Opacity, Signaling, and Bail-ins*

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Abstract

Should banks be transparent when a bail-in occurs? Banks that have experienced losses may bail-in creditors to optimally allocate resources between early and late withdrawers. However, if banks have private information about their losses, then bail-ins may signal asset quality. In the absence of signaling, banks can sell assets at a pooled price, effectively insuring creditors against asset risks. However, when bail-ins signal quality, banks may delay bail-ins and sell assets at higher prices, but this incentive to delay can trigger inefficient bank runs. To avoid such runs, banks should choose to be either fully transparent or entirely opaque so that their asset quality is not private information.

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1 Introduction

The financial crisis of 2007-08 led to a series of policy reforms aimed at increasing the stability and efficiency of the banking system. The outflows from fixed-income funds during the COVID-19 pandemic and the 2023 bank runs by the (ex-ante) uninsured depositors at Silicon Valley Bank (SVB) have underscored the importance of finalizing and implementing these reforms. These reforms focus on two main areas: Implementing measures such as bail-ins to preserve the resources of distressed intermediaries and enhancing transparency in the banking system. A timely adjustment of debt repayments through swing pricing can remove the cause of runs that arise when the price at which funds can be withdrawn does not properly reflect the value of the assets realized as established in Diamond and Dybvig (1983).[1] However, implementing bail-ins may depend on the information structure: If the loss is publicly known, bail-ins would be straightforward to implement. If though the loss remains unknown, bail-ins would be delayed until the information becomes available. If the loss is known only by the bank, banks may strategically decide whether to initiate a bail-in because it could reveal the loss. Depending on the information structure, bail-ins may, therefore, change bank operations during financial turmoil. This possibility can affect banks' desired level of asset opacity. This interaction leads to the policy question: Should the banking system be transparent or opaque in the presence of bail-ins?

Bail-ins create nontrivial interactions between asset valuation and withdrawal behavior, and their interaction depends on the information structure. Bail-ins are expected to help banks survive financial turmoil including that induced by bank runs. While bail-ins reduce banks' liabilities by preserving resources within distressed banks, they may also affect the

[1] See, for example, Jin, Kacperczyk, Kahraman, and Suntheim (2021), Kashyap, Kohn, and Wessel (2021), Keister and Mitkov (2021), Schmidt, Timmermann, and Wermers (2016), and Voellmy (2021).

valuation of banks' assets. For example, consider the case where banks have private information about losses.[2] Then, bail-ins may reveal the extent of the losses to the financial market, thus decreasing the price at which banks can liquidate assets. This signaling effect can cause banks to distort repayments, which will influence withdrawal behavior. To formalize such interactions, we propose a unified model of asset valuation and withdrawal behavior. We study a version of the Diamond and Dybvig (1983) model in which banks sell their risky assets to a financial market in order to repay short-term liabilities in line with Allen and Gale (1998). We consider a complete space for deposit contracts in this environment: Each of the banks sees withdrawal demand, and then chooses a repayment schedule. The bank can thereby adjust repayments in accordance with withdrawal demand and asset quality, which we interpret as a *bail-in*. In repaying early withdrawal, the bank sells risky assets in the financial market at a price that reflects what investors know. We, therefore, study the interactions between asset valuation and withdrawal behavior in three different information regimes: (i) both banks and investors know the asset return (*Transparency*), (ii) neither banks nor investors know the asset return (*Opacity*), and (iii) only the banks know the asset return (*Lemonisity*).

In both the Transparency and Opacity regimes, the equilibrium allocation of resources maximizes depositor welfare, consistent with the prior literature. Under Transparency, bank runs do not arise in equilibrium because banks immediately bail-in their depositors: Each of the banks chooses early repayment contingent on its realized asset return and withdrawal demand. Under Opacity, banks cannot bail-in losses from their assets until their asset qualities are revealed, which creates both a benefit and a cost to selling assets in the short

[2] The collapse of SVB provides a prime exemplar of a situation where the financial market was unaware of the unrealized losses on SVB's held-to-maturity (HTM) bonds because current accounting rules allow HTM securities to be reported at their original acquisition cost rather than at fair value.

term: On the one hand, selling assets early is costly because they are discounted. On the other hand, the bank's assets will trade in the financial market based on their expected returns while the long-term repayments depend on their realized returns, which provides depositors with insurance against asset risks. A run occurs only if the benefit from such insurance provision exceeds the cost from early liquidation.

A contribution of this paper is the analysis of the interaction between investors and depositors given bail-ins and Lemonisity. Because investors remain uninformed about asset quality under Lemonisity, the bank's actions may affect investors' beliefs about asset quality. The bank may then strategically choose a higher repayment schedule to induce a higher asset price. Such higher repayment schedule may increase depositors' incentives to run. To investigate this possibility, we augment our benchmark model by including the signaling effect of a repayment schedule in the spirit of Leland and Pyle (1977). When uninformed investors do not view the repayment schedule as a signal of asset quality, banks can sell their assets at a pooled price and provide depositors with two types of insurance: One is against asset risks as in Opacity, and the other is against liquidity shocks as in the standard Diamond-Dybvig model. The resultant allocation between early and late withdrawers maximizes depositor welfare. However, when the investors assess asset quality through a bank's repayment schedule, there exists a separating equilibrium. In such a situation, there is an increased gap between the early repayments of good and bad banks, and this signaling behavior undermines banks' ability to provide insurance against asset risks. Inefficient bank runs may occur as distorted short-term repayments attract some patient depositors to withdraw early, leading to excessive early liquidation. This result highlights that bad banks have an incentive to strategically mimic the actions of good banks and delay bail-ins in order to induce a higher asset price and good banks will respond by raising short-term repayments.

This effect is to undermine the insurance provision and distort the allocation between early and late withdrawers.[3]

Our additional contribution is the novel rationale behind a bank's choice to be either transparent or opaque. We show that, in the absence of investor valuations reflecting the signal implicit in a bail-in, information asymmetry in the asset market yields the best allocation of resources among the three information regimes, yet the worst allocation once such valuations are present. This result indicates that, while a bail-in itself can be a useful resolution scheme, the signaling role of bail-ins may prompt banks to delay bail-ins to sell their assets at a higher price. Anticipating the resulting allocative distortion, banks may choose to be completely transparent or opaque to avoid the costly signaling associated with bail-ins.

Literature: This paper contributes to two rapidly growing strands of the literature on financial stability. The first focuses on opacity in the banking system. Faria-e Castro, Martinez, and Philippon (2017) show that opacity creates an adverse selection in asset markets but prevents depositors from knowing negative information about banks. Monnet and Quintin (2017) show how opacity helps the liquidity of a bank asset in secondary markets. We also consider how opacity shapes asset prices by introducing the potential signaling role of banks' repayments. By doing so, we study risk-sharing benefits in different information regimes. In the literature, Kaplan (2006) and Dang, Gorton, Holmstrom, and Ordonez (2017) emphasize the risk-sharing benefits of opacity in the spirit of Hirshleifer (1971). We decompose such risk-sharing effects into risk-sharing on asset returns and on liquidity shocks. In particular, we compare the optimal allocation of resources under Opacity, where depositors

[3] The analysis of a bank's optimization problem conditional on market beliefs given the announced repayment schedule extends the literature on signaling in corporate finance. See Leland and Pyle (1977), Ross (1977), Bhattacharya (1980), John and Williams (1985), Myers and Majluf (1984), Miller and Rock (1985), Brennan and Kraus (1987), Constantinides and Grundy (1989), and Fulghieri, Garcia, and Hackbarth (2020).

benefit from the insurance against asset risks, and under Lemonisity, where they benefit from the insurance against both asset and liquidity risks. This comparison allows us to separate the contribution of each type of insurance to depositor welfare.

We consider not only asset valuation but also the withdrawal behavior of depositors in studying opacity and bail-ins. Jacklin and Bhattacharya (1988), Chen and Hasan (2006), and Faria-e Castro et al. (2017) study fundamental bank runs triggered by revealing information. In contrast, Izumi (2021) studies self-fulfilling bank runs caused by opacity in a version of the Diamond and Dybvig model. Our paper studies both fundamental and self-fulfilling bank runs in a similar framework, but in our paper, we allow banks to form a complete deposit contract and to have private information on asset returns. Some study the role of information in determining the probability of runs in a global game (Bouvard, Chaigneau, and Motta (2015), Ahnert and Nelson (2016), and Parlatore (2015)). Others study the risk-taking behavior under opacity in discussing financial stability (Cordella and Yeyati (1998), Hyytinen and Takalo (2002), and Moreno and Takalo (2016), Jungherr (2018)).

The second strand focuses on bail-ins. While this strand is rapidly growing and policy debates on bail-ins have been extensive, only a handful of papers formalize bail-ins in studying their effectiveness. Bolton and Oehmke (2019) study how regulators should coordinate in bailing in global banks. Walther and White (2020) analyze the (non) commitment of policymakers to bail-in depositors. Bernard, Capponi, and Stiglitz (2022) and Colliard and Gromb (2018) model negotiations between regulators and banks in allocating losses. While these papers study how regulators decide to bail-in depositors, Keister and Mitkov (2021) study how banks themselves decide to bail-in depositors and show such action is delayed if they anticipate bail-outs. Our paper also studies how banks themselves decide to bail-in depositors, but we consider the signaling channel of repayment actions by introducing information asymmetry in a financial market. In our paper, bail-ins reduce liabilities but may affect the valuation of banks' assets, which depends on the information structure. In this way, we shed light on a new but important incentive mechanism regarding bail-ins.[4]

2 Model

Our analysis is based on a version of Diamond and Dybvig (1983) with flexible banking contracts and a financial market as in Allen and Gale (1998). We introduce uncertainty to investment returns, and the value of the investment in a financial market depends on the information available in the market. We use this framework to consider three types of information structure individually. This section describes the model environment that includes agents, preferences, and technologies.

2.1 Environment

There are three periods, labeled $\tau = 0, 1, 2$, and a continuum of depositors of measure one indexed by $i \in [0, 1]$. There exist several banks. Each depositor has a preference given by

$$u(c_1 + \omega_i c_2) = \frac{(c_1 + \omega_i c_2)^{1-\gamma}}{1-\gamma}, \tag{1}$$

where c_τ is consumption in period τ and the coefficient of relative risk aversion γ is assumed to be greater than 1 as in Diamond and Dybvig (1983). The preference type of depositor i, expressed by ω_i, is a bi-nominal random variable with support $\Omega = \{0, 1\}$. If $\omega_i = 0$, depositor i is *impatient* and only cares about consumption in $\tau = 1$, while if $\omega_i = 1$, she is

[4] Capponi, Glasserman, and Weber (2020) develop a model of the feedback between mutual fund outflows and asset illiquidity. Whereas they consider a situation where a shock to a fund's net asset value is publicly known, our paper investigates a setting where the shock may be unknown to investors.

patient and values consumption in both $\tau = 1$ and $\tau = 2$. Each depositor is chosen to be impatient with a known probability $\pi \in (0, 1)$, and the fraction of impatient depositors is equal to π. The realized preference type is privately known by the depositor in $\tau = 1$. Each depositor is endowed with one unit of the good in $\tau = 0$.

There is a single, constant-returns-to-scale technology for transforming the endowment into consumption in $\tau = 2$. Goods invested in $\tau = 0$ mature in $\tau = 2$ and yield a random return R_z, where $z \in \{b, g\}$ and $0 < R_b < R_g$. We let $q_z \in (0, 1)$ denote the probability of the return R_z such that $q_b + q_g = 1$. State z realizes in $\tau = 1$.

The investment can be sold as an asset in $\tau = 1$ in a competitive financial market. There are a large number of wealthy risk-neutral investors who may purchase it in the market. Each investor has a large endowment in $\tau = 1$ and consumes in $\tau = 2$. The endowment is large enough that their positions are never constrained. They discount asset value by $\beta \in (0, 1)$.[5] This assumption reflects that when an asset is sold, the buyer cannot control the asset as efficiently as the seller (Williamson, 1988). Under this setting, early liquidation, caused by a bank run, for example, does real damage to the economy. Investors update their beliefs about the distribution of R_z using Bayes' rule based on the information set I, which represents what investors know when buying assets. They then anticipate the probability of state z' realizing is $\mathbb{B}[z = z'|I]$, where $\sum_{z' \in \{g,b\}} \mathbb{B}[z = z'|I] = 1$. This setup implies that the asset of a bank is valued at price p where

$$p = \beta(\mathbb{B}[z = g|I]R_g + \mathbb{B}[z = b|I]R_b). \tag{2}$$

This investment technology is operated by each bank, where depositors pool and invest

[5] Introducing risk-neutral investors is a common way to make the model tractable. See, for example, Allen and Gale (1998) and Izumi (2021).

resources and can withdraw either in $\tau = 1$ or $\tau = 2$. This intermediation technology can be interpreted as a financial intermediary or bank. As in Diamond and Dybvig (1983), depositors have incentives to pool their funds to insure themselves against liquidity risk. For the sake of simplicity, our analysis begins with the situation where endowments are already deposited at the bank in each location.

The amount of repayments depends on the withdrawal demand. Once a depositor learns her type, she decides whether she withdraws in $\tau = 1$ or waits until $\tau = 2$. While the bank cannot identify the type of each depositor, the bank can observe the withdrawal decisions of depositors before any withdrawal begins, and adjust the repayments. The bank is, thus, offering a flexible depositor contract, and the contract space is complete, unlike the sequential service as in Wallace (1988). Depositors are isolated from each other in $\tau = 1$ and $\tau = 2$, and they cannot trade with each other. Recall that depositors do not diversify across banks and each depositor holds a single bank account.

2.2 Decentralized economy

In a decentralized environment, a bank behaves competitively and acts to maximize the expected utility of its depositors. Banks are ex-ante identical: Each bank receives deposits and makes investments in $\tau = 0$. When R_z is realized in $\tau = 1$, there will be a measure q_g of banks whose investment yields R_g in $\tau = 2$ (*good banks*) and a measure $q_b = (1 - q_g)$ of banks whose investment yields R_b in $\tau = 2$ (*bad banks*). The realization of R_z may affect the bank's repayments, and the actual payoffs received by depositors are determined in a non-cooperative simultaneous-move game played by depositors at each bank in $\tau = 1$. To elaborate the game played by depositors at each bank, in the next sections we address depositors' withdrawal strategies, the bank's repayment schedule, how these two pieces determine the expected utility of a depositor, and the efficiency of a bank run caused by the game.

2.2.1 Withdrawal strategy

Conditional on her type, depositor i chooses a withdrawal strategy in $\tau = 1$, without knowing the realization of R_z. Let y_i denote the withdrawal strategy for depositor i such as

$$y_i : \Omega \mapsto \{0, 1\}, \tag{3}$$

where $y_i(\omega_i) = 1$ corresponds to withdrawal in $\tau = 1$ and $y_i(\omega_i) = 0$ corresponds to withdrawal in $\tau = 2$. Let ρ denote a measure of depositors withdrawing in $\tau = 1$ such that

$$\rho = \int_0^1 y_i(\omega_i) di. \tag{4}$$

2.2.2 Repayment schedule

The bank makes repayments conditional on ρ and z. It gives the same level of consumption to all depositors who withdraw in the same period since depositors are risk-averse. Let $c_{\tau,z}(\rho)$ denote the repayment made by the bank to each depositor who withdraws in period τ given ρ and z. We define the repayment schedule as the mapping from the spaces of ρ and z to the repayments in $\tau = 1$ and 2:

$$c : [0, 1] \times \{b, g\} \mapsto \mathbb{R}_+^2. \tag{5}$$

Given the asset price p in $\tau = 1$, each bank chooses the repayment schedule c to satisfy the feasibility constraint. Each bank finances the repayments at $\tau = 1$ by liquidating some amount of assets b and the repayments at $\tau = 2$ by using its remaining resources $(1 - b)R_z$.

The repayment schedule is hence feasible when there is some b such that $\rho c_{1,z}(\rho) \leq bp$ and $(1-\rho)c_{2,z}(\rho) \leq (1-b)R_z$. The two conditions imply the resource constraint becomes

$$\rho \frac{c_{1,z}(\rho)}{p} + (1-\rho)\frac{c_{2,z}(\rho)}{R_z} \leq 1, \forall z. \tag{6}$$

The repayment schedule c characterizes the operation of the bank and determines the payoffs of depositors.

2.2.3 Expected payoffs

The strategies of depositors y determine the level of consumption that each depositor receives in every possible case. Let $v_i(c, y)$ denote the expected utility of depositor i in $\tau = 0$ as a function of depositors' withdrawal strategies y and the bank's repayment schedule c:

$$v_i(c, y) = \mathbb{E}[u(y_i(\omega_i)c_{1,z}(\rho) + \omega_i(1 - y_i(\omega_i))c_{2,z}(\rho))], \tag{7}$$

where the expectation $\mathbb{E}$ is over ω_i and z. The bank is operated to maximize the expected utility of depositors (depositor welfare):

$$U(c, y) = \int_0^1 v_i(c, y)di. \tag{8}$$

2.2.4 Bank runs

When a positive measure of patient depositors withdraw in $\tau = 1$, there is said to be a *bank run*. A run involves the costly liquidation of immature assets. As discussed later, early liquidation may be efficient or inefficient, depending on the information structure. We therefore categorize runs by whether early liquidation caused by a run is efficient or inefficient.

Under an efficient (inefficient) bank run, further increasing depositor welfare is impossible (possible) by altering withdrawal behavior without changing the repayment schedule. An inefficient run occurs when a run is driven by self-fulfilling beliefs as in Diamond and Dybvig (1983).

2.3 Timeline

The sequence of events is summarized in Figure 1. In $\tau = 0$, depositors place their endowments in the bank in each location, the parameter value that governs the distribution of information regimes (θ) is determined, and the period ends.[6] In $\tau = 1$, the information regime (s) is firstly realized. Next, a depositor learns her preference type. Upon learning the information regime and her type, each depositor chooses a withdrawal strategy. Depositors know the bank's repayment schedule and the withdrawal demand, but they do not know the realization of the asset return. The bank observes the measure of depositors who demand to withdraw in $\tau = 1$, and decides the levels of repayments. When the bank decides the levels of repayments, it may or may not know R_z, which will be realized before early liquidation starts. Investors may or may not know R_z as well. In repaying depositors in $\tau = 1$, the bank sells assets in the financial market. These assets are valued by investors based on their expected payoffs given investors' information. In $\tau = 2$, the investment matures, and the bank repays the remaining depositors.

2.4 Discussion

Our environment is distinct from the literature in that we allow a complete contract space for bank deposits. Diamond and Dybvig (1983) study the environment where the bank

[6] The distribution of information regimes is set out and explained in Section 5.

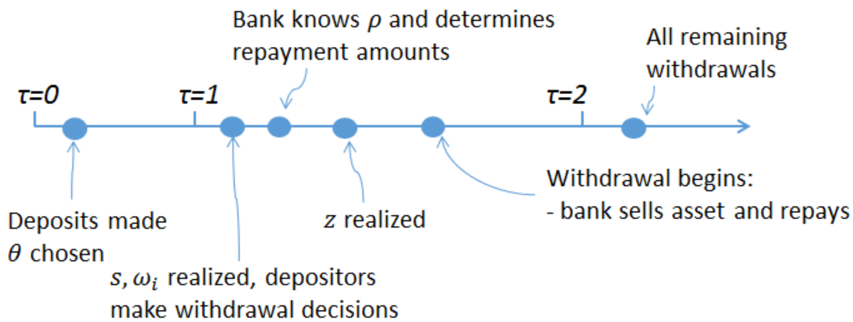

Figure 1: Timeline of the events

sets a repayment schedule before a depositor chooses a withdrawal strategy. Ennis and Keister (2009) explore the environment where the bank sets a repayment schedule at the same time when a depositor chooses an action. Neither approach allows the bank to adjust its repayment after knowing withdrawal strategies chosen by depositors. We allow the bank to choose its repayment level after knowing the withdrawal demand. This setting captures the features of swing pricing and liquidity fees introduced in the recent fixed income funds reforms.

3 The Constrained Efficient Allocation

We introduce a constrained benevolent planner who allocates resources to maximize depositor welfare subject to physical constraints: The planner cannot transfer goods among banks and is subject to the market constraint. The planner knows the preference type of depositors, and can force depositors to follow withdrawal decisions the planner recommended and take over bank operations through the planner's choice of a repayment schedule. The asset price in $\tau = 1$ reflects investors' information. The constrained optimal allocation of resources will, therefore, depend on the information structure, as the information structure affects the asset price.

Whereas the banks in the decentralized economy and the planner share the same objective function, the planner is different from the banks in two dimensions. First, only the planner can force depositors to follow withdrawal behavior the planner recommended. Second, only the planner can prohibit investors from assessing the repayment schedule when investors attempt to learn whether a bank is good or bad.

We will below characterize the constrained optimal allocation of resources for each information regime. Our goal is to establish the benchmark against which to evaluate the equilibrium in a decentralized economy in which depositors choose their withdrawal strategies and uninformed investors infer the asset return of the bank through the assessment of the bank's repayment schedule. In particular, we solve the problem of the planner that maximizes depositor welfare as given by (8) by choosing depositors' withdrawal actions y and the bank's repayment schedule c subject to the feasibility constraint given by (6). We determine the benchmark under each of three information regimes. The first regime is that the planner and investors know the realization of R_z in $\tau = 1$ (*Transparency*); the second structure is that neither the planner nor investors know the realization of R_z in $\tau = 1$ (*Opacity*); the third structure is that the planner knows the realization of R_z in $\tau = 1$, but investors do not (*Lemonisity*). In each case, depositors do not observe the realization of R_z, although they know the information regime.

Without going into the details, it is easy to see that the planner always chooses the withdrawal actions so that $\rho \in [\pi, 1]$. The planner directs impatient depositors to withdraw in $\tau = 1$ since impatient depositors do not value consumption in $\tau = 2$. However, the number of patient depositors who should withdraw in $\tau = 1$ is not a trivial question. The planner chooses how many patient depositors to withdraw in $\tau = 1$ instead of $\tau = 2$, which pins down the value of ρ. Because depositors are risk-averse, the planner provides the same level of consumption to any withdrawer in $\tau = 1$ based on ρ, and the $\tau = 2$ repayment will be the standard pro-rata division of remaining resources. We thus have an alternative way of expressing depositor welfare as a function of c and ρ, $V(c, \rho)$, defined by

$$V(c, \rho) = \mathbb{E}[\rho u(c_{1,z}(\rho)) + (1 - \rho)u(c_{2,z}(\rho))].$$

For purposes of exposition, we solve the planner's problem in two steps. First, the planner maximizes $V(c, \rho)$ for each ρ by choosing the bank's repayment schedule c. Specifically, the planner solves: $\forall \rho \in [\pi, 1]$, $\max_c V(c, \rho)$ subject to the constraints. If the planner knows the realization of the asset return, the planner is only subject to the feasibility constraint (6). Otherwise, the planner is also constrained to select a value for $c_{1,z}(\rho)$ that does not vary with z. Second, the planner maximizes $V(c, \rho)$ under the optimized repayment schedule by choosing ρ. Then, the solution of the planner's problem comprises the optimal level of withdrawal in $\tau = 1$ and the optimal repayment schedule. The next sections discuss the planner's problem in the information regimes of Transparency, Opacity, and Lemonisity, respectively.

3.1 Transparency

We first study the Transparency regime where both the planner and investors know the realization of R_z in $\tau = 1$. The asset price is therefore driven to $p = \beta R_z$.

We denote the solution of the planner's problem by (ρ^t, c^t), where the superscript t means the Transparency regime. Let ρ^t represent the measure of depositors who are chosen by the planner to withdraw in $\tau = 1$, and then c^t expresses the optimal repayment schedule. For each ρ and z, we denote the optimal level of repayment in $\tau = 1$ by $c^t_{1,z}(\rho)$ and the level of subsequent repayment in $\tau = 2$ by $c^t_{2,z}(\rho)$.

3.2 Opacity

The second regime we study is Opacity, where neither the planner nor investors know the realization of R_z in $\tau = 1$. The planner, thus, repays the same amount in $\tau = 1$ regardless of state z, which implies

$$c_{1,g}(\rho) = c_{1,b}(\rho). \tag{9}$$

The planner, therefore, maximizes depositor welfare $V(c, \rho)$ subject to the constraint (9) in addition to the feasibility constraint (6). Since investors do not know the realization of R_z and each of the banks sells the same amount of assets without causing positive or adverse selection in the distribution of assets traded in the market in $\tau = 1$, the price of an asset is uniform across banks and satisfies $p = \beta\mathbb{E}[R_z]$.

We denote the solution of the planner's problem by (ρ^o, c^o), where the superscript o represents the Opacity regime. Let ρ^o represent the measure of depositors who are chosen by the planner to withdraw in $\tau = 1$, and c^o is the optimal repayment schedule. Notice that repayments in $\tau = 1$ are not contingent on state z, while repayments in $\tau = 2$ will be contingent on state z because the remaining resources will depend on R_z. Thus, for each ρ and z, we denote the optimal level of period-1 repayment by $c^o_1(\rho)$ and the subsequent level of repayment in period 2 by $c^o_{2,z}(\rho)$.

3.3 Lemonisity

We finally study a setting of Lemonisity in which the planner knows the realization of R_z but investors do not. In such a situation, the planner chooses the repayment schedule depending on z, and he liquidates different amounts of assets in the two states. This action changes the expected payoffs of investors that buy an asset in the market. Note that investors offer the same price to all banks since they do not know which bank has good assets. As good banks increase (decrease) the number of assets they sell, there are more (fewer) assets that will yield R_g in the market. This can affect the investors' valuation of assets because when good banks increase (decrease) the number of assets they sell, investors will be more (less) likely to receive a good asset than the distribution of R_z predicts, i.e., the market reflects positive (adverse) selection. The asset price is therefore driven to $p = \tilde{\beta}\mathbb{E}[R_z]$. Here, $\tilde{\beta}$ is the discount factor applied to the asset's unconditional expected return that determines its price and reflects both the discount due to the buyer's inability to control the asset as efficiently as the seller and an adjustment that reflects the positive or adverse selection in the distribution of assets traded in the market. Thus, $\tilde{\beta}$ is not necessarily equal to β.

We denote the solution of the planner's problem by (ρ^l, c^l), where the superscript l represents the Lemonisity regime. This notation is defined analogously to that under Transparency. We denote the optimal level of period-1 repayment by $c^l_{1,z}(\rho)$ for each ρ and z and the subsequent level of repayment in period 2 by $c^l_{2,z}(\rho)$.

In evaluating the outcome of the planner's problem under Lemonisity with that under Transparency or Opacity, it is necessary to identify whether the Lemonisity regime exhibits positive or adverse selection. To solve this issue, we examine what range of $\tilde{\beta}$ is consistent with the solution of the planner's problem. Recall that investors cannot observe the asset return, and hence whether investors face positive or adverse selection is determined by how many good and bad assets are sold in the market. For example, if we assumed $\tilde{\beta} > \beta$ (i.e., that the discount in the asset's price was smaller than in the Transparency regime) but then found implied adverse selection (with the amount of the good assets sold in the market, $c^l_{1,g}(\rho^l)/p$, being smaller than that of the bad assets sold, $c^l_{1,b}(\rho^l)/p$), such an assumption would be inconsistent and we describe such $\tilde{\beta}$ values as unacceptable. We formally define the acceptability of $\tilde{\beta}$ as follows.

Definition 1. $\tilde{\beta}$ is acceptable if and only if $\tilde{\beta} > \beta \wedge c^l_{1,g}(\rho^l) > c^l_{1,b}(\rho^l)$, $\tilde{\beta} = \beta \wedge c^l_{1,g}(\rho^l) = c^l_{1,b}(\rho^l)$, or $\tilde{\beta} < \beta \wedge c^l_{1,g}(\rho^l) < c^l_{1,b}(\rho^l)$.

We will show in the next section that acceptable values of $\tilde{\beta}$ are always equal to or greater than β. If $\tilde{\beta} \geq \beta$, we are able to rank each information regime by maximized depositor welfare.

3.4 Results

We start by reporting the solution of the planner's problem for each information regime. We next analyze for each information regime the likelihood of a run induced by the planner's choice of a repayment schedule and investigate whether runs can be efficient in some information regimes. We conclude the section with a ranking of maximized depositor welfare achieved within each information regime.

Before reporting the solution of the planner's problem, we introduce functions $\chi(x)$ and $\tilde{\chi}(x,\rho)$ for purposes of exposition. $\chi(x)$ denotes $\mathbb{E}[R_z^x]/(\mathbb{E}[R_z])^x$ and $\tilde{\chi}(x,\rho)$ denotes $\tilde{\mathbb{E}}_\rho[R_z^x]/(\mathbb{E}[R_z])^x$, where $\tilde{\mathbb{E}}_\rho$ is the expectation operator under a modifed measure defined by the probability of state z being $q_z c^l_{1,z}(\rho)^{1-\gamma}/\mathbb{E}[c^l_{1,z}(\rho)^{1-\gamma}]$. Both functions are convenient for representing the benefit of price pooling. For example, $\chi(1-\gamma)$ captures a depositor's disutility from a lottery that pays R_g and R_b stochastically relative to that from sure payoff of

$\mathbb{E}[R_z]$. Depositors who liquidate early will suffer this disutility in the Transparency regime, but will not do so when they enjoy the price pooling of the Opacity regime.

We differentiate runs by their magnitude and refer to a setting with all patient depositors withdrawing in $\tau = 1$ as a full run, and a setting in which a positive measure of, but not all, patient depositors withdraw in $\tau = 1$ as a partial run.

The following lemma summarizes the solution of the planner's problem in each regime.

Lemma 1. *The constrained optimal allocation of resources is characterized by:*

(1) The optimal repayment:

Transparency: $c^t_{1,z}(\rho) = \beta R_z/(\rho + (1-\rho)\beta^{(\gamma-1)/\gamma})$.

$c^t_{2,z}(\rho) = c^t_{1,z}(\rho)(1/\beta)^{1/\gamma}$.

Opacity: $c^o_1(\rho) = \beta\mathbb{E}[R_z]/(\rho + (1-\rho)(\chi(1-\gamma)/\beta^{1-\gamma})^{1/\gamma})$.

$c^o_{2,z}(\rho) = c^o_1(\rho)(R_z/(\beta\mathbb{E}[R_z]))(\chi(1-\gamma)/\beta^{1-\gamma})^{1/\gamma}$.

Lemonisity: $c^l_{1,z}(\rho) = \tilde{\beta}\mathbb{E}[R_z]/(\rho + (1-\rho)(\tilde{\beta}\mathbb{E}[R_z]/R_z)^{(\gamma-1)/\gamma})$.

$c^l_{2,z}(\rho) = c^l_{1,z}(\rho)(R_z/(\tilde{\beta}\mathbb{E}[R_z]))^{1/\gamma}$.

(2) The optimal withdrawal:

Transparency: $\rho^t = \pi$.

Opacity: *If* $\chi(1-\gamma) < \beta^{1-\gamma}$, $\rho^o = \pi$.

If $\chi(1-\gamma) \geq \beta^{1-\gamma}$, $\rho^o = 1$.

Lemonisity: *If* $\tilde{\chi}((1-\gamma)/\gamma, \pi) \leq \tilde{\beta}^{(1-\gamma)/\gamma}$, $\rho^l = \pi$.

If $\tilde{\chi}((1-\gamma)/\gamma, 1) \geq \tilde{\beta}^{(1-\gamma)/\gamma}$, $\rho^l = 1$.

If else, a unique solution $\rho^l \in (\pi, 1)$ *s.t.* $\tilde{\chi}((1-\gamma)/\gamma, \rho^l) = \tilde{\beta}^{(1-\gamma)/\gamma}$ *exists.*

Proof. See Appendix A.1. □

For the remaining paper, we will assume that $\tilde{\beta}$ is acceptable unless otherwise mentioned. In this way, we can improve the predictability of our model.

The lemma shows that the planner liquidates different volumes of assets, depending on information structures. The planner allows depositors to consume relatively similar levels of goods in $\tau = 1$ and in $\tau = 2$, and thus, the volume of assets sold per early withdrawer depends on the relative value of an asset in $\tau = 1$ to that in $\tau = 2$. For example, under Lemonisity, the volume of assets sold per early withdrawer is $1/(\rho + (1-\rho)(\tilde{\beta}\mathbb{E}[R_z]/R_z)^{(\gamma-1)/\gamma})$, which decreases with the relative price of an asset in $\tau = 1$, $\tilde{\beta}\mathbb{E}[R_z]/R_z$. Notice that the relative period-1 price of an asset is lower for good banks than for bad ones under any $\tilde{\beta}$. The planner instructs good banks to sell more assets than it instructs bad banks to sell. An investor is more likely to receive a good asset in the market than q_g, and thus, adverse selection never occurs. Thus, we can conclude that $\tilde{\beta} \geq \beta$. Under Opacity, assets are sold at the pooled price that provides an opportunity to insure depositors against the risk in the asset. The volume of assets sold per early withdrawer, $1/(\rho + (1-\rho)(\chi(1-\gamma)/\beta^{1-\gamma})^{1/\gamma})$, therefore decreases with the benefit from pooled pricing, $\chi(1-\gamma)/\beta^{1-\gamma}$. Here, $\chi(1-\gamma)/\beta^{1-\gamma}$ captures the disutility from a lottery relative to a certain payoff equal to the discounted expected payoff.

The lemma also shows that the optimal level of early withdrawal varies by information structures. Under Transparency, no run is induced by the planner: Investors value assets based on the realized return, so there is no benefit to depositors of insurance against asset risks by liquidating prior to investors coming to know the realization of the risky payoff. Under Opacity and Lemonisity, assets are sold at a pooling price in period 1. Then, the optimal withdrawal strategies of patient depositors trade off the benefit of the insurance and the cost of premature liquidation. Under Opacity, $\chi(1-\gamma)$ represents the benefit of insurance against asset risks whereas $\beta^{1-\gamma}$ reflects the cost of premature liquidation. The planner has an incentive to induce a run in the sense of choosing a repayment schedule that leads some patient investors to withdraw in $\tau = 1$ if and only if $\chi(1-\gamma) \geq \beta^{1-\gamma}$, i.e., when the benefit of insurance exceeds the cost.[7] Under Lemonisity, $\tilde{\chi}((1-\gamma)/\gamma, \rho)$ represents the benefit of insurance against asset risks whereas $\tilde{\beta}^{(1-\gamma)/\gamma}$ reflects the cost of premature liquidation.[8] When the planner's optimal choice of early withdrawal ρ^l is between π and 1, it satisfies $\tilde{\chi}((1-\gamma)/\gamma, \rho^l) = \tilde{\beta}^{(1-\gamma)/\gamma}$, and the planner has an incentive to induce a partial run. If the cost of premature liquidation is so low that it is below $\tilde{\chi}((1-\gamma)/\gamma, 1)$, which is the lower bound of $\tilde{\chi}((1-\gamma)/\gamma, \rho)$, the planner has an incentive to induce a full run. On the other hand, if the cost of premature liquidation is so high that it is above $\tilde{\chi}((1-\gamma)/\gamma, \pi)$, which is the upper bound of $\tilde{\chi}((1-\gamma)/\gamma, \rho)$, the planner has no incentive to induce a run.

Comparing the likelihood of a run under Opacity and Lemonisity is not straightforward. First, a partial run is induced by the planner only under Lemonisity. Second, whether a run is induced or not under Lemonisity depends on $\tilde{\beta}$, which varies by whether positive or adverse selection occurs. We, therefore, restrict our focus on a full run. If a full run is induced, both good and bad banks liquidate all of their assets in $\tau = 1$. As a result, neither positive nor adverse selection occurs. Then, $\tilde{\beta} = \beta$. Because $\tilde{\chi}((1-\gamma)/\gamma, 1) = \chi((1-\gamma)/\gamma)$, the relative value of selling assets early is $\chi((1-\gamma)/\gamma)/\beta^{(1-\gamma)/\gamma}$ under Lemonisity, which is equivalent to that under Opacity for a less risk-averse depositor.[9] Therefore, we conclude that the insurance benefit is always greater under Opacity than under Lemonisity. If a full run is induced under Lemonisity, it is also induced under Opacity. We summarize this finding in the following proposition.

Proposition 1. *If a full run is induced under Lemonisity, a full run is induced under*

[7]Precisely speaking, any $\rho \in [\pi, 1]$ becomes a solution if $\chi(1-\gamma) = \beta^{1-\gamma}$. For purposes of exposition, we choose $\rho = 1$ as a solution when $\chi(1-\gamma) = \beta^{1-\gamma}$ in Lemma 1.

[8]$\tilde{\chi}(x, \rho)$ is equivalent to $\chi(x)$ if $\rho = 1$. Also, notice $1-\gamma$ and $(1-\gamma)/\gamma$ are both decreasing in γ if $\gamma > 1$.

[9]For example, if the coefficient of CRRA is 2, $(1-\gamma)/\gamma = -0.5$, implying $\tilde{\chi}((1-\gamma)/\gamma, 1) = \chi(1-1.5)$ and $\beta^{(1-\gamma)/\gamma} = \beta^{1-1.5}$. As a result, the relative value of selling assets early is equivalent to that where the coefficient of CRRA is 1.5 under the Opacity regime.

Opacity.

Proof. See Appendix A.2. □

Depositor welfare becomes largest under Lemonisity and smallest under Transparency. Under Lemonisity and Opacity, price pooling occurs in $\tau = 1$, providing depositors with insurance against asset risks. However, constraint (9) weakens insurance against liquidity risks under Opacity. By knowing the asset return in $\tau = 2$, the planner can better smooth consumption over time under Lemonisity, and thus depositor welfare under Lemonisity is equal to or larger than that under Opacity if investors set the price of an asset in $\tau = 1$ by discounting its unconditional expected return by the factor β. Notice $\tilde{\beta} \geq \beta$ always holds as adverse selection never occurs. Depositor welfare can, therefore, further increase under Lemonisity. On the other hand, depositor welfare under Transparency is always lower than that under Opacity. Because price pooling in $\tau = 1$ provides depositors with insurance against asset risks under Opacity but not under Transparency, depositor welfare becomes larger under Opacity. In summary, we can derive the following proposition.

Proposition 2. *$V(c^t, \rho^t) < V(c^o, \rho^o)$. Moreover, $V(c^o, \rho^o) \leq V(c^l, \rho^l)$.*

Proof. See Appendix A.3. □

3.5 Discussion

So far, we have implicitly assumed that the planner can preclude investors from knowing the repayment schedule when they are investigating the asset return of the bank to determine the price that they will pay for its assets. Recall that depositors choose their withdrawal strategies without knowing the actual repayment level and investors also do not know it. As a result, the planner utilizes positive selection to enhance depositor welfare, meaning that the planner is better off by precluding the assessment of investors. The next section explores a decentralized economy in which the planner leaves investors to chase signals when investigating asset returns. This change dramatically affects depositor welfare under Lemonisity.

4 The Equilibrium Allocation

We will now study equilibrium in the decentralized economy. In this economy, depositors choose their withdrawal strategies in $\tau = 1$, and then the bank decides a repayment schedule based on the withdrawal demand. In repaying depositors, the bank sells assets in the market, and the asset price depends on the information regime. Our interest is in the interaction between depositors' withdrawal strategies and asset valuation.

We first study a simultaneous-move game played only by depositors. Based on the withdrawal demand, the bank makes repayments to maximize depositor welfare.[10] Our focus is on equilibria, where each depositor chooses her withdrawal strategy to maximize her individual expected utility. An equilibrium of this withdrawal game is defined as follows.

Definition 2. An equilibrium of this withdrawal game is profile of strategies y^* such that, for each i and y_i,[11]

$$v_i(c(y_i^*, y_{-i}^*), (y_i^*, y_{-i}^*)) \geq v_i(c(y_i, y_{-i}^*), (y_i, y_{-i}^*)),$$

where c is the bank's repayment schedule.

[10] Banks operate in a perfectly competitive environment and hence choose the contract that maximizes depositor welfare (Ennis & Keister, 2006)

[11] Note that the repayment schedule c depends on ρ, which is determined by y. We denote the bank's repayment schedule conditional on y by $c(y)$.

Based on the strategy profile that depositors choose, the bank sets the repayment schedule to maximize depositor welfare. Because impatient depositors always withdraw in $\tau = 1$, $y_i^*(\omega_i) = 1$ if $\omega_i = 0$. This implies that the amount of early withdrawal associated with y^* is equal to or greater than π. It, therefore, suffices to analyze the range of $\rho \in [\pi, 1]$ for the repayment schedule of the bank.

It is perhaps worth emphasizing that investors are not players in the game, and they are the pricing device of assets. Under Transparency, investors know the asset return and value the asset at the discounted realized return βR_z. Under Opacity, investors do not know the return but do not strategically interact with the bank nor depositors because no one knows the asset return. Under constraint (9), each bank sells the same amount of assets in $\tau = 1$. Therefore, there is no positive or adverse selection in the distribution of assets traded in the market. In such a case, investors value the asset at the discounted expected return $\beta\mathbb{E}[R_z]$.

We use this game to analyze equilibria under Transparency and Opacity, and in the later section, we will generalize the game to incorporate strategic interactions between the bank and investors under Lemonisity. Specifically, we will consider that the bank's repayment schedule signals the asset quality to investors in the decentralized economy. This feature motivates the signaling subgame between the bank and investors.

4.1 Equilibrium under Transparency

The bank maximizes depositor welfare $V(c, \rho)$ by choosing the repayment schedule c subject to the feasibility constraint (6) under the asset price $p = \beta R_z$. The solution becomes the best response function of the bank. Because this maximization problem is the same as the first step of the previous planner's problem, the solution is c^t. The solution is characterized by the first-order condition:

$$u'(c_{1,z}^t(\rho)) = \frac{R_z u'(c_{2,z}^t(\rho))}{\beta R_z}, \forall z, \tag{10}$$

which implies that $c_{1,z}^t(\rho) < c_{2,z}^t(\rho), \forall z, \forall \rho$. The payoff of withdrawing in $\tau = 2$ is thus always greater than that in $\tau = 1$. The dominant strategy for a patient depositor is to withdraw in period 2, and hence there exists a no-run equilibrium and there does not exist a run equilibrium.

Proposition 3. *A bank run never occurs under Transparency.*

Proof. See Appendix A.4. □

This no-run equilibrium supports the constrained optimal allocation of resources characterized in Section 3 in which good banks always pay greater amounts than bad ones both in $\tau = 1$ and $\tau = 2$. It is straightforward to show the ratio $c_{\tau,g}^t(\rho)/c_{\tau,b}^t(\rho) = R_g/R_b, \forall \tau, \forall \rho$. Another characteristic of the allocation is that repayments in both $\tau = 1$ and $\tau = 2$ are monotonically decreasing over ρ, as in the standard Diamond and Dybvig (1983) model. Since $\rho = \pi$ in the no-run equilibrium, depositor welfare is lower when π is higher, i.e., when the volume of assets sold to meet withdrawals is higher and thus the quantity of assets sold at a discount is higher.

4.2 Equilibrium under Opacity

Under Opacity, the bank maximizes $V(c, \rho)$ by choosing c subject to constraints (6) and (9). Because this maximization problem is the same as the first step of the previous planner's problem, the best response function of the bank is c^o. It is then characterized by

$$u'(c_1^o(\rho)) = \frac{\mathbb{E}[R_z u'(c_{2,z}^o(\rho))]}{\beta \mathbb{E}[R_z]}, \forall z. \tag{11}$$

If a patient depositor withdraws in $\tau = 1$, she receives $c_1^o(\rho)$ that is not contingent on state z. However, if she withdraws in $\tau = 2$, she incurs the risk in the asset return. The bank is, therefore, providing insurance against the risk in the asset return in period 1, while selling the asset in $\tau = 1$ will be discounted by the factor β in the financial market. Whether she prefers to withdraw in period 1 or not depends on the magnitude of this insurance and the discount.

Lemma 2. $u(c_1^o(\rho)) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \mathbb{E}[u(c_{2,z}^o(\rho))], \forall \rho,$ *if* $\chi(1-\gamma) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \beta^{1-\gamma}$.

Proof. See Appendix A.5. □

This lemma implies that the best response of a depositor does not depend on others' strategies. When the insurance value is greater, the dominant strategy is to withdraw in $\tau = 1$. When the market discount is greater, the dominant strategy is to withdraw in period 2. Therefore, whether a run occurs and whether the run is a full or partial run depends on parameter values:

Proposition 4. *The economy experiences*

$$\begin{Bmatrix} \text{an efficient full run} \\ \text{an efficient full run or an efficient partial run or no run} \\ \text{no run} \end{Bmatrix} \text{if } \chi(1-\gamma) \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} \beta^{1-\gamma}.$$

Proof. See Appendix A.6. □

This result shows that, under Opacity, there does not exist parameter values consistent with both no-run equilibrium and run equilibrium unless $\chi(1-\gamma) = \beta^{1-\gamma}$. The equilibrium run, if any, is always efficient because one would not be able to improve depositor welfare by changing withdrawal behavior, and the constrained optimal allocation of resources is supported in the equilibrium.

4.3 Equilibrium under Lemonisity

Under Lemonisity, there is information asymmetry regarding the realization of the asset return in $\tau = 1$: The bank knows it while investors do not know it. Like the previous sections, depositors decide withdrawal decisions without knowing the asset return. After observing the withdrawal demand, the bank can decide the repayment schedule. Unlike the previous sections, the repayment schedule chosen by the bank affects the belief of investors and hence the asset price. In this section, we augment the model to explicitly recognize the signaling role of the bank's repayment schedule.

We study a two-stage game in which the first stage is the withdrawal subgame and the second stage is a signaling subgame in the spirit of Leland and Pyle (1977). In the first stage, depositor i chooses y_i upon observing her type ω_i. In the second stage, the bank chooses the repayment schedule c, upon observing the asset return R_z and the withdrawal demand ρ, and then investors evaluate the bank's asset based on their posterior beliefs on the bank's z. The investors know the probability distribution of z, but do not know the asset return of each bank. They observe the bank's period-1 repayment c_1, and then they evaluate the bank's asset return based on the bank's choice on c_1.[12]

We use β, not $\tilde{\beta}$, for pricing assets. In a separating equilibrium, the investors know the asset return through the repayment level in period 1 and therefore discount the return by the factor β that reflects purely the inability of the buyer of an asset to operate it as well as its original owner. In a pooling equilibrium, every bank sells the same amount of assets in

[12] The difference from the constrained optimal allocation of resources is to allow investors to consider c_1 in asset pricing here. Specifically, in the pricing equation (2), we now include c_1 as part of the information set.

$\tau = 1$ and there is no positive or adverse selection in the distribution of assets traded in the market.

Investors in this model determine asset prices based on c_1 and their posterior beliefs. The equilibrium in this game, therefore, is characterized by withdrawal strategies, the repayment schedule, and the investors' posterior beliefs:

Definition 3. The equilibrium of the banking game is the pair of the bank's repayment schedule and profile of depositors' strategies (c^*, y^*) such that

- Withdrawal stage: Given c^*, for each i and y_i,

$$v_i(c^*(y_i^*, y_{-i}^*), (y_i^*, y_{-i}^*)) \geq v_i(c^*(y_i, y_{-i}^*), (y_i, y_{-i}^*)),$$

- Signaling stage: Given $\rho^* = \int_0^1 y_i^*(\omega_i)di$, c^* is the bank's optimal repayment schedule that maximizes depositor welfare given some Bayes consistent beliefs of investors. Specifically, c^* satisfies:

  $\forall \rho \in [\pi, 1]$, $c^* \in \arg\max_c V(c, \rho)$ subject to the feasibility constraint (6), where

$$p = \beta(\mathbb{B}[z = g | c_1 = c_{1,z}(\rho)]R_g + \mathbb{B}[z = b | c_1 = c_{1,z}(\rho)]R_b),$$

  under some beliefs of investors satisfying:

  $\forall z' \in \{g, b\}$, $\forall c_1' \in \mathbb{R}_+$, $\mathbb{B}[z = z' | c_1 = c_1']$ is Bayes consistent with each bank's optimal period-1 repayment when the withdrawal demand is ρ^*.

The equilibrium of the banking game requires the optimality of withdrawal behavior in accordance with Definition 2 and the optimality of a repayment schedule in the signaling stage. We model the signaling stage in the spirit of Leland and Pyle (1977). Our focus in this stage is on each bank's sequential rationality and investors' Bayes consistent beliefs as in a Perfect Bayesian equilibrium. In the subsequent sections we solve for the equilibrium of the banking game in a decentralized economy.

4.3.1 Separating equilibrium

We first characterize a separating equilibrium, where good and bad banks choose different strategies. Because Bayes consistency does not restrict off-equilibrium beliefs, there are potentially many beliefs that support separating equilibria. However, for the analysis of a separating equilibrium, it suffices to study the beliefs where the investors believe that the bank is bad whenever the period-1 repayment is different from the good bank's. These beliefs minimize the incentive of each bank to deviate from equilibrium. If a repayment schedule does not become optimal under these beliefs, then it never becomes optimal under other beliefs that support separating equilibria. We thus focus on the following *point* belief in analyzing a separating equilibrium:

- $\mathbb{B}[z = g \mid c_1 = \bar{c}_{1,g}] = 1$,
- $\mathbb{B}[z = g \mid c_1 \neq \bar{c}_{1,g}] = 0$,

where $\bar{c}_{1,g} = c^*_{1,g}(\rho^*)$ is the repayment of each good bank in $\tau = 1$. Here, $c^*_{\tau,z}(\rho)$ denotes the bank's optimal repayment to each depositor who withdraws in period τ given ρ and z.

Upon learning its asset return and ρ, each of the banks chooses c_1 by internalizing its effect on the asset price. Each of the good banks can sell its assets at a higher price if investors are convinced that the asset return R_z is R_g. Each of the good banks has to signal about the return through c_1. Each of the bad banks may mimic the behavior of the good banks to sell its assets at a higher price. Then, we find that each of the good banks always chooses to pay more than socially optimal:

Proposition 5. *In a separating equilibrium, $c^*_{1,g}(\rho^*) > c^t_{1,g}(\rho^*)$ and $c^*_{1,b}(\rho^*) = c^t_{1,b}(\rho^*)$.*

Proof. See Appendix A.7. □

In a separating equilibrium, investors can distinguish the good banks from the bad banks. Then, each of the good banks sells its assets at βR_g, while each of the bad banks sells its assets at βR_b. Whether such an equilibrium exists or not depends on the extent to which good banks can raise c_1 without bad banks mimicking the raised value of c_1.

The bad banks give up mimicking $c^*_{1,g}(\rho^*)$ because doing so is too costly in that the bad banks must distribute too much in $\tau = 1$ relative to the small amount they will then be able to pay in $\tau = 2$, which hinders them from smoothing consumption. In such a case, the bad banks will choose to distribute $c^t_{1,b}(\rho^*)$, resulting in the optimal allocation of resources between early and late withdrawers at the bad banks. However, good banks distort their repayment schedules to induce a price consistent with the asset having a good return by preventing the bad banks from mimicking the good banks. The resulting allocation is thus worse than the optimal allocation of resources between early and late withdrawers at the good banks.

One interesting finding is that there is no full run in a separating equilibrium, and thus $\rho^* < 1$ always holds. If all depositors were to withdraw in $\tau = 1$, then bad banks would choose to mimic good banks. The cost of mimicking is that doing so distorts consumption smoothing between periods 1 and 2. However, when all depositors withdraw in $\tau = 1$, then bad banks do not have to worry about the period-2 repayments and there is no cost of mimicking. Therefore, a full run does not occur in a separating equilibrium.

4.3.2 Inefficient bank runs

Although a full run does not occur, a partial run can occur in a separating equilibrium. Although good banks can choose to allocate their resources optimally among early and late withdrawers, they choose to deviate from such an allocation in order to induce a higher price. Specifically, they pay early withdrawers excessively to differentiate themselves from the bad banks. Anticipating this distorted allocation, some depositors are incentivized to run on the banks. Since a separating equilibrium exists only if $\rho^* < 1$, such a run is always partial.

Such a partial run is inefficient. In redeeming more withdrawals in $\tau = 1$, banks have to liquidate more assets in $\tau = 1$. Liquidating assets in $\tau = 1$ is costlier than holding them until $\tau = 2$. As in the canonical Diamond and Dybvig (1983) model, this run equilibrium yields lower depositor welfare than the no-run equilibrium. This result shows that an inefficient run can be caused by a signaling motive even if each bank can use a complete deposit contract.

Proposition 6. *In a separating equilibrium, a partial inefficient run can occur.*

Proof. See Appendix A.8. □

4.3.3 Pooling equilibrium

We will now turn our focus to a pooling equilibrium in this environment, where both the good and bad banks choose the same strategy. When analyzing a pooling equilibrium, we again set the point belief to minimize the banks' incentives to deviate from equilibrium such that: given $\bar{c}_{1,p}$

- $\mathbb{B}[z = g \mid c_1 = \bar{c}_{1,p}] = q_g$,
- $\mathbb{B}[z = g \mid c_1 \neq \bar{c}_{1,p}] = 0$,

where $\bar{c}_{1,p} = c^*_{1,z}(\rho^*), \forall z$, is the common repayment in $\tau = 1$. If a repayment schedule is not optimal under these beliefs, then it never becomes optimal under other beliefs that support pooling equilibria. It, therefore, suffices to study this belief for the analysis of a pooling equilibrium.

In a pooling equilibrium, the good banks give up differentiating themselves from the bad banks, and the bad banks mimic the good banks. Investors cannot distinguish the good banks from the bad banks, and hence they purchase any asset at $\beta\mathbb{E}[R_z]$. The number of withdrawals is one determinant of whether a pooling equilibrium exists or not. As discussed in the earlier section, the cost of mimicking the good banks for the bad banks is that doing so undermines consumption smoothing between $\tau = 1$ and $\tau = 2$. As more depositors withdraw in $\tau = 1$, such a cost becomes smaller, and each of the bad banks has a higher incentive to mimic the good banks. In particular, the full-run equilibrium under Opacity is supported as a pooling equilibrium. In addition, a partial run is also supported in a pooling equilibrium. We find:

Proposition 7. *There exists a pooling equilibrium with any $\rho^* \in [\underline{\rho}, 1]$, where $\underline{\rho}$ is some lower bound, and*

$$c^*_{1,z}(\rho^*) = \beta\mathbb{E}[R_z]/(\rho^* + (1-\rho^*)(\chi(1-\gamma)/\beta^{1-\gamma})^{1/(\gamma-1)}), \forall z.$$

Proof. See Appendix A.9. □

We compare depositor welfare under each regime in the next section.

4.4 Comparison

We conclude the analysis of equilibria in the decentralized economy with the comparison of depositor welfare associated with each equilibrium. We first compare the equilibrium in Opacity and Transparency and find:

Proposition 8. *The equilibrium under Opacity is strictly welfare-superior to the equilibrium under Transparency.*

Proof. See Appendix A.10. □

This result is attributed to the fact that banks can provide insurance against asset risks in period 1 in the spirit of the classic Hirshleifer (1971) effect. Because the equilibrium matches the constrained optimal allocation of resources under Opacity and Transparency, this result is consistent with Proposition 2.

It is straightforward to show that a separating equilibrium under Lemonisity is even worse than the equilibrium under Transparency:

Proposition 9. *A separating equilibrium under Lemonisity is strictly welfare-inferior to the equilibrium under Transparency.*

Proof. See Appendix A.11. □

This result is driven by the fact that the good banks distort the allocation of resources between early and late withdrawers. Since investors can infer the realization of the asset return, the difference from the equilibrium under Transparency is the distorted allocation that is chosen by the good banks. This result holds even if an inefficient run occurs since such a run only increases costly early liquidation without providing insurance against asset risks.

A pooling equilibrium under Lemonisity also has a clear relation with the equilibrium under Opacity.

Proposition 10. *A pooling equilibrium under Lemonisity is weakly welfare-inferior to the equilibrium under Opacity.*

Proof. See Appendix A.12. □

These equilibria yield the same level of welfare when a run occurs under both equilibria, but a pooling equilibrium can be worse when a run occurs only under a pooling equilibrium. Propositions 9 and 10 imply that information asymmetry in the asset market reduces depositor welfare in equilibrium. When a repayment schedule has a signaling role, banks distort the allocation of resources between early and late withdrawers to induce preferable asset prices, which in turn, results in worse depositor welfare.

5 Optimal Obfuscation

The preceding sections have studied the constrained optimal allocation of resources and the decentralized equilibrium under each information regime. In this section, we endogenize the information regime. Specifically, the planner or the bank chooses the opacity of its asset in period 0, which determines the probability distribution of information regimes (s). Let θ denote the level of obfuscation chosen by the planner or the bank. θ, for example, reflects accounting quality. We define the probability distribution as follows:

$$\left\{\begin{array}{lcc} \mathbb{P}[s=t] & = & 1-\theta \\ \mathbb{P}[s=l] & = & \theta(1-\theta^{\eta-1}) \\ \mathbb{P}[s=o] & = & \theta^{\eta} \end{array}\right\}, \tag{12}$$

where $\eta \in [1, +\infty) \cup \{+\infty\}$. In this setup, θ captures the probability of "opacity" shock, which is the probability that investors fail to observe z, and $\theta^{\eta-1}$ represents the probability that the planner or the bank fails to observe z. $(\eta - 1)$ captures how many times the planner or the bank has to receive opacity shocks more than investors to fail to observe asset returns.

For example, suppose that the accountant of the bank or an external pricing service provider produces multiple reports about the bank's assets. Suppose that the initial report is publicly available and the remaining reports are available only to the planner or the bank. The initial report is, for instance, the bank's accounting statement or the announcement of its net asset value (NAV). The remaining reports are the planner's or the bank's internal documents. With probability θ, each report fails to contain the information about asset quality (i.e., each report obfuscates asset quality with probability θ). θ is higher when, for example, the bank's assets are less likely to be marked-to-market, accounting rules give more discretion about whether a bank's assets are to be reported at fair value, or the report's contents are dated. Investors only read the initial report published to them and, because they spread their research efforts across a portfolio of assets, choose not to investigate further. The planner or the bank, in contrast, reads all the reports. Suppose the planner or the bank reads two reports ($\eta = 2$). If asset quality is not obfuscated in the initial report, then both investors and the planner/bank come to know asset quality. Thus, the Transparency regime occurs with probability $1 - \theta$. If the first report obfuscates asset quality, then investors will fail to learn asset quality while the planner or the bank will read and may learn from the second report. If obfuscation again occurs at the second read, the planner or the bank fails to know asset quality as well. Opacity therefore occurs with probability θ^2. If obfuscation does not occur at the second read, the planner or the bank comes to know asset quality. Lemonisity thus occurs with probability $\theta(1 - \theta)$.

When $\eta = +\infty$, the planner or the bank never fails to observe asset returns. We then assume $\mathbb{P}[s = o] = 0, \forall\theta$, so that the economy never experiences Opacity. We use this probability distribution to characterize the optimal level of θ where the planner or the bank chooses to maximize expected depositor welfare in period 0.[13]

5.1 Optimal obfuscation in a centralized economy

In this section, we examine the case where the planner endogenously chooses the information structure. Specifically, the planner first optimizes depositor welfare in accordance with the constrained optimal allocation of resources described in Section 3 and second chooses the level of obfuscation that maximizes depositor welfare expected over information regimes. We characterize the planner's problem of the optimal level of obfuscation as

$$\max_{\theta \in [0,1]} \sum_{j \in \{t,l,o\}} \mathbb{P}[s = j] V(c^j, \rho^j). \tag{13}$$

As θ increases, the information regime shifts from Transparency, Lemonisity, to Opacity. Proposition 2 suggests that depositor welfare is largest under Lemonisity. Depending on the choice of parameters, the planner's objective function can be inverse U-shaped and an interior solution can exist. Specifically, we summarize the solution of the planner's problem in Proposition 11.

[13]We use this specification of obfuscation for purposes of exposition. We can alternatively use any probability distributions that satisfy that an increase in θ makes the Lemonisity regime more likely to realize and a substantial increase in θ makes the Opacity regime more likely to realize. Such an alternative specification will not change our discussions on the optimal level of obfuscation because the welfare rank of information regimes is independent of θ.

Proposition 11. *The optimal level of obfuscation in a centralized economy is θ^c such that*

$$\theta^c = \min\{((V(c^l, \rho^l) - V(c^t, \rho^t))/\eta(V(c^l, \rho^l) - V(c^o, \rho^o)))^{1/(\eta-1)}, 1\}.$$

Proof. Trivial. □

Proposition 11 shows that the optimal level of obfuscation is determined under a trade-off between insurance against asset risks and insurance against liquidity risks. The optimal level of obfuscation increases with $V(c^l, \rho^l) - V(c^t, \rho^t)$, which is the difference of depositor welfare between Lemonisity and Transparency. Because this difference reflects the benefit from insurance against asset risks, the optimal level of obfuscation increases with this difference. However, it decreases with $V(c^l, \rho^l) - V(c^o, \rho^o)$, which is the difference of depositor welfare between Lemonisity and Opacity. Because this difference reflects the distortion to insurance against liquidity risks that arises because of constraint (9), the optimal level of obfuscation is decreasing in this term.

Note that a corner solution is possible. Recall from Proposition 1 that if a full run occurs under Lemonisity, then a full run also occurs under Opacity. If a full run occurs, there is no distinction of Lemonisity and Opacity. Under both regimes, the planner sells all the assets at the same pooled price in period 1. As there is neither positive nor adverse selection, $\tilde{\beta} = \beta$ under Lemonisity. Then, $V(c^l, \rho^l) - V(c^o, \rho^o) = 0$, meaning that there is no distortion to insurance against liquidity risks. The planner keeps raising the level of obfuscation until hitting the upper bound of 1. Alternatively, when $\eta = +\infty$, the probability of Opacity becomes 0 as the planner never fails to observe asset returns. The planner, therefore, keeps raising the level of obfuscation, because constraint (9) never binds. We, however, find no possibility that the planner would choose complete transparency. At $\theta = 0$, the marginal value of raising obfuscation level is positive as the gain from insurance against asset risks exceeds the loss from distortion to insurance against liquidity risks.

5.2 Optimal obfuscation in a decentralized economy

We will now study the optimal obfuscation level in equilibrium. The bank chooses θ in period 0, and each choice of θ creates a banking game in $\tau = 1$. Anticipating the depositor welfare associated with the equilibrium path in each information regime, the bank chooses θ to maximize expected depositor welfare.

Under Transparency and Opacity ($s = t, o$), there is no difference between the constrained optimal and the equilibrium allocation of resources. The bank expects depositor welfare $V(c^t, \rho^t)$ and $V(c^o, \rho^o)$, respectively. However, under Lemonisity, the bank expects the equilibria that involve signaling in the decentralized economy. Denoting the depositor welfare associated with the equilibrium that involves signaling by $V(c^{signal}, \rho^{signal})$, the bank's problem is:

$$\max_{\theta \in [0,1]} \sum_{j \in \{t, signal, o\}} \mathbb{P}[s = j] V(c^j, \rho^j), \tag{14}$$

where there are multiple candidates for $(c^{signal}, \rho^{signal})$ as we have multiple equilibria in $s = signal$. The solution to this problem depends on which equilibrium path we consider for $s = signal$.

We first consider a separating equilibrium. From Propositions 8 and 9, it is known that a separating equilibrium in $s = signal$ yields the least depositor welfare. Therefore, the solution to the problem is at a corner. Whether the optimal level of obfuscation is 0 or 1 depends on the value of η:

Proposition 12. *Consider a separating equilibrium in $s = signal$. The optimal level of* *obfuscation in a decentralized economy is* $\theta^d = 1$ *if* $\eta < +\infty$*, and* $\theta^d = 0$ *if* $\eta = +\infty$*.*

Proof. Trivial. □

When $\eta = +\infty$, there is no benefit of raising θ as maximizing θ only raises the probability of Lemonisity occurring, and thus the bank minimizes θ as much as possible.

We then consider a pooling equilibrium. Proposition 10 implies that the equilibrium in $s = o$ is dominant in terms of depositor welfare:

Proposition 13. *Consider a pooling equilibrium in* $s = signal$*. The optimal level of obfuscation in a decentralized economy is* $\theta^d = 1$ *if* $\eta < +\infty$*, and* $\theta^d \in \{0, 1\}$ *if* $\eta = +\infty$*.*

Proof. Trivial. □

When $\eta = +\infty$, Opacity never occurs. The expected depositor welfare becomes the average of that under Transparency and Lemonisity weighted by θ. The optimal level of obfuscation in a decentralized economy θ^d is therefore either 0 or 1, depending on the depositor welfare under a pooling equilibrium.

The intuition behind these results is that banks choose to be completely transparent or give up acquiring the information about asset returns to avoid costly signaling, anticipating the distortion of depositor welfare associated with the information asymmetry. This result implies that some banks choose to be perfectly opaque, as Dang et al. (2017) point out, but we also show that other banks choose to be perfectly transparent.

5.3 Discussion

In the presence of bail-in tools, asymmetric information delivers two possible but opposing results. When bail-ins do not signal the asset quality, banks may insure depositors against asset risks by selling assets at a pooled price to uninformed investors and also against liquidity risks by adjusting repayments through bail-ins. When bail-ins signal the asset quality, bail-ins may reveal the asset quality to uninformed investors, undermining the risk-sharing benefits. Thus, the optimal level of obfuscation can be moderate in the former scenario and extremely low or high in the latter scenario.

Which case is more likely in the current banking system? The literature has argued that evaluating banks' assets by uninformed investors is often costly, which indicates the first scenario. However, disclosing banks' flexible repayments could be common if swing pricing were introduced. For example, with swing pricing, UK fixed income funds can flexibly set repayments through swing factors (Jin et al., 2021). If swing factors were required to be disclosed in a timely manner, they could signal asset quality to investors who would buy assets liquidated by funds seeking to meet redemptions. The second case then would be increasingly plausible.

6 Conclusion

Introducing bail-in tools and enhancing transparency were two major reforms after the financial crisis of 2007-08. While each of the reforms has been studied intensively, it is not well understood how they interact. This paper has studied the interaction between opacity and bail-ins with a particular focus on signaling roles of bail-ins. In identifying such an interaction, we consider depositors' withdrawal behavior and asset valuation. We have presented a model of financial intermediation where banks' incentives to bail-in depositors depend on information regimes.

Our model has the following three key ingredients: (i) each bank sells assets in the market in redeeming short-term repayments, (ii) a repayment schedule may signal the asset quality, (iii) each bank can form a complete deposit contract, which we interpreted as bail-ins. Banks may bail-in depositors when they are distressed, and such an action allocates resources optimally between early and late withdrawers. Transparency allows banks to bail-in depositors in a timely manner. Opacity causes a delay in bail-ins, allowing banks to sell assets at a pooled price and provide insurance against asset risks. However, if banks privately know the losses, bail-ins may signal the asset quality. When bail-ins do not signal the quality, banks immediately bail-in depositors and sell assets at a pooled price, which can insure depositors against both asset and liquidity risks.[14] When bail-ins signal the quality, banks attempt to delay bail-ins to sell their assets at a higher price. Such incentives to delay bail-ins result in excessive short-term repayments and inefficient runs.

We used this model to discuss the optimal degree of obfuscation. We find that information asymmetry in the asset market induces the optimal allocation of resources between early and late withdrawers unless bail-ins signal the asset quality to financial markets. However, if bail-ins signal the asset quality, the allocation will be distorted and yield even lower depositor welfare than the other information regimes. To avoid the signaling cost of bail-ins, banks choose to be transparent or opaque so that they will not know asset quality privately.

Regulators or banks may adjust disclosure policies to achieve the optimal level of obfuscation. For example, they can modulate θ by introducing stricter accounting rules that require banks' assets to be measured at fair value or weaker rules that allow these assets to be measured at book value. Alternatively, they can adjust the frequency of updating and disclosing

[14]Under Opacity, in $\tau = 1$, banks cannot adjust repayments, depending on asset returns. As a result, they pay too low if they are good and too high if they are bad. Under Lemonisity without signaling, banks can adjust up (down) repayments if they are good (bad), relative to their repayments under Opacity. Then, banks provide better insurance against liquidity risks: Depositors, facing liquidity shocks, experience smoother consumption, because the consumption level of an impatient depositor becomes closer to that of a patient one. Banks, knowing their asset returns privately, bail-in depositors even if they face a pooled price.

the NAVs of fixed income funds. However, because of potential unintended consequences, policy makers need to be cautious when considering disclosure policies and bail-ins. For example, the recent reforms of fixed income funds aimed to enhance the disclosure of their repayments, and at the same time, have authorized swing prices and implemented liquidity fees. Under the situation where funds can know the asset quality privately, these bail-in tools may become signaling instruments and distort the allocation of resources between early and late withdrawers. In such a situation, enhancing disclosure may lead to transparency, but it may also induce a signaling game between investors and banks which reduces depositor welfare by distorting the allocation of resources between early and late withdrawers.

Alternatively, regulators may consider restricting banks from holding certain types of assets to achieve the optimal level of obfuscation. Specifically, they may categorize types of assets based on the resulting information structure and prohibit banks from holding the assets that result in undesirable outcomes. For example, limiting banks to holding only assets designed as Level 1 assets by Statement 157 of the Financial Accounting Standards Board could implement Transparency. Dang et al. (2017) view commercial real estate loans as assets whose characteristics and values are opaque. Restricting banks from holding these loans may reduce the likelihood of Opacity or Lemonisity. Another example of an asset that could result in Lemonisity is HTM securities, where the investors' assessments of the asset's valuation can depend on the bank's choice of accounting rules. A further example is an off-chain digital asset, where a possibility of double-spending makes information on the asset's value asymmetric. Given that Lemonisity is the least desirable equilibrium outcome, regulators may always desire to prohibit banks from holding assets associated with Lemonisity.

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Online Appendix

A Proof

A.1 Proof for Lemma 1

We solve the planner's problem in two steps. We first optimize c given ρ and second optimize ρ under the optimized repayment schedule. In our exposition, we use α ($\alpha \in \{g, b, m\}$) to represent the type of asset return. If $\alpha = z$ ($z \in \{g, b\}$), the return is R_z. If $\alpha = m$, the return is the expectation, i.e., $\mathbb{E}[R_z]$.

Under Transparency and Lemosity, the planner's problem given ρ is

$$\begin{aligned} \max_{\{c_{1,z}(\rho),c_{2,z}(\rho)\}_{z\in\{g,b\}}} \quad & \mathbb{E}[\rho u(c_{1,z}(\rho)) + (1-\rho)u(c_{2,z}(\rho))] \\ \text{s.t.} \quad & \rho\frac{c_{1,z}(\rho)}{p} + (1-\rho)\frac{c_{2,z}(\rho)}{R_z} \leq 1, \forall z. \end{aligned}$$

Then, the problem is reducible to the problem contingent on state z:

$$\begin{aligned} \max_{c_{1,z}(\rho),c_{2,z}(\rho)} \quad & \rho u(c_{1,z}(\rho)) + (1-\rho)u(c_{2,z}(\rho)) \\ \text{s.t.} \quad & \rho\frac{c_{1,z}(\rho)}{\tilde{\beta}R_\alpha} + (1-\rho)\frac{c_{2,z}(\rho)}{R_z} \leq 1. \end{aligned}$$

Because $R_m = \mathbb{E}[R_z]$, $\alpha = z$ with $\tilde{\beta} = \beta$ under Transparency and $\alpha = m$ under Lemosity. The first order condition implies:

$$u'(c_{1,z}(\rho)) = \frac{R_z}{\tilde{\beta}R_\alpha}u'(c_{2,z}(\rho)).$$

The solution for $c_{2,z}(\rho)$ is therefore

$$c_2^{\alpha,z}(\rho) \;=\; c_1^{\alpha,z}(\rho)\left(\frac{R_z}{\tilde{\beta}R_\alpha}\right)^{1/\gamma}.$$

As the constraint binds, the solution for $c_{1,z}(\rho)$ is

$$c_1^{\alpha,z}(\rho) \;=\; \frac{\tilde{\beta}R_\alpha}{\rho+(1-\rho)(R_z/(\tilde{\beta}R_\alpha))^{(1-\gamma)/\gamma}}.$$

Thus, $c^t_{\tau,z}(\rho) = c_\tau^{z,z}(\rho)$ with $\tilde{\beta}=\beta$ and $c^l_{\tau,z}(\rho) = c_\tau^{m,z}(\rho)$.

Using the Lagrangian, we can define the value function evaluated at the optimal repayment schedule as

$$L(\rho) \;=\; \mathbb{E}[\rho u(c_1^{\alpha,z}(\rho)) + (1-\rho)u(c_2^{\alpha,z}(\rho))] + \sum_{z\in\{g,b\}} \lambda^{\alpha,z}(\rho)\left(1 - \frac{\rho c_1^{\alpha,z}(\rho)}{\tilde{\beta}R_\alpha} - \frac{(1-\rho)c_2^{\alpha,z}(\rho)}{R_z}\right),$$

where $\lambda^{\alpha,z}(\rho)$ is the non-negative Lagrange multiplier for the resource constraint in state z. Then, from the first-order condition,

$$\lambda^{\alpha,z}(\rho) \;=\; q_z\tilde{\beta}R_\alpha u'(c_1^{\alpha,z}(\rho)).$$

Using the envelope theorem,

$$\begin{aligned}
\frac{dL(\rho)}{d\rho} &= (\mathbb{E}[u(c_1^{\alpha,z}(\rho))] - \mathbb{E}[u(c_2^{\alpha,z}(\rho))]) + \sum_{z\in\{g,b\}} \lambda^{\alpha,z}(\rho)\left(\frac{c_2^{\alpha,z}(\rho)}{R_z} - \frac{c_1^{\alpha,z}(\rho)}{\tilde{\beta}R_\alpha}\right) \\
&= (\mathbb{E}[u(c_1^{\alpha,z}(\rho))] - \mathbb{E}[u(c_2^{\alpha,z}(\rho))]) + \sum_{z\in\{g,b\}} q_z\tilde{\beta}R_\alpha u'(c_1^{\alpha,z}(\rho))\left(\frac{c_2^{\alpha,z}(\rho)}{R_z} - \frac{c_1^{\alpha,z}(\rho)}{\tilde{\beta}R_\alpha}\right) \\
&= (\mathbb{E}[u(c_1^{\alpha,z}(\rho))] - \mathbb{E}[u(c_2^{\alpha,z}(\rho))]) + \sum_{z\in\{g,b\}} q_z((1-\gamma)u(c_2^{\alpha,z}(\rho)) - (1-\gamma)u(c_1^{\alpha,z}(\rho))) \\
&= \gamma(\mathbb{E}[u(c_1^{\alpha,z}(\rho))] - \mathbb{E}[u(c_2^{\alpha,z}(\rho))]).
\end{aligned}$$

We thus claim Remark 1.

Remark 1. For $s \in \{t, l\}$, $dL(\rho)/d\rho \gtreqless 0 \Leftrightarrow \mathbb{E}[u(c_{1,z}^s(\rho))] - \mathbb{E}[u(c_{2,z}^s(\rho))] \gtreqless 0$.

As $c_{1,z}^t(\rho) < c_{2,z}^t(\rho), \forall z, \forall \rho$, $\mathbb{E}[u(c_{1,z}^t(\rho))] < \mathbb{E}[u(c_{2,z}^t(\rho))], \forall \rho$. Remark 1 implies $dL(\rho)/d\rho < 0, \forall \rho$. As a result, $L(\rho)$ is greatest when ρ is its smallest possible value π, implying $\rho^t = \pi$. Next, notice

$$\begin{aligned}
\frac{\mathbb{E}[u(c_{1,z}^l(\rho))]}{\mathbb{E}[u(c_{2,z}^l(\rho))]} &= \frac{\mathbb{E}[c_{1,z}^l(\rho)^{1-\gamma}]}{\mathbb{E}[c_{2,z}^l(\rho)^{1-\gamma}]} \\
&= \frac{\mathbb{E}[c_{1,z}^l(\rho)^{1-\gamma}]}{\mathbb{E}[(c_{1,z}^l(\rho)(R_z/(\tilde{\beta}R_m))^{1/\gamma})^{1-\gamma}]} \\
&= \frac{(\tilde{\beta}R_m)^{(1-\gamma)/\gamma}}{\mathbb{E}[c_{1,z}^l(\rho)^{1-\gamma}R_z^{(1-\gamma)/\gamma}]/\mathbb{E}[c_{1,z}^l(\rho)^{1-\gamma}]} \\
&= \frac{\tilde{\beta}^{(1-\gamma)/\gamma}R_m^{(1-\gamma)/\gamma}}{\tilde{\mathbb{E}}_\rho[R_z^{(1-\gamma)/\gamma}]} \\
&= \frac{\tilde{\beta}^{(1-\gamma)/\gamma}}{\tilde{\chi}((1-\gamma)/\gamma, \rho)}.
\end{aligned}$$

Before determining the sign of $dL(\rho)/d\rho$, we examine function $\tilde{\chi}(x,\rho)$. The probability of the good state under the measure used by the expectation operator $\tilde{\mathbb{E}}_\rho$ as defined in Section

3.4 is

$$\frac{q_g c_{1,g}^l(\rho)^{1-\gamma}}{\mathbb{E}[c_{1,z}^l(\rho)^{1-\gamma}]} = \left(1 + \frac{q_b}{q_g}\left(\frac{c_{1,b}^l(\rho)}{c_{1,g}^l(\rho)}\right)^{1-\gamma}\right)^{-1}.$$

Notice

$$\frac{c_{1,b}^l(\rho)}{c_{1,g}^l(\rho)} = \frac{\rho(\tilde{\beta}R_m)^{(1-\gamma)/\gamma} + (1-\rho)R_g{}^{(1-\gamma)/\gamma}}{\rho(\tilde{\beta}R_m)^{(1-\gamma)/\gamma} + (1-\rho)R_b{}^{(1-\gamma)/\gamma}}.$$

Also, notice

$$\begin{aligned}\frac{\partial(c_{1,b}^l(\rho)/c_{1,g}^l(\rho))}{\partial\rho} &= \frac{(\tilde{\beta}R_m)^{(1-\gamma)/\gamma}(R_b{}^{(1-\gamma)/\gamma} - R_g{}^{(1-\gamma)/\gamma})}{(\rho(\tilde{\beta}R_m)^{(1-\gamma)/\gamma} + (1-\rho)R_b{}^{(1-\gamma)/\gamma})^2} \\ &> 0.\end{aligned}$$

Therefore,

$$\frac{\partial(q_g c_{1,g}^l(\rho)^{1-\gamma}/\mathbb{E}[c_{1,z}^l(\rho)^{1-\gamma}])}{\partial\rho} > 0.$$

Recall

$$\tilde{\chi}(x,\rho) = \frac{\tilde{\mathbb{E}}_\rho[R_z^x]}{R_m^x}.$$

As $R_g^x < R_b^x, \forall x < 0$, the numerator decreases with the probability of good state under the measure used by expectation operator $\tilde{\mathbb{E}}_\rho$ if $x < 0$. Also, $\tilde{\mathbb{E}}_1 = \mathbb{E}$, trivially. From these observations, we claim Remark 2.

Remark 2. If $x < 0$, $\partial\tilde{\chi}(x,\rho)/\partial\rho < 0$. $\tilde{\chi}(x,1) = \chi(x)$.

Remark 2 implies $\mathbb{E}[u(c^l_{1,z}(\rho))]/\mathbb{E}[u(c^l_{2,z}(\rho))]$ strictly increases with ρ. If $\tilde{\beta}^{(1-\gamma)/\gamma}/\tilde{\chi}((1-\gamma)/\gamma,\pi) \geq 1$, $\mathbb{E}[u(c^l_{1,z}(\rho))]/\mathbb{E}[u(c^l_{2,z}(\rho))] \geq 1, \forall\rho$, suggesting $\mathbb{E}[u(c^l_{1,z}(\rho))] - \mathbb{E}[u(c^l_{2,z}(\rho))] \leq 0, \forall\rho$, and $dL(\rho)/d\rho \leq 0, \forall\rho$. Because these hold with strict inequality when $\rho > \pi$, the optimal level of ρ is the smallest possible value π, implying $\rho^l = \pi$. If $\tilde{\beta}^{(1-\gamma)/\gamma}/\tilde{\chi}((1-\gamma)/\gamma, 1) \leq 1$, $\mathbb{E}[u(c^l_{1,z}(\rho))]/\mathbb{E}[u(c^l_{2,z}(\rho))] \leq 1, \forall\rho$, suggesting $\mathbb{E}[u(c^l_{1,z}(\rho))] - \mathbb{E}[u(c^l_{2,z}(\rho))] \geq 0, \forall\rho$, and $dL(\rho)/d\rho \geq 0, \forall\rho$. Because these hold with strict inequality when $\rho < 1$, the optimal level of ρ is its largest possible value 1, implying $\rho^l = 1$. Otherwise, there is a unique $\rho^l \in (\pi, 1)$ such that $\mathbb{E}[u(c^l_{1,z}(\rho^l))]/\mathbb{E}[u(c^l_{2,z}(\rho^l))] = 1$. Then, $\mathbb{E}[u(c^l_{1,z}(\rho^l))] - \mathbb{E}[u(c^l_{2,z}(\rho^l))] = 0$ and $dL(\rho^l)/d\rho = 0$. Trivially, if $\rho < \rho^l$, $dL(\rho)/d\rho > 0$, and, if $\rho > \rho^l$, $dL(\rho)/d\rho < 0$. Then, ρ^l maximizes the value function.

Under Opacity, the planner is subject to constraint (9) and its problem given ρ is

$$\begin{aligned} \max_{c_1(\rho),\{c_{2,z}(\rho)\}_{z\in\{g,b\}}} \quad & \rho u(c_1(\rho)) + \mathbb{E}[(1-\rho)u(c_{2,z}(\rho))] \\ \text{s.t.} \quad & \rho\frac{c_1(\rho)}{\beta R_m} + (1-\rho)\frac{c_{2,z}(\rho)}{R_z} \leq 1, \forall z. \end{aligned}$$

The first order condition implies:

$$u'(c_1(\rho)) = \frac{\mathbb{E}[R_z u'(c_{2,z}(\rho))]}{\beta R_m}.$$

Its solution for $c_1(\rho)$ and $c_{2,z}(\rho)$ is therefore

$$\begin{aligned} c^o_1(\rho) &= \frac{\beta R_m}{\rho + (1-\rho)(\chi(1-\gamma)/\beta^{1-\gamma})^{1/\gamma}}, \\ c^o_{2,z}(\rho) &= \frac{\beta R_m}{\rho + (1-\rho)(\chi(1-\gamma)/\beta^{1-\gamma})^{1/\gamma}} \frac{R_z}{\beta R_m}\left(\frac{\chi(1-\gamma)}{\beta^{1-\gamma}}\right)^{1/\gamma}, \forall z, \end{aligned}$$

respectively.

Using the Lagrangian, we can define the value function evaluated at the optimal repayment schedule as

$$L(\rho) = \rho u(c_1^o(\rho)) + \mathbb{E}[(1-\rho)u(c_{2,z}^o(\rho))] + \sum_{z\in\{g,b\}} \lambda_z^o(\rho)\left(1 - \frac{\rho c_1^o(\rho)}{\beta R_m} - \frac{(1-\rho)c_{2,z}^o(\rho)}{R_z}\right),$$

where $\lambda_z^o(\rho)$ is the non-negative Lagrange multiplier for the resource constraint in state z. Then, from the first-order condition,

$$\lambda_z^o(\rho) = q_z R_z u'(c_{2,z}^o(\rho)).$$

Using an envelope theorem,

$$\begin{aligned}
\frac{dL(\rho)}{d\rho} &= (u(c_{1,z}^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))]) + \sum_{z\in\{g,b\}} \lambda_z^o(\rho)\left(\frac{c_{2,z}^o(\rho)}{R_z} - \frac{c_1^o(\rho)}{\beta R_m}\right) \\
&= (u(c_{1,z}^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))]) + \sum_{z\in\{g,b\}} q_z R_z u'(c_{2,z}^o(\rho))\left(\frac{c_{2,z}^o(\rho)}{R_z} - \frac{c_1^o(\rho)}{\beta R_m}\right) \\
&= (u(c_{1,z}^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))]) + \sum_{z\in\{g,b\}} q_z((1-\gamma)u(c_{2,z}^o(\rho)) - (1-\gamma)u(c_1^o(\rho))) \\
&= \gamma(u(c_{1,z}^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))]).
\end{aligned}$$

We thus claim Remark 3.

Remark 3. $dL(\rho)/d\rho \gtreqless 0 \Leftrightarrow u(c_1^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))] \gtreqless 0$.

Next, notice

$$
\begin{aligned}
\frac{u(c_1^o(\rho))}{\mathbb{E}[u(c_{2,z}^o(\rho))]} &= \frac{c_1^o(\rho)^{1-\gamma}}{\mathbb{E}[c_{2,z}^o(\rho)^{1-\gamma}]} \\
&= \frac{c_1^o(\rho)^{1-\gamma}}{\mathbb{E}[c_1^o(\rho)^{1-\gamma}(R_z/(\beta R_m))^{1-\gamma}(\chi(1-\gamma)/\beta^{1-\gamma})^{(1-\gamma)/\gamma}]} \\
&= \frac{\beta^{1-\gamma}R_m^{1-\gamma}}{\mathbb{E}[R_z^{1-\gamma}]}(\beta^{1-\gamma}/\chi(1-\gamma))^{(1-\gamma)/\gamma} \\
&= \left(\frac{\beta^{1-\gamma}}{\chi(1-\gamma)}\right)^{1/\gamma}.
\end{aligned}
$$

From this result, Remark 3 tells us the sign of $dL(\rho)/d\rho$. If $\beta^{1-\gamma}/\chi(1-\gamma) > 1$, $u(c_1^o(\rho))/\mathbb{E}[u(c_{2,z}^o(\rho))] > 1, \forall\rho$, suggesting $u(c_1^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))] < 0, \forall\rho$, and $dL(\rho)/d\rho < 0, \forall\rho$. The optimal level of ρ is the smallest possible value π, implying $\rho^o = \pi$. If $\beta^{1-\gamma}/\chi(1-\gamma) \leq 1$, $u(c_1^o(\rho))/\mathbb{E}[u(c_{2,z}^o(\rho))] \leq 1, \forall\rho$, suggesting $u(c_1^o(\rho)) - \mathbb{E}[u(c_{2,z}^o(\rho))] \geq 0, \forall\rho$, and $dL(\rho)/d\rho \geq 0, \forall\rho$. The optimal level of ρ is the largest possible value 1, implying $\rho^o = 1$.

A.2 Proof for Proposition 1

Before proving Proposition 1, we first study $\beta^x/\chi(x)$. Let $f(x) = \beta^x/\chi(x)$. Then, $f'(x) = \beta^x(\ln\beta\chi(x) - \chi'(x))/\chi(x)^2$. Notice

$$
\begin{aligned}
\chi'(x) &= \frac{\mathbb{E}[\ln R_z R_z^x](\mathbb{E}[R_z])^x - \mathbb{E}[R_z^x]\ln\mathbb{E}[R_z](\mathbb{E}[R_z])^x}{(\mathbb{E}[R_z])^{2x}} \\
&= \frac{\mathbb{E}[\ln R_z R_z^x]}{(\mathbb{E}[R_z])^x} - \ln\mathbb{E}[R_z]\chi(x).
\end{aligned}
$$

Also, notice

$$
\begin{aligned}
f'(x) &= \frac{\beta^x(\ln\beta\chi(x) - \chi'(x))}{\chi(x)^2} \\
&= \frac{\beta^x(\ln\beta\chi(x) - (\mathbb{E}[\ln R_z R_z^x]/(\mathbb{E}[R_z])^x - \ln\mathbb{E}[R_z]\chi(x)))}{\chi(x)^2} \\
&= \frac{\beta^x(\ln\beta\mathbb{E}[R_z]\chi(x) - \mathbb{E}[\ln R_z R_z^x]/(\mathbb{E}[R_z])^x)}{\chi(x)^2} \\
&= f(x)\left(\ln\beta\mathbb{E}[R_z] - \frac{\mathbb{E}[\ln R_z R_z^x]}{\mathbb{E}[R_z^x]}\right).
\end{aligned}
$$

Then, if $f'(x) = 0$,

$$
\begin{aligned}
f''(x) &= -f(x)\frac{\partial(\mathbb{E}[\ln R_z R_z^x]/\mathbb{E}[R_z^x])}{\partial x} \\
&= -f(x)\frac{\mathbb{E}[(\ln R_z)^2 R_z^x]\mathbb{E}[R_z^x] - (\mathbb{E}[\ln R_z R_z^x])^2}{(\mathbb{E}[R_z^x])^2} \\
&= f(x)\left(\left(\frac{\mathbb{E}[R_z^x \ln R_z]}{\mathbb{E}[R_z^x]}\right)^2 - \frac{\mathbb{E}[R_z^x(\ln R_z)^2]}{\mathbb{E}[R_z^x]}\right) \\
&= f(x)((\hat{\mathbb{E}}[\ln R_z])^2 - \hat{\mathbb{E}}[(\ln R_z)^2]),
\end{aligned}
$$

where $\hat{\mathbb{E}}$ is the expectation operator under the modifed measure defined by the probability of state $z \in Z$ being $q_z R_z^x/\mathbb{E}[R_z^x]$. Due to the convexity of a quadratic function, Jensen's inequality implies

$$
\begin{aligned}
f''(x) &= f(x)((\hat{\mathbb{E}}[\ln R_z])^2 - \hat{\mathbb{E}}[(\ln R_z)^2]) \\
&< 0.
\end{aligned}
$$

Remark 4. If $f'(x) = 0$, $f''(x) < 0$.

We now prove $\chi((1-\gamma)/\gamma) \geq \beta^{(1-\gamma)/\gamma} \Rightarrow \chi(1-\gamma) \geq \beta^{(1-\gamma)}$. Suppose $\chi((1-\gamma)/\gamma) \geq$

$\beta^{(1-\gamma)/\gamma}$.

To establish contradiction, assume $\chi(1-\gamma) < \beta^{1-\gamma}$. Then, $f(1-\gamma) > 1$ and $f((1-\gamma)/\gamma) \leq 1$. Because $f(1-\gamma) > 1$ and $f(0) = 1$, if $f((1-\gamma)/\gamma) < 1$, f has an interior minimum at $x = d$, where $d \in (1-\gamma, 0)$. Then, $f'(d) = 0$ and $f''(d) \geq 0$. But, this is not possible to hold as $f''(x) < 0$ if $f'(x) = 0$ according to Remark 4. Thus, $f((1-\gamma)/\gamma) = 1$.

f is not flat on the interval $[(1-\gamma)/\gamma, 0]$, so $f(x') > 1$ or $f(x') < 1$ at some $x' \in ((1-\gamma)/\gamma, 0)$. If $f(x') < 1$ at some $x' \in ((1-\gamma)/\gamma, 0)$, f has an interior minimum at $x = d$, where $d \in ((1-\gamma)/\gamma, 0)$. Based on the previous argument, this is not possible to hold. Thus, $f(x') > 1$ at some $x' \in ((1-\gamma)/\gamma, 0)$.

Because $f(1-\gamma) > 1$ and $f(x') > 1$ at some $x' \in ((1-\gamma)/\gamma, 0)$ whereas $f((1-\gamma)/\gamma) = 1$, f has an interior minimum at $x = d$, where $d \in (1-\gamma, x')$. Based on the previous argument, this is not possible to hold.

Therefore, the initial assumption is wrong. We claim Remark 5.

Remark 5. $\chi((1-\gamma)/\gamma) \geq \beta^{(1-\gamma)/\gamma} \Rightarrow \chi(1-\gamma) \geq \beta^{(1-\gamma)}$.

If a full run occurs under Lemosity, $\rho^l = 1$. Then, $c^l_{1,z}(\rho^l) = \tilde{\beta} R_m, \forall z$. Because both the price of an asset and the period-1 repayment level are uniform across banks, there is neither positive nor adverse selection in the distribution of assets traded in the market. Therefore, if $\tilde{\beta}$ is acceptable, $\tilde{\beta} = \beta$. Lemma 1 suggests a full run under Lemosity is equivalent to $\tilde{\beta}^{(1-\gamma)/\gamma}/\tilde{\chi}((1-\gamma)/\gamma, 1) \leq 1$. Given Remark 2, this condition, under acceptable $\tilde{\beta}$, is equivalent to

$$\beta^{(1-\gamma)/\gamma}/\chi((1-\gamma)/\gamma) \quad \leq \quad 1.$$

Applying Remark 5, we can show

$$\beta^{(1-\gamma)}/\chi(1-\gamma) \;\; \leq \;\; 1.$$

Lemma 1 implies $\rho^o = 1$.

A.3 Proof for Proposition 2

Consider the following planner's problem:

$$\begin{array}{cc} \max_{\{c_{1,z}(\rho),c_{2,z}(\rho)\}_{z\in\{g,b\}}} & \mathbb{E}[\rho u(c_{1,z}(\rho)) + (1-\rho)u(c_{2,z}(\rho))] \\ \text{s.t.} & \rho\dfrac{\mathbb{E}[c_{1,z}(\rho)]}{\beta R_m} + (1-\rho)\dfrac{c_{2,z}(\rho)}{R_z} \leq 1, \forall z. \end{array}$$

The first order condition implies:

$$u'(c_{1,z}(\rho)) \;\; = \;\; \frac{\mathbb{E}[R_z u'(c_{2,z}(\rho))]}{\beta R_m}, \forall z.$$

Section A.1 suggests this condition is satisfied under c^o. Because c^o satisfies the resource constraint, it becomes the solution of this problem. Also, notice c^t satisfies the resource constraint. However, c^t does not satisfy the above condition, as $c_{1,g}(\rho) = c_{1,b}(\rho)$ is required to satisfy it. c^t is not the solution of this problem. From this observation, we can conclude $V(c^t, \rho^t) < V(c^o, \rho^t) \leq V(c^o, \rho^o)$, which completes the proof of the first part of the proposition.

If $\tilde{\beta} = \beta$, the planner's problem under Opacity is same as the problem under Lemosity except for the presence of constraint (9). Because the planner is more constrained, its value is equal to or smaller under Opacity than under Lemosity. Therefore, if $\tilde{\beta} = \beta$,

$V(c^o, \rho^o) \leq V(c^l, \rho^l)$. We now know

$$\begin{aligned} \frac{c_{1,b}^l(\rho)}{c_{1,g}^l(\rho)} &= \frac{\rho(\tilde{\beta}R_m)^{(1-\gamma)/\gamma} + (1-\rho){R_g}^{(1-\gamma)/\gamma}}{\rho(\tilde{\beta}R_m)^{(1-\gamma)/\gamma} + (1-\rho){R_b}^{(1-\gamma)/\gamma}} \\ &\leq 1. \end{aligned}$$

Therefore, adverse selection never occurs for any $\tilde{\beta}$ and ρ. Under acceptable $\tilde{\beta}$, $\tilde{\beta} \geq \beta$. Thus, it suffices to show that $V(c^l, \rho^l)$ increases with $\tilde{\beta}$ to prove the latter part of the proposition. Using the Lagrangean, we can define the value function evaluated at the optimized repayment schedule and withdrawal amount under Lemosity as

$$\begin{aligned} L(\tilde{\beta}) &= \mathbb{E}[\rho^l u(c_{1,z}^l(\rho^l)) + (1-\rho^l)u(c_{2,z}^l(\rho^l))] \\ &\quad + \sum_{z\in\{g,b\}} \lambda_z^l(\rho^l)\left(1 - \frac{\rho^l c_{1,z}^l(\rho^l)}{\tilde{\beta}R_m} - \frac{(1-\rho^l)c_{2,z}^l(\rho^l)}{R_z}\right), \end{aligned}$$

where $\lambda_z^l(\rho)$ is the non-negative Lagrange multiplier for the resource constraint in state z given ρ. Using an envelope theorem, we find:

$$\begin{aligned} \frac{dL(\tilde{\beta})}{d\tilde{\beta}} &= \sum_{z\in\{g,b\}} \lambda_z^l(\rho^l)\frac{\rho^l c_{1,z}^l(\rho^l)}{\tilde{\beta}^2 R_m} \\ &\geq 0. \end{aligned}$$

This result suggests that $V(c^l, \rho^l)$ increases with $\tilde{\beta}$.

A.4 Proof for Proposition 3

Under the withdrawal subgame, given ρ and c, each patient depositor runs if $\mathbb{E}[u(c_{1,z}(\rho))] > \mathbb{E}[u(c_{2,z}(\rho))]$ and waits if $\mathbb{E}[u(c_{1,z}(\rho))] < \mathbb{E}[u(c_{2,z}(\rho))]$. Otherwise, the patient depositor becomes indifferent between running and waiting. Then, the equilibrium number of withdrawal ρ^* satisfies the following: $\rho^* = \pi$ if $\mathbb{E}[u(c_{1,z}(\rho^*))] < \mathbb{E}[u(c_{2,z}(\rho^*))]$, $\rho^* \in [\pi, 1]$ if $\mathbb{E}[u(c_{1,z}(\rho^*))] = \mathbb{E}[u(c_{2,z}(\rho^*))]$, and $\rho^* = 1$ if $\mathbb{E}[u(c_{1,z}(\rho^*))] > \mathbb{E}[u(c_{2,z}(\rho^*))]$.

Under Transparency, $c = c^t$. According to Section A.1, $\mathbb{E}[u(c^t_{1,z}(\rho))] < \mathbb{E}[u(c^t_{2,z}(\rho))], \forall \rho$, and hence $\rho^* = \pi$.

A.5 Proof for Lemma 2

See Section A.1.

A.6 Proof for Proposition 4

Under Opacity, $c = c^o$. According to Section A.1, the following is true. If $\chi(1-\gamma) < \beta^{1-\gamma}$, $u(c^o_1(\rho)) > \mathbb{E}[u(c^o_{2,z}(\rho))], \forall \rho$, and hence $\rho^* = \pi$. If $\chi(1-\gamma) = \beta^{1-\gamma}$, $u(c^o_1(\rho)) = \mathbb{E}[u(c^o_{2,z}(\rho))], \forall \rho$, and hence $\rho^* \in [\pi, 1]$. If $\chi(1-\gamma) > \beta^{1-\gamma}$, $u(c^o_1(\rho)) > \mathbb{E}[u(c^o_{2,z}(\rho))], \forall \rho$, and hence $\rho^* = 1$.

A.7 Proof for Proposition 5

We first define a couple of functions and values. Given repayment c_1 in $\tau = 1$, $h_2^{\alpha,z}(c_1, \rho)$ denotes the repayment in period 2 when the asset price is R_α at $\tau = 1$ and R_z at $\tau = 2$. As $\tilde{\beta} = \beta$ under signaling equilibira,

$$h_2^{\alpha,z}(c_1, \rho) \quad = \quad \lim_{\rho' \to \rho} R_z \frac{1 - \rho' c_1/(\beta R_\alpha)}{1 - \rho'}.$$

We define this function in its limit form as it allows us to compute this function at $\rho = 1$. We then find the following.

Remark 6. (i) $h_2^{\alpha,z}(c_1,\rho)/h_2^{\alpha,z'}(c_1,\rho) = R_z/R_{z'}$, $\forall\rho$, $\forall c_1$. (ii) $h_2^{\alpha,z}(c_1,\rho)$ strictly increases with R_α and R_z and strictly decreases in c_1, $\forall\rho < 1$.

Also, we define the following values: for given ρ,

- A bad bank's value when unmimicking: $V_{b,fb}(\rho) = \rho u(c^t_{1,b}(\rho)) + (1-\rho)u(c^t_{2,b}(\rho))$,
- A good bank's value when deviating: $V_{g,dev}(\rho) = \rho u(c_1^{b,g}(\rho)) + (1-\rho)u(c_2^{b,g}(\rho))$,
- A bad bank's value when mimicking: $V_{b,mimic}(\rho) = \rho u(\bar{c}_{1,g}) + (1-\rho)u(h_2^{g,b}(\bar{c}_{1,g},\rho))$,
- A good bank's value when undeviating: $V_{g,signal}(\rho) = \rho u(\bar{c}_{1,g}) + (1-\rho)u(h_2^{g,g}(\bar{c}_{1,g},\rho))$,

where $c_\tau^{\alpha,z}(\rho)$ is defined in accordance with Section A.1 with $\tilde{\beta} = \beta$.

$(\bar{c}_{1,g},\rho^*)$ is the outcome of a separating equilibrium if and only if, given the point belief function defined in Section 4.3.1, (i) No mimic: $V_{b,fb}(\rho^*) \geq V_{b,mimic}(\rho^*)$, (ii) No deviation: $V_{g,signal}(\rho^*) \geq V_{g,dev}(\rho^*)$, and (iii) $q_g u(\bar{c}_{1,g}) + q_b u(c^t_{1,b}(\rho^*)) \leq q_g u(h_2^{g,g}(\bar{c}_{1,g},\rho^*)) + q_b u(c^t_{2,b}(\rho^*))$ under $\rho^* = \pi$, $q_g u(\bar{c}_{1,g}) + q_b u(c^t_{1,b}(\rho^*)) = q_g u(h_2^{g,g}(\bar{c}_{1,g},\rho^*)) + q_b u(c^t_{2,b}(\rho^*))$ under $\rho^* \in (\pi, 1)$, and $q_g u(\bar{c}_{1,g}) + q_b u(c^t_{1,b}(\rho^*)) \geq q_g u(h_2^{g,g}(\bar{c}_{1,g},\rho^*)) + q_b u(c^t_{2,b}(\rho^*))$ under $\rho^* = 1$. The first two conditions are standard conditions for sequential rationality. The last one is the condition for an equilibrium of the withdrawal subgame. At a separating equilibrium, a good bank chooses the repayment level $(\bar{c}_{1,g}, h_2^{g,g}(\bar{c}_{1,g},\rho^*))$, and a bad bank chooses the repayment level $(c^t_{1,b}(\rho^*), c^t_{2,b}(\rho^*))$.[15]

If a bad bank chooses $\bar{c}_{1,g}$ such that $\bar{c}_{1,g} = c^t_{1,g}(\rho^*)$, its consumption at $\tau = 2$ is $h_2^{g,b}(c^t_{1,g}(\rho^*),\rho^*) = (R_b/R_g)h_2^{g,g}(c^t_{1,g}(\rho^*),\rho^*) = (R_b/R_g)c^t_{2,g}(\rho^*) = c^t_{2,b}(\rho^*)$ according to Remark 6 (i). Therefore, if a bad bank chooses $\bar{c}_{1,g}$ such that $c^t_{1,b}(\rho^*) < \bar{c}_{1,g} \leq c^t_{1,g}(\rho^*)$, its consumption at $\tau = 2$ is $h_2^{g,b}(\bar{c}_{1,g},\rho^*) \geq c^t_{2,b}(\rho^*)$.

[15] As discussed later, $\bar{c}_{1,g} \neq c^t_{1,b}(\rho^*)$ in a separating equilibrium. If $\bar{c}_{1,g} = c^t_{1,b}(\rho^*)$, a bad bank has an incentive to mimic. Thus, in a separating equilibrium, a bad bank's best repayment level under the region where the bank is believed to be bad based on the point belief function of investors is $c^t_{1,b}(\rho^*)$.

Suppose $c^t_{1,b}(\rho^*) < \bar{c}_{1,g} \leq c^t_{1,g}(\rho^*)$. If a bad bank chooses the best option within the range where a bank is believed to be bad, a bad bank chooses $(c^t_{1,b}(\rho^*), c^t_{2,b}(\rho^*))$. Then, as $(c^t_{1,b}(\rho^*), c^t_{2,b}(\rho^*)) \leq (\bar{c}_{1,g}, h^{g,b}_2(\bar{c}_{1,g}, \rho))$ with $c^t_{1,b}(\rho^*) < \bar{c}_{1,g}$, a bad bank is better off by choosing $\bar{c}_{1,g}$ than choosing the best option within the range where a bank is believed to be bad. Thus, there is an incentive for a bad bank to mimic.

Suppose $\bar{c}_{1,g} = c^t_{1,b}(\rho^*)$ and $\rho^* < 1$. $(c^t_{1,b}(\rho^*), c^t_{2,b}(\rho^*)) \leq (c^t_{1,b}(\rho^*), h^{g,b}_2(c^t_{1,b}(\rho^*), \rho^*))$ where $c^t_{2,b}(\rho^*) = h^{b,b}_2(c^t_{1,b}(\rho^*), \rho^*) < h^{g,b}_2(c^t_{1,b}(\rho^*), \rho^*)$, according to Remark 6 (ii). A bad bank is better off by choosing $\bar{c}_{1,g}$ as it earns more value than the maximum possible value it earns when it is believed to be bad.

Suppose $\bar{c}_{1,g} = c^t_{1,b}(\rho^*)$ and $\rho^* = 1$. A bad bank is better off by choosing $\bar{c}_{1,g}$; otherwise, it can at most offer the first-period repayment less than $c^t_{1,b}(\rho^*)$.

Suppose $\bar{c}_{1,g} < c^t_{1,b}(\rho^*)$ and $\rho^* < 1$. Denote $V_{b,fb}(\rho^*) - V_{b,mimic}(\rho^*)$ by $\Delta_b(\rho^*)$. Also denote

$V_{g,dev}(\rho^*) - V_{g,signal}(\rho^*)$ by $\Delta_g(\rho^*)$. We can show:

$$\begin{aligned}
\Delta_g(\rho^*) - \Delta_b(\rho^*) &= (\rho^* u(c_1^{b,g}(\rho^*)) + (1-\rho^*)u(c_2^{b,g}(\rho^*))) \\
&\quad -(\rho^* u(c_1^{b,b}(\rho^*)) + (1-\rho^*)u(c_2^{b,b}(\rho^*)) \\
&\quad -(1-\rho^*)(u(h_2^{g,g}(\bar{c}_{1,g},\rho^*)) - u(h_2^{g,b}(\bar{c}_{1,g},\rho^*))), \\
&\quad \text{from the optimality of } (c_1^{b,g}(\rho^*),\, c_2^{b,g}(\rho^*)) \text{ under } \alpha = b, z = g, \\
&\geq (\rho^* u(c_1^{b,b}(\rho^*)) + (1-\rho^*)u(h_2^{b,g}(c_1^{b,b}(\rho^*),\rho^*))) \\
&\quad -(\rho^* u(c_1^{b,b}(\rho^*)) + (1-\rho^*)u(c_2^{b,b}(\rho^*)) \\
&\quad -(1-\rho^*)(u(h_2^{g,g}(\bar{c}_{1,g},\rho^*)) - u(h_2^{g,b}(\bar{c}_{1,g},\rho^*))) \\
&\quad \text{from } c_2^{b,b}(\rho^*) = h_2^{b,b}(c_1^{b,b}(\rho^*),\rho^*), \\
&= (1-\rho^*)(u(h_2^{b,g}(c_1^{b,b}(\rho^*),\rho^*)) - u(h_2^{b,b}(c_1^{b,b}(\rho^*),\rho^*))) \\
&\quad -(1-\rho^*)(u(h_2^{g,g}(\bar{c}_{1,g},\rho^*)) - u(h_2^{g,b}(\bar{c}_{1,g},\rho^*))), \\
&\quad \text{from Remark 6 (i)}, \\
&= (1-\rho^*)(u(R_g h_2^{b,b}(c_1^{b,b}(\rho^*),\rho^*)/R_b) - u(h_2^{b,b}(c_1^{b,b}(\rho^*),\rho^*))) \\
&\quad -(1-\rho^*)(u(R_g h_2^{g,b}(\bar{c}_{1,g},\rho^*)/R_b) - u(h_2^{g,b}(\bar{c}_{1,g},\rho^*))) \\
&= (1-\rho^*)\frac{(R_g/R_b)^{1-\gamma} - 1}{1-\gamma}(h_2^{b,b}(c_1^{b,b}(\rho^*),\rho^*)^{1-\gamma} - h_2^{g,b}(\bar{c}_{1,g},\rho^*)^{1-\gamma}).
\end{aligned}$$

Remark 6 (ii) suggests $h_2^{g,b}(\bar{c}_{1,g},\rho^*) > h_2^{b,b}(c_1^{b,b}(\rho^*),\rho^*)$, so $\Delta_g(\rho^*) - \Delta_b(\rho^*) > 0$. If a bad bank does not have an incentive to mimic ($\Delta_b(\rho^*) \geq 0$), a good bank always has an incentive to deviate ($\Delta_g(\rho^*) > 0$).

Suppose $\bar{c}_{1,g} < c_{1,b}^t(\rho^*)$ and $\rho^* = 1$, a good bank deviates by offering the first-period repayment $c_{1,b}^t(\rho^*)$.

A.8 Proof for Proposition 6

The immediate implication of Proposition 5 is that a full run never occurs under a separating equilibrium. Because paying greater than $c^t_{1,g}(1) = \beta R_g$ in period 1 is impossible for a good bank, there is no separating equilibrium where $\rho^* = 1$.

Remark 7. In a separating equilibrium, $\rho^* < 1$.

However, a partial run can still occur. Moreover, such a partial run is inefficient. To prove this claim, I provide an explicit numerical example. Consider the following set of parameters.

π	γ	q_g	R_g	R_b	β
0.2	3	0.5	1.8	0.7	0.73

We solve the set of outcomes $(\bar{c}_{1,g}, \rho^*)$ supported as separating equilibria. In Figure 2, the thick black line represents this set. The dotted black line represents the boundary where a bad bank mimics or not. I also label the region where patient depositors wait and the region where they run. At the boundary between the two regions, patient depositors are indifferent between waiting and running. The figure shows that a partial run equilibrium exists when $(\bar{c}_{1,g}, \rho^*) = (2.20, 0.35)$. We also find $V(c^*, \rho^*) = -1.58 < -1.37 = V(c^*, \pi)$ at this equilibrium, which indicates the inefficiency of the partial run.

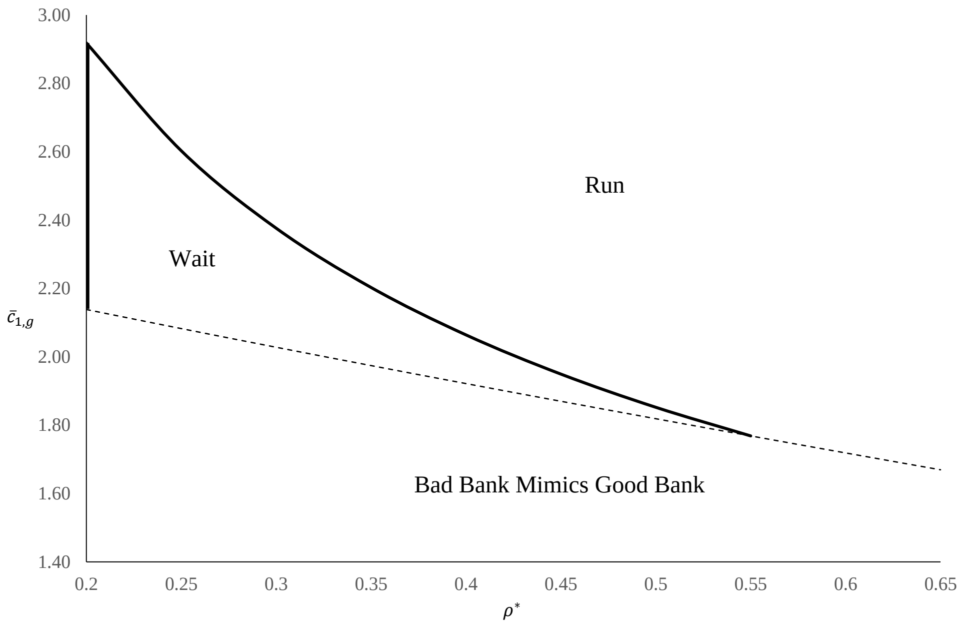

Figure 2: Separating Equilibria

A.9 Proof for Proposition 7

Notice

$$
\begin{aligned}
u(\bar{c}_{1,p}) &= \mathbb{E}[u(h_2^{m,z}(\bar{c}_{1,p},\rho))] \\
\Leftrightarrow \bar{c}_{1,p}^{1-\gamma} &= \mathbb{E}[R_z^{1-\gamma}]\left(\frac{1-\rho\bar{c}_{1,p}/(\beta R_m)}{1-\rho}\right)^{1-\gamma} \\
\Leftrightarrow \bar{c}_{1,p} &= (\mathbb{E}[R_z^{1-\gamma}])^{1/(1-\gamma)}\frac{1-\rho\bar{c}_{1,p}/(\beta R_m)}{1-\rho} \\
\Leftrightarrow (1-\rho)\beta R_m\bar{c}_{1,p} &= (\mathbb{E}[R_z^{1-\gamma}])^{1/(1-\gamma)}(\beta R_m-\rho\bar{c}_{1,p}) \\
\Leftrightarrow ((1-\rho)\beta R_m+\rho(\mathbb{E}[R_z^{1-\gamma}])^{1/(1-\gamma)})\bar{c}_{1,p} &= \beta R_m(\mathbb{E}[R_z^{1-\gamma}])^{1/(1-\gamma)} \\
\Leftrightarrow \bar{c}_{1,p} &= \frac{\beta R_m(\mathbb{E}[R_z^{1-\gamma}])^{1/(1-\gamma)}}{(1-\rho)\beta R_m+\rho(\mathbb{E}[R_z^{1-\gamma}])^{1/(1-\gamma)}} \\
&= \frac{\beta\mathbb{E}[R_z]}{\rho+(1-\rho)(\chi(1-\gamma)/\beta^{1-\gamma})^{1/(\gamma-1)}}.
\end{aligned}
$$

Given such $\bar{c}_{1,p}$ and ρ, a patient depositor is indifferent between waiting and running. Each ρ can be supported as an equilibrium of the withdrawal subgame. Also, for such $\bar{c}_{1,p}$,

$$
\begin{aligned}
&\rho u(\bar{c}_{1,p})+(1-\rho)u(h_2^{m,z}(\bar{c}_{1,p},\rho))-(\rho u(c_1^{b,z}(\rho))+(1-\rho)u(c_2^{b,z}(\rho))) \\
=\ & \frac{c_1^{b,z}(\rho)^{1-\gamma}}{\gamma-1}\left(\rho+(1-\rho)\left(\frac{R_z}{\beta R_b}\right)^{(1-\gamma)/\gamma}\right)-\frac{\bar{c}_{1,p}^{1-\gamma}}{\gamma-1}\left(\rho+(1-\rho)\frac{\beta^{1-\gamma}}{\chi(1-\gamma)}\left(\frac{R_z}{\beta R_m}\right)^{1-\gamma}\right) \\
=\ & \frac{\bar{c}_{1,p}^{1-\gamma}}{\gamma-1}\left(\frac{c_1^{b,z}(\rho)}{\bar{c}_{1,p}}\right)^{1-\gamma}\left(\rho+(1-\rho)\left(\frac{R_z}{\beta R_b}\right)^{(1-\gamma)/\gamma}\right) \\
&-\frac{\bar{c}_{1,p}^{1-\gamma}}{\gamma-1}\left(\rho+(1-\rho)\frac{\beta^{1-\gamma}}{\chi(1-\gamma)}\left(\frac{R_z}{\beta R_m}\right)^{1-\gamma}\right) \\
=\ & \frac{\bar{c}_{1,p}^{1-\gamma}}{\gamma-1}\left(\rho+(1-\rho)\left(\frac{\beta^{1-\gamma}}{\chi(1-\gamma)}\right)^{1/(1-\gamma)}\right)^{1-\gamma}\left(\frac{R_b}{R_m}\right)^{1-\gamma}\left(\rho+(1-\rho)\left(\frac{R_z}{\beta R_b}\right)^{(1-\gamma)/\gamma}\right)^{\gamma} \\
&-\frac{\bar{c}_{1,p}^{1-\gamma}}{\gamma-1}\left(\rho+(1-\rho)\frac{\beta^{1-\gamma}}{\chi(1-\gamma)}\left(\frac{R_z}{\beta R_m}\right)^{1-\gamma}\right),
\end{aligned}
$$

where $c_\tau^{\alpha,z}(\rho)$ is defined in accordance with Section A.1 with $\tilde{\beta} = \beta$. From this result, notice $\rho u(\bar{c}_{1,p}) + (1-\rho)u(h_2^{m,z}(\bar{c}_{1,p}, \rho)) - (\rho u(c_1^{b,z}(\rho)) + (1-\rho)u(c_2^{b,z}(\rho)))$ is positive at $\rho = 1$, $\forall z$. Therefore, $\forall z$, it is above 0, $\forall \rho$, or $\exists \underline{\rho}_z < 1$ such that it is nonnegative, $\forall \rho \geq \underline{\rho}_z$. Thus, $\forall \rho \geq \max\{\underline{\rho}_g, \underline{\rho}_b\}$, $\rho u(\bar{c}_{1,p}) + (1-\rho)u(h_2^{m,z}(\bar{c}_{1,p}, \rho)) - (\rho u(c_1^{b,z}(\rho)) + (1-\rho)u(c_2^{b,z}(\rho)))$ is nonnegative, $\forall z$.

$\rho u(\bar{c}_{1,p}) + (1-\rho)u(h_2^{m,z}(\bar{c}_{1,p}, \rho))$ corresponds to the depositor welfare for the bank in state z under the outcome of a pooling equilibrium and $\rho u(c_1^{b,z}(\rho)) + (1-\rho)u(c_2^{b,z}(\rho))$ corresponds to the maximum possible value for the bank in state z when it deviates under the point belief function. Therefore, $\forall \rho \geq \max\{\underline{\rho}_g, \underline{\rho}_b\}$, each bank does not have an incentive to deviate from the outcome of a pooling equilibrium.

A.10 Proof for Proposition 8

At the equilibrium under Opacity, the depositor welfare is $V(c^o, \rho^o)$.[16] At the equilibrium under Transparency, the depositor welfare is $V(c^t, \rho^t)$. Proposition 2 suggests $V(c^t, \rho^t) < V(c^o, \rho^o)$.

A.11 Proof for Proposition 9

Recall the planner's problem under Transparency. The planner's problem under Transparency given the level of withdrawal under a separating equilibrium is

$$\begin{array}{cc} \max_{\{c_{1,z}(\rho^{signal}), c_{2,z}(\rho^{signal})\}_{z\in\{g,b\}}} & \mathbb{E}[\rho^{signal} u(c_{1,z}(\rho^{signal})) + (1-\rho^{signal})u(c_{2,z}(\rho^{signal}))] \\ \text{s.t.} & \rho^{signal}\dfrac{c_{1,z}(\rho^{signal})}{\beta R_z} + (1-\rho^{signal})\dfrac{c_{2,z}(\rho^{signal})}{R_z} \leq 1, \forall z. \end{array}$$

[16]Suppose $\chi(1-\gamma) = \beta^{1-\gamma}$. $V(c^o, \rho) = V(c^o, \rho^o), \forall \rho$.

There exists a unique solution that is $\{c^t_{1,z}(\rho^{signal}), c^t_{2,z}(\rho^{signal})\}_{z\in\{g,b\}}$. Notice the bank's repayment level under a separating equilibrium also satisfies the resource constraint. Because $\bar{c}_{1,g} \neq c^t_{1,g}(\rho^{signal})$, according to Proposition 5, $V(c^t, \rho^{signal}) > V(c^{signal}, \rho^{signal})$. Thus, $V(c^t, \rho^t) \geq V(c^t, \rho^{signal}) > V(c^{signal}, \rho^{signal})$.

A.12 Proof for Proposition 10

Recall the planner's problem under Opacity. The planner's problem under Opacity given the level of withdrawal under a pooling equilibrium is

$$\begin{aligned} \max_{c_1(\rho^{signal}),\{c_{2,z}(\rho^{signal})\}_{z\in\{g,b\}}} \quad & \rho^{signal} u(c_1(\rho^{signal})) + \mathbb{E}[(1-\rho^{signal})u(c_{2,z}(\rho^{signal}))] \\ \text{s.t.} \quad & \rho^{signal}\frac{c_1(\rho^{signal})}{\beta R_m} + (1-\rho^{signal})\frac{c_{2,z}(\rho^{signal})}{R_z} \leq 1, \forall z. \end{aligned}$$

There exists a unique solution that is $c^o_1(\rho^{signal}), \{c^o_{2,z}(\rho^{signal})\}_{z\in\{g,b\}}$. Notice the bank's repayment level under a pooling equilibrium also satisfies the resource constraint. Thus, $V(c^o, \rho^o) \geq V(c^o, \rho^{signal}) \geq V(c^{signal}, \rho^{signal})$.