their assets are bad. As this cross-subsidization is self-financed inside the system, no taxation is used in equilibrium.

One interpretation of what happened during the recent financial crisis is that some banks (commercial) were under deposit insurance (and nothing happened to them). Some others (shadow) were using securitization. Securitization may be a fragile contract. In particular if adverse selection concerns are present among banks, these contracts may not be sustainable and the same problem analyzed in the paper develops. Again, this is a subject that requires more research.

Comparison with the Bagehot's Rule The classic rule for a central bank to follow in a crisis is Walter Bagehot's (1873) rule that the central bank should lend freely, at a high rate, and on good collateral. In the recent financial crisis, Ben Bernanke, Mervyn King and Mario Draghi, the respective heads of the Federal Reserve System, the Bank of England, and the European Central Bank, reported that they followed Bagehot's advice; see Bernanke (2014a and 2014b), King (2010) and Draghi (2013). But, in fact, there was more to their responses to the crisis. All three central banks also engaged in anonymous or secret lending to banks.

Indeed, it is not obvious why Bagehot's advice would work to restore confidence, or would be expected to work. It worked because of secrecy. Bagehot did not mention secrecy because ". . . a key feature of the British [banking] system, its in-built protective device for anonymity was overlooked [by Bagehot]" (Capie (2007), p. 313). Capie explains that in England geographically between the country banks and the Bank of England was a ring of discount houses. Also, see Capie (2002). If a country bank needed money during a crisis it could borrow from its discount house, which in turn might borrow from the Bank of England. In this way, the identities of the actual end borrowers was not publicly known.[15]

While the identities of discount window borrowers were not publicly known, the Bank of England knew those identities and, in particular, the identities of the non-bank borrowers in the crisis of 1866, the Overend-Gurney Panic. See Flandreau and Ugolini (2011)) on the importance of non-bank borrowers (from the shadow banking system). They argue that access to the Bank of England's discount facility meant that these non-bank borrowers faced increased monitoring by the Central Bank.

4 Conclusions

A financial crisis occurs when some public information causes depositors to worry about the collateral backing their deposits such that they want to produce information about the bank's portfolio. This is a bank run. Secret public lending during a financial crisis is important to avoid runs and asset examination. Bernanke (2009): "Releasing the names of [the borrowing] institutions in real-time, in the midst of the financial crisis, would have undermined the effectiveness of the emergency lending and the confidence of investors and borrowers " (p. 1). Recreating confidence means raising the perceived average value of collateral in the economy so that it is not profitable to produce information about banks. The government can achieve this by exchanging bonds (or cash) for lower quality assets. Interestingly, there is no need to replace all the bad assets in the economy to discourage information acquisition. There is an informational externality in the use of opacity by pooling assets. Opacity was adopted not only by governments to deal with crises but also by private bank clearinghouses in the U.S. prior to the Federal Reserve System. Clearinghouse banks pooled their assets so that deposits were claims on all the assets not just one bank's assets.

[15] King (1936) provides more discussion on the industrial organization of British banking in the 19^{th} century. Also see Pressnell (1956). The Bank of England did not always get along with the discount houses, and there is a complicated history to their interaction. See, e.g., Flandreau and Ugolini (2011).

The Central Bank can choose the haircut optimally to determine the optimal amount of bond collateral that is put into the economy. The ability to adopt a policy of opacity depends on the threat of stigma, to realign its opacity incentives with those of the banks. Stigma is costly for borrowers, as their participation reveals their holding of worse assets in expectation. Opacity does not try to avoid stigma but stigma is crucial to avoid transparency. Stigma is not observed in equilibrium, not because opacity but because participation on lending facilities imply paying facing a discount rate.

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