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Bank Transparency, Asset and Liquidity Risks[*]

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Abstract

We study the effects of bank transparency on both banks' asset and liquidity risks, and ultimately, on banking sector stability and welfare. We show how enhanced bank transparency increases banks' vulnerability to excessive deposit outflows, but this threat of a liquidity crisis incentivizes banks to choose safer assets. We find that bank stability and welfare are a non-monotonic function of transparency, and that they are maximized at an intermediate level of transparency, which is larger than the one preferred by banks but lower than what would result in excessive deposit outflows. Our model also suggests that bank transparency and deposit insurance are complementary policy tools, and that bank regulators should adjust disclosure requirements for banks procyclically.

Keywords: bank transparency, bank runs, asset risk taking, banking stability, deposit insurance

JEL Codes: G21, G28, D83

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1 Introduction

Whether making banks more transparent improves stability and welfare is an unsettled issue. Transparency should be beneficial because it facilitates market discipline, which has been recognized as an important mechanism for controlling various moral hazard problems in banks. However, public disclosure about banks' financial conditions will not calm markets if it provides news worse than markets' expectations (as, for example, became evident in the US and Swiss banking crisis in the spring of 2023). To tackle this issue, this paper constructs a model in which changes in bank transparency affect both sides of banks' balance sheets. As in Diamond and Dybvig (1983), depositors (banks' creditors) face liquidity shocks, and a bank provides liquidity by allowing depositors who have liquidity needs to consume more. The bank can choose riskiness of its asset, and it can fail if either its asset risk or liquidity risk realizes. Depositors receive interim information about the bank's asset returns, and they will withdraw early if they perceive the return to be sufficiently low. The bank is more transparent when the depositors' information is more reliable. Our model also includes partial deposit insurance scheme, which often is a key part of bank crisis episodes (Allen et al., 2011), but rarely considered in the literature of bank transparency.

Under this setting, we document that deposit outflows are more sensitive to information about banks' performance when banks are more transparent. We then show that through this mechanism, enhanced transparency can discipline banks' asset risk taking: Depositors are more prone to withdraw when they learn pessimistic information about a bank's performance if that information is more precise. To prevent them from doing so, the bank has to lower asset risk. Because encountering bank runs is costly, the bank may find it optimal to become safe enough so that there are no excessive deposit outflows.

These results are consistent with the empirical findings. For example, Chen et al. (2022) find that enhanced bank transparency makes uninsured deposit flows sensitive to weak bank performance. Anderson and Copeland (2023) document that, after New York state bank regulators suspended the publication of balance sheets of state-charter banks over 1933-1935, these state-charter banks not only suffered smaller deposit outflows compared to national-charter banks, but were also able to hold more risky assets. Similarly, Wang (2021) shows that the bank holding companies that exited from the SEC disclosure system (so were subject to fewer disclosure requirements) between 2012 and 2016 were able to hold both more deposits and illiquid assets.

Our results suggest that even if a bank run reduces welfare, higher transparency can be welfare improving through two reasons. First, enhanced transparency increases the efficiency of bank runs in liquidating insolvent banks. Second, enhanced transparency makes the threat of bank runs more pertinent and, thus, it may reduce the banks' incentive to seek risk. However, too much transparency can also be welfare reducing, also for two reasons: First, because depositors may have excessive incentive to withdraw, it is possible that the level of bank risk required to avoid excessive deposit outflows is too low compared to the socially optimal level. When this happens, a reduction in bank transparency raises social welfare. The government should hence loosen information disclosure requirements on banks when they are likely to be excessively conservative, for example, during recessions – a policy implication which is confirmed when we study the relation of bank transparency regulation and business cycle in more detail. Second, if depositors' information is sufficiently precise, it becomes too costly for a bank to prevent a bank run upon bad news about the bank's performance. Thus, our model predicts, in line with the evidence in Correia et al. (2024), that bank runs can occur only if depositors obtain sufficiently reliable information that banks' performance is poor. In such circumstances the disciplining effect of liquidity risk vanishes due to a bank's limited liability, and the bank will take more risk, the more precise is the depositors' information.

As a result of these tradeoffs, the optimal bank transparency is at an intermediate level: It should be higher than what is preferred by the banks themselves but lower than the one that would prompt excessive deposit outflows. We also find that bank transparency and deposit insurance coverage are complementary policy tools: A broader deposit insurance coverage dilutes the disciplining effect of liquidity risk on banks' asset risk taking and enhanced transparency is needed to restore depositors' incentives to act upon adverse news about bank performance.

The literature on bank transparency is large, although the question of identifying a welfare-maximizing policy in the presence of equilibrium asset and liquidity risks has received less attention. Related papers include Calomiris and Kahn (1991) where depositors' private information acquisition and liquidation threat provide incentives for bank managers not to abscond funds from the bank, and Allen and Gale (1998), where depositors start a bank run if the expected return of the bank's assets is sufficiently low, and this threat of a bank run may incentivize the bank to choose optimal risk sharing between early and late withdrawing depositors. Matutes and Vives (2000), Hyytinen and Takalo (2002), Vauhkonen (2012), and Moreno and Takalo (2023), for example, show how providing investors with information of the bank's asset risk choice ex ante can discipline banks' asset risk taking. Chen and Hasan (2006, 2008) and Parlatore (2024), for example, find like we do, that higher transparency can trigger inefficient bank runs. Similarly, the literature using global game techniques to pin down a unique equilibrium in bank run settings (e.g., Bouvard et al., 2015; Iachan and Nenov, 2015; Moreno and Takalo, 2016) also find that creditors' incentives to rollover a bank's debt may be weakened if they obtain more precise information about bank performance.

As the stress tests emerged as a novel policy tool to enhance bank transparency in the aftermath of the Global Financial Crisis, much of the subsequent literature has analyzed the effects of stress tests on financial stability – see Goldstein and Leitner (2022) for an overview and, e.g., Leitner and Williams (2023), Moreno and Takalo (2023), and Orlov et al. (2023) for more recent contributions. The public signal in our model can be interpreted as a disclosure of stress test results. A related literature studies the effects of transparency in the case of non-financial firms – e.g., Gigler et al. (2014) imply that managers may pursue inefficient short-term projects if firms are required to disclose information too frequently.

A main difference between our paper and those in the literature is that in our model, banks provide valuable liquidity services and changes in bank transparency affect both sides of the banks' balance sheet, while most papers take the existence of banks given or study the effects of bank transparency on just one side of the balance sheet. These features of the model allow us to consider simultaneously both the destabilizing and the disciplining effect of bank transparency when discussing stability and welfare issues. For example, Parlatore (2024) finds that an increase in transparency always reduces welfare, whereas in our setting an increase in transparency can also have a disciplining merit and therefore it can either improve or reduce welfare so that an intermediate level of transparency is optimal from the welfare point view. We also study the optimal bank transparency in the presence of partial deposit insurance. In this respect, a close paper to ours is Faria-e-Castro et al. (2017) who show that, since bad news about banks may prompt inefficient runs, the government should provide a candid evaluation of the banking industry's financial health only if it is in a strong fiscal position to provide deposit insurance. Our results about the optimality of procyclical transparency regulation contrasts with the findings in Bouvard et al. (2015) and Alvarez and Barlevy (2021) where more transparency is good during crises but maybe harmful in normal times, but is in line with Dang et al. (2017, 2020) who suggest that opaqueness is typically desirable to allow banks to take risk while simultaneously reducing their liquidity risk, especially in crisis times when banks' creditors pay more attention to bad news about banks' performance.

The rest of the paper is organized as follows. Section 2 describes the assumptions of the model. Section 3 studies the equilibrium effects of bank transparency, whereas Section 4 studies its stability and welfare effects. Section 5 discusses several extensions of the model, e.g., we consider how optimal bank transparency regulation should vary with deposit insurance coverage and business cycle. Section 6 concludes.

2 A Model of Bank Transparency, Asset and Liquidity Risks

Consider a three-date ($t = 0, 1, 2$) model with a *bank*, a unit measure of *depositors*, and a governmental *regulatory agency*. The bank, which maximizes its owners' payoff, exercises market power. All the agents are risk-neutral. Thus, in a departure, e.g., from Diamond and Dybvig (1983), our depositors are risk-neutral, and we could think them as investors holding the bank's debt instruments as well as small retail depositors. We follow the tradition in the literature and label the bank's creditors as depositors irrespective of their type.[1]

At $t = 0$, each depositor receives an endowment of one dollar. As in Diamond and Dybvig (1983), a bank is established to satisfy the depositors' liquidity needs. Depositors make deposits at $t = 0$ if and only if their expected payoff from depositing is no lower than U_0, where $U_0 > 1$ is the highest payoff that a depositor can receive from other alternatives. Depositors face *liquidity shocks*: Some of them die (early diers) at $t = 1$, and the others die (late diers) at $t = 2$. The proportion of early diers is $f \in (0, 1)$ and depositors learn their types at $t = 1$. Depositors' types are i.i.d. and we assume, as usually, that with a continuum of i.i.d. random variables, the mean equals the expectation with probability 1 (Judd, 1985). Early diers must withdraw their deposits from the bank at $t = 1$. An early dier will suffer a utility loss X if his date-1 consumption is strictly lower than δ, where X and δ are constants with $X > 0$ and $1 < \delta < 1/f < U_0$. Late diers can consume at dates 1 and 2, and they have no time preference for consumptions. A *bank run* occurs if the late diers, too, withdraw at $t = 1$.

The deposit contract is $(d_1, d_2) \in [0, \infty)^2$ where d_t denotes the repayment that

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[1] The bank's market power is another difference to liquidity risk models building on Diamond and Dybvig (1983) with a perfectly competitive bank. On the other hand, the models analyzing the banks' asset risks, e.g., Matutes and Vives (1996, 2000), Hellmann et al. (2000), and Repullo (2004), often assume that banks have market power. We follow this latter tradition. Drechsler et al. (2017), Egan et al. (2017) and Carletti et al. (2024) emphasize banks' market power and, according to Philippon (2015), that market power has been increasing over the past decades. See, e.g., Moreno and Takalo (2016) and Parlatore (2024), for the effects of transparency in a perfectly competitive banking sector.

the bank promises to a depositor if she withdraws at date $t \in \{1, 2\}$. For now, we consider a generic deposit contract with $d_2 > d_1 = \delta$. Any deposit contract chosen by a bank with market power should satisfy these properties: $d_1 = \delta$ is the smallest date-1 repayment which allows an early dier to avoid the utility loss X if she successfully withdraws at $t = 1$, while setting $d_2 > d_1$ provides late diers with an incentive to rollover if they believe that they can successfully withdraw at $t = 2$. The bank cannot identify a depositor's type and operates under the sequential service constraint. Depositors' claims also have seniority, implying that if the bank is unable to meet its obligations, its depositors receive in expectation a pro rata share of the bank's residual value. We shall discuss more about the deposit contract in Section 5.

At $t = 0$, the bank chooses an *investment* $p \in [0, 1]$. The investment matures at $t = 2$. For each dollar invested, the date-2 return of the investment is $R(p)$ when it succeeds, which happens with probability p, and is r when it fails (with probability $1-p$). Thus, p serves as an inverse measure of the bank's asset portfolio riskiness, e.g., we may think that with probability $1 - p$ the share of defaulting borrowers in the bank's loan portfolio is so high that the bank becomes insolvent and r is the liquidation value of the bank's assets in an insolvency.[2] The bank's asset portfolio can also be liquidated prematurely at $t = 1$. Early liquidation of a dollar's investment generates one dollar. We impose the following mild restrictions on the bank's investment returns:

Assumption 1. *(a) The return function of a successful investment* $R : [0, 1] \rightarrow$

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[2] Alternatively, we may also think that the bank has many investments in its portfolio, and each of which can be decomposed to a common and an idiosyncratic component. If idiosyncratic investments can be pooled perfectly, we are left with the common component whose riskiness is captured by p – see, e.g., Allen and Gale (2004).

$[\bar{R}, \underline{R}]$ *is twice differentiable, strictly decreasing, and concave; (b) Its first derivative* $R'(p)$ *is bounded and satisfies* $R'(1) < r - \underline{R}$*; (c) The parameters satisfy*

$$0 \leq r < 1 < \frac{(1-f)d_2}{1-fd_1} \leq \underline{R} < \bar{R}.$$

Assumption 1 has several intuitive implications. One is that riskier investments fail more likely but yield higher returns conditional on success (part (a)). Another is that the bank can fully pay off depositors if its investment succeeds and no bank run occurs at date 1: Since early liquidation of the bank's investment at $t = 1$ recovers its principal, it is optimal for the bank to invest all its funds at $t = 0$ and, if no bank run occurs, liquidate proportion fd_1 of its investment to satisfy the deposit outflows at $t = 1$ (recall that $d_1 = \delta < 1/f$)). Part (c) of Assumption 1 implies that, in the absence of a bank run, the bank's proceeds from a perfectly safe investment of $p = 1$ ($(1 - fd_1)R(1) = (1 - fd_1)\underline{R}$) are sufficient for meet the deposit outflows at $t = 2$ ($(1 - f)d_2$) and, since $R'(p) < 0$ by part (a) of Assumption 1, the same applies for any risky investment with $p \in (0, 1)$.

Writing

$$V(p) = pR(p) + (1-p)r - 1, \tag{1}$$

as the net present value of the investment, part (a) of Assumption 1 implies that $V(p)$ is strictly concave, that is, $V''(p) = 2R'(p) + pR''(p) < 0$.[3] Then $p^{NPV} \equiv \arg\max_{p\in[0.1]} V(p)$ is the unique p that satisfies

$$V'(p) = R(p) + pR'(p) - r = 0. \tag{2}$$

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[3] Note that V is also a (increasing) function of r in addition to p. Throughout the paper we suppress the function arguments that are of no interest in the current section. For example, here $V(p) \equiv V(p, r)$.

Parts (b) and (c) of Assumption 1 imply $V'(0) > 0$ and $V'(1) < 0$, $p^{NPV} \in (0, 1)$ and $V(p^{NPV}) > 0$.

At $t = 1$, when depositors learn their types, they observe p. This assumption is common in the literature but is subject to discussion; for example the textbooks of Freixas and Rochet (2008) discuss both the observable and unobservable asset risk cases. We therefore also consider the case where the bank's choice of p is unobservable to depositors in Section 5. However, depositors do not observe the bank's actual asset performance. Instead, the depositors receive a *signal* S with realization $s \in \{h, l\}$ about the bank's investment (about its returns or about the true success probability). If the bank's investment succeeds and the return is $R(p)$, then $s = h$ with probability q and $s = l$ with probability $1 - q$. If the bank's investment fails and the return is r, then $s = h$ with probability $1 - q$ and $s = l$ with probability q, where q is the precision of the signal S with $q \in [0.5, 1]$. Given the bank's asset risk, the signal, and the realized depositor types, the early diers withdraw by the assumption, and the late diers decide whether to withdraw or rollover.

We consider generic *bank transparency* by assuming that it is directly related to q: the higher is q, the more informative is S about the bank's investment performance. In practice, various factors may affect the transparency of banks. A bank is more transparent if it is listed or is otherwise required to make more extensive public information disclosures, if more analysts collect and publish information about it, if its business model is less complicated, and if it voluntarily reveals more information. Bank transparency is also influenced by banking regulations such as those included in Pillar 3 of the Basel framework which force banks to disclose more information.

In addition, regulators usually obtain information about banks' asset portfolio risks. For example, in a stress test, a regulatory agency inquires about a bank's ability to absorb losses it may incur in an adverse economic scenario and publishes the results of this inquiry. The signal realization $s = h(l)$ can be interpreted as meaning that, according to the stress test results, the bank's asset returns are sufficiently high (low), given the bank's capital, that it would (would not) survive such a scenario – Goldstein and Leitner (2018) identify conditions where such simple disclosure rules of a stress test are optimal. The stringency of stress tests and the extent of disclosure of its results and underlying models affect the informativeness of stress tests and transparency of banks to the public (e.g., Leitner and Williams, 2023; Orlov et al., 2023). We take no stance to these subtle differences in the determinants of bank transparency and will work directly with the level of q. For the moment, we take q as given – in Sections 4 and 5 we assume that q is set by the government's regulatory agency as the *minimum level of transparency* which banks must obey (while being voluntarily able to be more transparent).

In our model, the bank is exposed to both liquidity and asset risks: The bank may fail at date 1 due to excessive deposit outflows, and it may fail at date 2 due to the failure of its investment. Because bank failures cause social costs, a *dead-weight loss* $Z \geq 0$ is incurred if the bank fails. We may think that the size of Z varies across different banks; for example, large, systemically important banks have large Z whereas small local lenders have small Z. We assume that the size of the dead-weight loss is independent of the reason (asset or liquidity risk) for bank failure. Also, irrespective of the reason for bank failure, the government provides *partial deposit insurance*: If a depositor cannot get paid from the bank at either $t = 1$ or $t = 2$, the government gives her a fixed reimbursement of size $y \geq 0$, where y is not too high to eliminate late diers' incentives to withdraw at $t = 1$ – see Section 3 for the exact condition. Even if a deposit insurance scheme has a complete coverage de jure, banks can still fail if their asset risk taking realizes (like in our model), which makes the deposit insurance de facto partial.[4] For simplicity, we assume no direct cost of providing deposit insurance for the government.

The timing of events can be summarized as follows: At $t = 0$, the bank is established. Given the deposit contract (d_1, d_2), depositors decide whether to deposit. If they do, the bank invests and chooses p. At $t = 1$, the depositors' types and the signal S are revealed. Early diers withdraw. Late diers decide on whether to withdraw or rollover. If a bank run occurs, the bank fails. If there is no bank run at $t = 1$, the bank's investment matures and its risk realizes at $t = 2$. The bank pays off the remaining depositors if possible.

We look for perfect Bayesian equilibria where all the agents maximize their payoffs by using sequentially rational strategies that are consistent with their beliefs. The agents have rational prior beliefs, and their (in particular, the late diers') posterior beliefs are derived from their equilibrium strategies and priors by using Bayes' rule, if possible. We discuss only symmetric perfect Bayesian equilibria where all the agents (in particular, the late diers) take the same action. We further assume, building on Chen (1999) and Chen and Hasan (2006), that depositors choose the Pareto dominant equilibrium when there are multiple sym-

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[4] According to International Association of Deposit Insurers, as of July 2019, 145 jurisdictions have established an explicit deposit insurance system, and another 25 jurisdictions are considering the possibility (see `http://www.iadi.org/en/deposit-insurance-systems/`, accessed March 20, 2024). Most explicit deposit insurance systems only provide partial coverage and even unlimited, explicit deposit insurance is not necessarily credible nor equivalent to receiving the funds unambiguously and immediately upon withdrawal (e.g., Allen et al., 2011; Shy et al., 2016). An implicit or not fully credible deposit insurance scheme is equivalent to partial deposit insurance in expectation.

metric perfect Bayesian equilibria. In what follows, we call perfect Bayesian Pareto dominant equilibria simply equilibria unless otherwise indicated. This equilibrium selection mechanism allows us to focus on bank runs that are results of depositors' perceptions about banks' riskiness instead of "sunspots".[5]

3 Equilibria

We first investigate the realization of the bank's liquidity risk at date 1, then the bank's choice of asset risk at date 0. Finally, we analyze the depositors' depositing decision at date 0. As the bank's payoff is always non-negative, we do not need to consider its participation constraint.

3.1 Bank's Asset and Liquidity Risks

At $t = 1$, depositors learn their types and the realization of the signal S. While early diers always withdraw at $t = 1$, late diers' decision to withdraw or to rollover is affected by the realization of S. Let p_s denote the probability that the bank's investment will succeed when the realization of S is $s \in \{l, h\}$. By Bayes' rule, we have

$$p_h \equiv \frac{pq}{pq + (1-p)(1-q)} > p > \frac{p(1-q)}{(p(1-q) + (1-p)q} \equiv p_l. \tag{3}$$

Consider the depositors' rollover decisions at $t = 1$ upon $s = l$. Suppose a

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[5] An alternative method to rule out uninteresting "sunspot" equilibria would be to follow the global game literature (e.g., Rochet and Vives, 2004; Goldstein and Pauzner, 2005; Bouvard et al., 2015; Iachan and Nenov, 2015; Moreno and Takalo, 2016), and regard p as a random variable with realizations from which depositors obtain private signals, and use iterated elimination of strictly dominated strategies. In our case of p is the bank's choice variable. We discuss the relation of our equilibrium concept to the one used in the global game literature further in Section 5.

late dier who believes that all the other late diers rollover. As shown in Chen and Hasan (2006), given the assumption that depositors choose the Pareto dominant equilibrium when there are multiple equilibria, no late dier will withdraw if and only if the depositor under consideration prefers to rollover. Otherwise, withdrawing at $t = 1$ is a strictly dominant strategy for all the late diers.

Let v_F denote the late dier's expected payoff $t = 2$ if she rollovers at $t = 1$ and the bank's investment fails. We have

$$v_F \equiv \frac{(1 - fd_1)r}{1 - f} + \left[1 - \frac{(1 - fd_1)r}{(1 - f)d_2}\right] y. \tag{4}$$

The right-hand side of the definition (4) shows how the late dier under consideration receives d_2 at $t = 2$ from the bank with probability $(1-fd_1)r/\big[(1-f)d_2\big]$, and receives y from the government otherwise, if only early diers withdraw at $t = 1$ and the bank's investment fails at $t = 2$.[6] We assume that

$$y < \frac{d_1 - \frac{(1-fd_1)r}{1-f}}{1 - \frac{(1-fd_1)r}{(1-f)d_2}}$$

so that $v_F < d_1$. As a result, the late dier may withdraw at $t = 1$ if she believes that the bank's asset risk is likely to realize. Given $s = l$, the late dier's payoff is d_1 if she withdraws, and is $p_l d_2 + (1 - p_l)v_F$ if she rollovers. Thus, the late dier prefers to rollover if and only if $p_l d_2 + (1 - p_l)v_F \geq d_1$, or equivalently, using

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[6] At $t = 1$, the bank liquidates the proportion fd_1 of its investment to meet the deposit outflows. Thus, the liquidation value of the failed bank at $t = 2$ is $(1 - fd_1)r$, while the bank's debt obligation is $(1 - f)d_2$. Given the sequential service constraint and seniority of depositors' claims, each depositor gets paid from the bank with probability $(1 - fd_1)r/\big[(1 - f)d_2\big]$.

equation (3), if and only if

$$p \geq p_l^{Run}(q) \equiv \frac{q}{q+(1-q)\left(\frac{d_2-d_1}{d_1-v_F}\right)}. \tag{5}$$

Then, upon $s = l$, no late dier withdraws $t = 1$ if $p \geq p_l^{Run}(q)$, and all the late diers withdraw otherwise.

Applying the similar logic to the depositors' rollover decisions at $t = 1$ upon $s = h$, the late dier under consideration prefers to rollover if and only if $p_h d_2 + (1-p_h)v_F \geq d_1$, or equivalently, using equation (3), if and only if

$$p \geq p_h^{Run}(q) \equiv \frac{1-q}{1-q+q\left(\frac{d_2-d_1}{d_1-v_F}\right)} \tag{6}$$

Given $s = h$, no late dier withdraws at $t = 1$ if $p \geq p_h^{Run}(q)$, and all the late diers withdraw otherwise. The following lemma characterizes the mappings $p_s^{Run}(q), s \in \{h, l\}$, and their implications for bank runs. (The proofs of all the lemmas, propositions, and corollaries are provided in the Appendix.)

Lemma 1. *(a)* $p_l^{Run}(q)$ *is an increasing and* $p_h^{Run}(q)$ *a decreasing function of* q *on* $(0.5, 1)$ *satisfying*

$$p_l^{Run}(0.5) = p_h^{Run}(0.5) = p_0^{Run} \equiv \frac{d_1 - v_F}{d_2 - v_F},$$

$p_l^{Run}(1) = 1$, *and* $p_h^{Run}(1) = 0$. *Moreover,* $p_l^{Run}(q) > p_h^{Run}(q)$ *for* $q \in (0.5, 1]$.

(b) If $p \geq p_l^{Run}(q)$, *no bank run at date* 1 *occurs. If* $p \in [p_h^{Run}(q),\, p_l^{Run}(q))$, *a bank run at date* 1 *occurs upon* $s = l$. *If* $p < p_h^{Run}(q)$, *a bank run at date* 1 *occurs irrespective of the signal* S.

Part (a) of Lemma 1 suggests that when the signal is more informative, late diers have stronger incentive to respond to bad news about the bank and withdraw, so it requires a higher p to make them to rollover. Similarly, when q is higher, good news implies more likely that the bank's investment will be successful, making late diers more inclined to rollover for a given p. Therefore, $p_l^{Run}(\cdot)$ is increasing and $p_h^{Run}(\cdot)$ decreasing on $(0.5, 1)$. The p_0^{Run} defined in Lemma 1 represents the threshold of p that triggers a bank run when the signal S is uninformative ($q = 0.5$). If depositors received no additional information at $t = 1$, a bank run would occur if and only if $p < p_0^{Run}$. When the signal is informative ($q > 0.5$), the threshold of p required to prevent a bank run is higher when the news is bad ($s = l$) than when it is good ($s = h$). As a result, the partition of the bank's asset riskiness characterized by part (b) of Lemma 1 arises: A sufficiently safe bank never encounters a run, a moderately risky bank encounters a run upon bad news but does not encounter a run upon good news, and a sufficiently risky bank always encounters a run. The last case ($p < p_h^{Run}(q)$) cannot be an equilibrium asset choice, since in the anticipation of a sure bank run at $t = 1$, depositors would not lend their money to the bank at $t = 0$. We thus ignore it in what follows.

We next characterize the bank's choice of p at $t = 0$. Using the subscripts R and N denote the environments where a bank run at $t = 1$ can occur and cannot occur, respectively, we may write the bank's expected payoff in the no-run environment as

$$\pi_N(p) = p\big[(1 - fd_1)R(p) - (1 - f)d_2\big]. \tag{7}$$

The bank's investment succeeds with probability p and yields $(1 - fd_1)R(p)$ at $t = 2$, since the fraction fd_1 of its investment has been liquidated to meet deposit outflows at $t = 1$. At $t = 2$, the bank is a residual claimant: it first meets the late diers' claims $(1 - f)d_2$ and keeps the remaining return of a successful investment. (In the case of a date-2 bankruptcy occurring with probability $1 - p$, the bank's liquidation value $(1 - fd_1)r$ is fully paid off to late diers.) By Assumption 1, the bank's no-run payoff $\pi_N(p)$ is concave in p.

Consider next the environment where a bank run at $t = 1$ occurs if $s = l$ and no bank run occurs if $s = h$. The bank's expected payoff in this case is

$$\pi_R(p, q) = pq\big[(1 - fd_1)R(p) - (1 - f)d_2\big] = q\pi_N(p), \tag{8}$$

i.e., the difference to the no-run case of equation (7) is that the bank is only able to make profits if its investment succeeds and there is no bank run. As the bank's expected run-payoff $\pi_R(p)$ is proportional to its no-run expected payoff $\pi_N(p)$, we can define

$$p_B \equiv \arg\max_{p\in[0,1]} \pi_N(p) = \arg\max_{p\in[0,1]} \pi_R(p, q),$$

i.e., p_B is the p that satisfies $d\pi_i/dp = 0$, $i \in \{N, R\}$, and is hence given by

$$(1 - fd_1)[R(p) + pR'(p)] - (1 - f)d_2 = 0. \tag{9}$$

We may refer p_B as the bank's *preferred asset risk choice*: it is the p the bank would like to choose if it is not concerned about a date-1 liquidity crisis. The following lemma characterizes the properties of p_B.

Lemma 2. $0 < p_B < p^{NPV} < 1$. *In addition, p_B is independent of q.*

As the bank is residual claimant in our model, it needs to pay off depositors before receiving the remaining return of the investment. Therefore, as in Jensen and Meckling (1976), the bank has stronger incentive to pursue risk than the shareholders of an all-equity firm, and p_B is lower than p^{NPV} maximizing the net present value of the bank's asset portfolio. For the same reason, p_B is independent of q: if there is a run at $t = 1$, the bank receives no profits.

In the remaining of the paper, we make the following assumption.

Assumption 2. *$p_B > p_0^{Run}$.*

Assumption 2 together with Lemma 1 allows to focus our analysis on information-based bank runs: If the bank chooses its preferred asset p_B, a bank run at $t = 1$ cannot occur if depositors receive good news $(s = h)$ about the performance of the bank's investment. This assumption simplifies the analysis without changing the main results – see Section 5 for a discussion of the case when Assumption 2 fails to hold. Moreover, the assumption appears to be reasonable: If the bank chooses p_B and $p_B < p_0^{Run}$, a bank run at $t = 1$ always occurs in the absence of news and may even occur upon good news, which implies that depositors would be very panicking. In such a case it could be difficult to convince the depositors to lend their money to the bank at $t = 0$.

To characterize the bank's risk choice p as a function of bank transparency q, it is useful to define q_N as the q that satisfies $p_B = p_l^{Run}(q)$, and q_R as the q that satisfies $\pi_R(p_B, q) = \pi_N(p_l^{Run}(q))$. The threshold q_N defines whether the bank's asset risk choice in the no-run environment is constrained by date-1 liquidity concern and the threshold q_R defines whether it is more profitable for the bank to choose its preferred asset p_B and expose it to a run upon $s = l$ or to choose a safer asset $p_l^{Run}(q) > p_B$ to avoid bank runs.

Lemma 3. *Both q_N and q_R are uniquely determined, and $0.5 < q_N < q_R < 1$.*

Moreover, $p_B > p_l^{Run}(q)$ *for* $q < q_N$*,* $p_B < p_l^{Run}(q)$ *for* $q > q_N$*,* $\pi_R(p_B, q) < \pi_N(p_l^{Run}(q))$ *for* $q \in [q_N, q_R)$*, and* $\pi_R(p_B, q) > \pi_N(p_l^{Run}(q))$ *for* $q > q_R$*.*

The thresholds q_N and q_R divide the parameter range in terms of bank transparency into three regions with different equilibrium behaviors by the bank and its depositors, as shown by the following proposition characterizing the bank's asset risk choice $p^*(q)$ and the existence of bank runs in equilibrium.

Proposition 1. *If* $q \leq q_N$ *or if* $q > q_R$*, the bank chooses its preferred asset, i.e.,* $p^*(q) = p_B$*, which is independent of the level of transparency. If* $q \in (q_N, q_R)$*, the bank chooses a safer asset than its preferred asset, i.e.,* $p^*(q) = p_l^{Run}(q) > p_B$*, and the bank's asset riskiness decreases with the level of transparency. There are no bank runs if* $q < q_R$ *or if* $s = h$*.*

Proposition 1 and the definition $p_l^{Run}(q_N) = p_B$ imply that the bank's equilibrium asset risk choice $p^*(\cdot)$ is a well-defined, non-decreasing function on $q \in [0.5, 1] \backslash \{q_R\}$ but has a downward jump at $q = q_R$. If $q \leq q_N$, the bank is opaque and bad news about its asset performance is less likely to cause excessive deposit outflows for any given risk choice. In such opaque circumstances, $p_l^{Run}(q) \leq p_B$, so the bank can choose its preferred asset risk without a threat of a liquidity crisis at $t = 1$, so the bank sets $p^*(q) = p_B$ which is independent of q.

When the bank becomes more transparent ($q > q_N$), the threat of a liquidity crisis begins to constraint the bank's risk choice. In so far q nonetheless remains below q_R, the benefits of preventing a bank run are relatively large and its costs relatively small, so the bank distorts its asset choice towards safer assets by setting $p^*(q) = p_l^{Run}(q) > p_B$ to prevent bank runs.[7] At these intermediate levels of bank

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[7] Recall from Lemma 1 that $p_l^{Run}(q)$ is, for a given q, the least safe asset which eliminates the

transparency where $q \in (q_N, q_R)$, the bank's asset riskiness is decreasing in q: when the signal becomes more reliable, an increasingly safer asset is required to prevent bank runs upon bad news.

As q increases, the farther away is $p_l^{Run}(q)$ from the bank's preferred choice p_B, and the higher is the cost of eliminating runs for the bank. Moreover, the benefit of eliminating runs for the bank is decreasing in q: the bank benefits from preventing the run triggered by bad news $s = l$ only if that news is misleading which happens with probability $p(1-q)$.[8] Ultimately, when bank transparency rises to a sufficiently high level so that $q > q_R$, it is no longer profitable to eliminate bank runs, so the bank resorts to its preferred asset $p^*(q) = p_B$ and exposes itself to a run upon $s = l$. Therefore, the equilibrium mapping $p^*(q)$ experiences a downward jump at $q = q_R$, and is independent of q for $q > q_R$. This downward jump is visible in Figure 1, which plots $p^*(q)$ in a numerical example.[9] As shown in the figure, the bank sets $p^*(q) = p_B = 0.852$ if $q \leq q_N = 0.671$ and if $q > q_R = 0.974$, and sets $p^*(q) = p_l^{Run}(q) = q/(1.24 - 0.24q)$ if $q \in (q_N, q_R)$.

Besides characterizing the bank's asset risk choice, Proposition 1 predicts that bank runs can occur only when depositors obtain sufficiently reliable ($q \geq q_R$) news that a bank's asset performance will be poor ($s = l$), but not otherwise.[10]

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bank run triggered by $s = l$. Since $\pi_N(p)$ is concave in p and maximized at p_B choosing any larger p than $p_l^{Run}(q)$ to avoid a bank run would yield smaller profits.

[8] The probabilities that the bank can receive the profit $(1 - fd_1)R(p) - (1-f)d_2$ are p and pq if the bank run triggered by the signal realization $s = l$ is eliminated and is not eliminated, respectively. Thus, eliminating the bank run increases the bank's probability of receiving positive profits by $p - pq = p(1-q)$.

[9] In the numerical examples throughout the paper we use the following values and functional forms: $f = 0.2$, $\delta = 1.02$, $d_2 = 1.04$, $r = 0.95$, $R(p) = r + 1.4(p^{NPV} - p/2)$, $y = 0.2$, $X = 3$, $Z = 0.04$, and $U_0 = 1.023$. In this example, $p^{NPV} = 0.92$.

[10] When q is exactly q_R, the bank is by the definition of q_R indifferent between choosing $p_l^{Run}(q_R)$ to prevent bank runs and choosing p_B and allowing a bank run upon $s = l$. Otherwise, the equilibrium is unique.

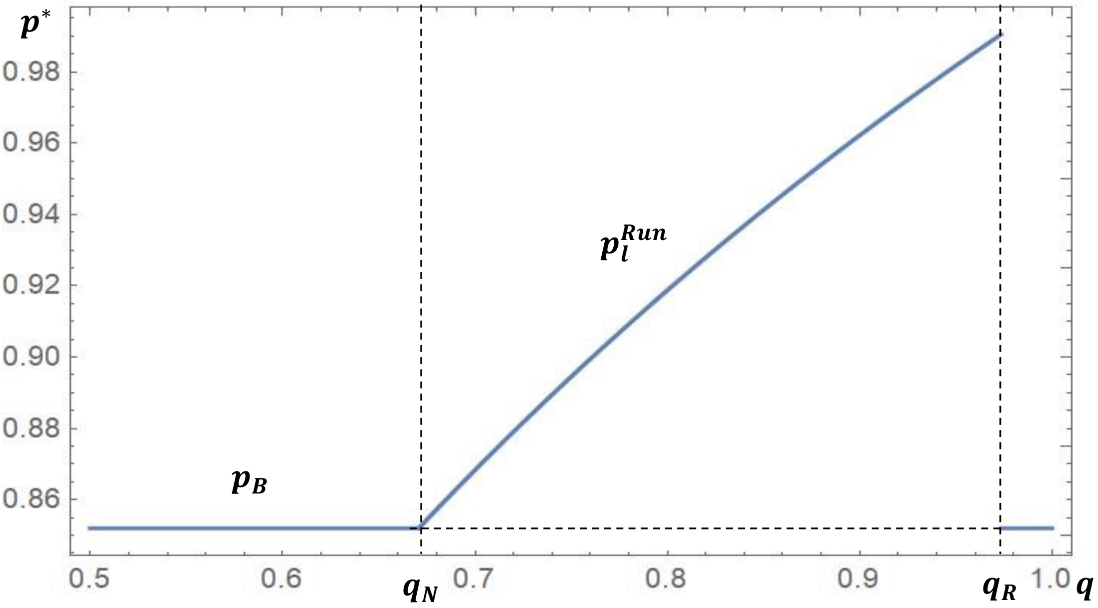

Figure 1: Bank Transparency and Asset Risk

Notes: This figure shows the relation between the optimal $p^*(q)$ for the bank (in the vertical axis) and the level of bank transparency q (in the horizontal axis) when $f = 0.2$, $\delta = 1.02$, $d_2 = 1.04$, $y = 0.2$, $r = 0.95$, and $R(p) = r + 1.4(p^{NPV} - p/2)$.

For example, "sunspots" or noisy information do not lead to bank runs in our model. The result is in line with the evidence in Correia et al. (2024) according to which bank runs arise from weak bank performance rather than vice versa.

Combining Proposition 1 with equations (7) and (8) gives the bank's expected profit in equilibrium as

$$\pi^*(q) \equiv \pi(p^*(q), q) = \begin{cases} \pi_N(p_B) & \text{if } q \leq q_N \\ \pi_N(p_l^{Run}(q)) & \text{if } q \in (q_N, q_R) \\ \pi_R(p_B, q) & \textit{if } q > q_R. \end{cases} \tag{10}$$

Using equation (10) we can characterize the bank's expected profit as a function of the level of transparency as follows:

Proposition 2. *The banks expected profit* $\pi^*(q)$ *is independent of the level of transparency if* $q \leq q_N$*, decreases with the level of transparency if* $q \in (q_N, q_R)$*, and increases with the level of transparency if* $q > q_R$*. The bank's expected profit* $\pi^*(q)$ *reaches its maximal value when* $q \leq q_N$ *or when* $q = 1$*, and its minimal value when* $q = q_R$*.*

The explanations for low and intermediate levels of transparency are familiar from the ones associated with Proposition 1: If $q \leq q_N$, the bank can choose its preferred asset risk level p_B without date-1 liquidity concerns, so its payoff $\pi_N(p_B)$ is independent of q. If $q \in (q_N, q_R)$, the bank's payoff $\pi_N(p_l^{Run}(q))$ decreases with q since, when q increases, the bank has to choose a higher p further away from the bank's preferred choice p_B to eliminate the bank run ($\pi_N(p)$ is concave and decreases with p when $p > p_B$). By contrast, in the high levels of transparency where $q > q_R$, the bank's payoff is $\pi_R(p_B, q)$ which increases with q: an increase in q does not affect the bank's risk choice p_B but reduces the probability of an inefficient bank run triggered by misleading bad news. Figure 2 plots the mapping $\pi^*(q)$ using our numerical example.

Proposition 2 also implies that the bank would like to choose some $q \leq q_N$ or $q = 1$: The bank's expected profit $\pi^*(q)$ is maximized when $q \leq q_N$ or at $q = 1$ – cf. Figure 2. In both cases the bank can choose its optimal asset risk level p_B and fails only if its asset risk taking fails: if $q \leq q_N$, there are no date-1 bank runs and if $q = 1$, only efficient bank runs occur.

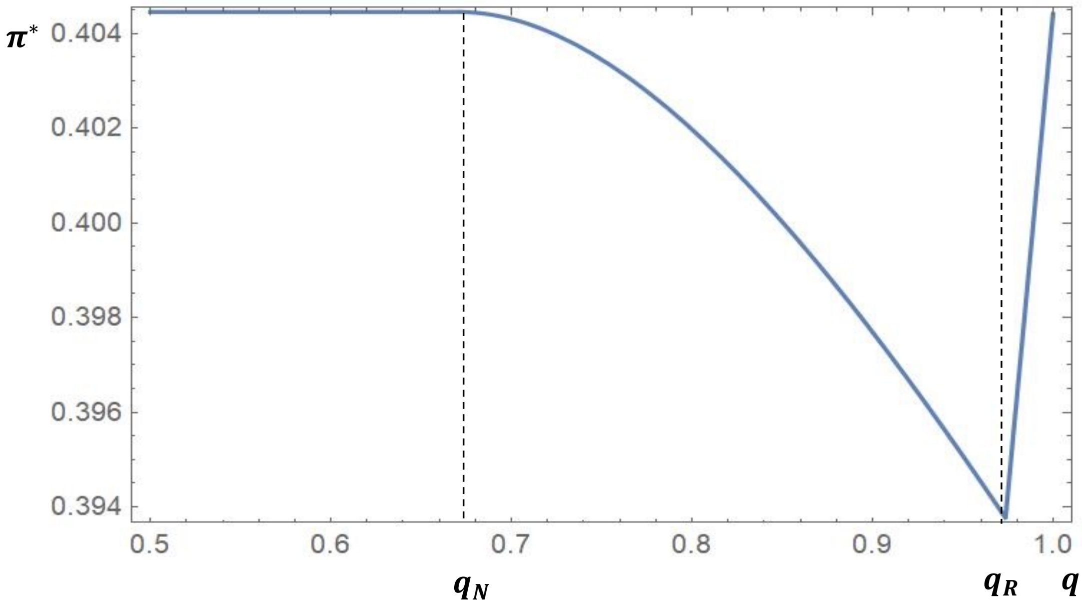

Figure 2: Bank Transparency and Bank's Expected Payoff

Notes: This figure shows the relation between the bank's expected payoff $\pi^*(q)$ (in the vertical axis) and the level of bank transparency q (in the horizontal axis) when $f = 0.2$, $\delta = 1.02$, $d_2 = 1.04$, $y = 0.2$, $r = 0.95$, and $R(p) = r + 1.4(p^{NPV} - p/2)$.

3.2 Deposit Decisions

To complete the equilibrium analysis, we study the depositors' decision whether to deposit at date 0. Let us write

$$U_N(p) = fd_1 + (1-f)\big[pd_2 + (1-p)v_F\big] \tag{11}$$

and

$$\begin{aligned} U_R(p,q) = pq\big[fd_1 + (1-f)d_2\big] + (1-p)(1-q)\big[fd_1 + (1-f)v_F\big] \\ + \big[(1-p)q + p(1-q)\big]\big[1 + (1-\frac{1}{d_1})(y - fX)\big]. \end{aligned} \tag{12}$$

as the depositors' expected payoff at $t = 0$ with no bank run and with a bank run upon $s = l$, respectively. The first and second terms on the right-hand side of equation (11) characterize the depositor's expected payoff if she turns out to be an early dier and a late dier, respectively: an early dier gets the promised payment d_1 for sure, and a late dier will get the promised repayment d_2 if the bank is solvent; otherwise, she will get a smaller payment upon bank failure (equation (4)).

The depositor's expected payoff when there is a run upon bad news is more complicated: the first and second terms on the right-hand side of equation (12) describe the depositor's expected payoff when news is good and, as a result, there is no bank run. The first term shows the payoff when good news truthfully indicates a solvent bank and the second term describes the payoff when the good news is misleading and the bank is insolvent. The last term describes the depositor's expected payoff when there is a bank run because of bad news; the signal realization $s = l$ can truthfully reflect an insolvent bank, or it can be misleading and a suggest a failure of a solvent bank.

Let $U^*(q)$ denote the depositors' expected payoff from depositing at $t = 0$. From Proposition 1, if $q \leq q_N$, $U^*(q) = U_N(p_B)$, which is independent of q. If $q \in (q_N, q_R)$, $U^*(q) = U_N(p_l^{Run}(q))$, which is increasing in q since $p_l^{Run}(\cdot)$ and $U_N(\cdot)$ are increasing. Thus, when $q \in (q_N, q_R)$, an increase in q incentivizes the bank to choose a safer asset, which reduces the bank's expected return but increases the depositors' expected payoff. If $q > q_R$, $U^*(q) = U_R(p_B, q)$, which may be either increasing or decreasing in q depending on the size of an early dier's utility loss X from low consumption in the case of a bank run. Depositors make deposits at $t = 0$ if and only if $U^*(q) \geq U_0$. This condition holds, for example, for all the feasible q our numerical example.

4 Stability and Welfare Analysis

In this section, we investigate the optimal level of bank transparency from the viewpoints of both banking sector stability and social welfare. Although the objective of a government's regulatory agency should be to maximize total welfare, the stability mandate of bank regulators may explicitly call for maximization of banking sector stability instead. Bank regulators may also implicitly care more about banking sector stability than total welfare because bank failures involve high social costs and bank regulators will be blamed when banks fail. We shall say that banking sector stability is measured by the probability that the bank does not fail.

We assume that the regulatory agency chooses the level of bank transparency q at the beginning of date 0, before the bank and depositors take actions. We interpret the regulatory agency's choice of q as the binding minimum level of transparency; the bank can choose a higher level if it wishes. Thus, we need to compare the regulator's choice of q with the bank's choice of q. We begin with the stability analysis in Section 4.1, and conduct welfare analysis in Section 4.2.

4.1 Transparency and Stability

In Section 3 we show how changes in bank transparency have impacts on banking sector stability via both sides of a bank's balance sheet: It may affect the probability that the bank fails at $t = 2$ due to unsuccessful asset risk taking and the probability that the bank fails at $t = 1$ due to a bank run. Building on Proposition 1, we obtain the following result:

Proposition 3. *Banking sector stability is independent of the level of transparency if* $q \leq q_N$*, and increases with the level of transparency if* $q \in (q_N, q_R)$ *or if* $q \in$

$(q_R, 1]$. *The banking sector is more stable when* $q \in (q_N, q_R)$ *than otherwise, and its stability is maximized at* $q = q_R$.

If $q \leq q_N$, Proposition 1 shows that the bank's optimal asset risk choice $p^*(q)$ is p_B, and there are no runs. Hence, when the banking sector is relatively opaque, its stability is measured by p_B, which independent of q. If $q \in (q_N, q_R)$, Proposition 1 suggests that $p^*(q) = p_l^{Run}(q)$, which prevents bank runs and hence acts as a measure of banking sector stability. Moreover, $p_l^{Run}(q)$ increases with q and is larger than p_B. Hence, when bank transparency is at an intermediate level, the banking sector is safer than under opaqueness, and its stability increases with q.

Once the level of bank transparency q rises above q_R, banking sector stability worsens drastically, as implied by Proposition 1: First, there is a discrete, downward jump in $p^*(q)$ from $p_l^{Run}(q_R)$ to p_B (cf. Figure 1). Second, the bank becomes exposed to a run upon the signal realization $s = l$. Thus, the bank will fail if either its liquidity or asset risk realizes, and banking sector stability can be measured by $p_B q$ at these high levels of transparency where $q > q_R$.[11] Since p_B is independent of q, $p_B q$ increases with q and reaches its maximal value p_B when $q = 1$. Thus, when the banking sector is relatively transparent to begin with, a further increase in bank transparency makes the banking sector safer since it reduces the probability of an inefficient bank run when the bank is actually solvent $(p_B(1-q))$. Then, maximal transparency leads to the maximum stability, since the bank will fail only if its asset risk realizes, which happens with probability $1 - p_B$.

To summarize, at the low levels of transparency where $q \leq q_N$, banking sector stability is measured by p_B, which equals the maximum banking sector stability

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[11] The liquidity risk is not realized when $s = h$, which happens with probability $pq+(1-p)(1-q)$. Given $s = h$, the asset risk is not realized with probability p_h as defined by equation (3). Multiplying p_h by $pq + (1-p)(1-q)$ gives pq.

that can be achieved at the high levels of transparency where $q > q_R$. In contrast, at the intermediate levels of transparency where $q \in (q_N, q_R)$, banking sector stability is $p_l^{Run}(q) > p_B$ where $p_l^{Run}(q)$ increases with q. Thus, the maximum stability is obtained when the level of bank transparency is q_R. However, choosing the exact stability-maximizing level of transparency is problematic because there is a downward jump in stability if the level of transparency is even marginally above the stability-maximizing level.[12]

Comparing Propositions 2 and 3 also suggests a need for transparency regulation: The bank's interests are in conflict with the regulatory agency's stability mandate since the bank would like to choose a low level of bank transparency where $q \leq q_N$ or the maximum level of $q = 1$ rather than an intermediate level $q \in (q_N, q_R)$ more conducive for stability, and its expected profit decreases with q at those intermediate levels of transparency where stability increases with q.

In practice, being perfectly transparent ($q = 1$) is hardly feasible nor desirable for a bank. The bank will prefer relative opaqueness where $q \leq q_N$, if the bank's maximum feasible transparency level in practice is even marginally below the perfect level of $q = 1$ or if the bank encounters even an infinitely small cost from increasing q from a low level below q_N to the perfect level of $q = 1$ (for banks' compliance costs of transparency regulation, see Hyytinen and Takalo, 2002). Moreover, if choosing $q = 1$ were both feasible and desirable for a bank, transparency regulation as a binding minimum level of transparency would be moot as the regulatory agency could never improve outcomes from the bank's choice. We therefore assume in what follows that the bank either does not want or cannot be

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[12] Stability is maximized at $q = q_R$ assuming that the bank chooses $p^*(q_R) = p_l^{Run}(q_R)$. However, since $p^*(q_R) = p_B$ *minimizing* stability is also an equilibrium, a stability maximizing regulatory agency may alternatively choose q below but arbitrarily close to q_R.

perfectly transparent, which implies that the bank prefers the relative opaqueness of $q \leq q_N$. Facing the challenges of implementing the exact stability-maximizing level, it might thus be practical for the regulatory agency concerned with stability to choose an intermediate level of transparency where $q \in (q_N, q_R)$ which will not put the bank at risk of excessive deposit outflows but is more stringent that the level of transparency preferred by the bank.

The stability maximizing level of transparency characterized by Proposition 3 approximates the welfare-maximizing level if there are very large external costs of bank failures (as will be formalized in Corollary 1 of the next subsection). With more moderate social costs of bank failures, the stability maximizing level of transparency is, however, not necessarily the same as the level of transparency which maximizes social welfare. We therefore characterize the welfare-maximizing level of transparency next.

4.2 Transparency and Welfare

If no bank run will occur at date 1, social welfare is given by

$$W_N(p, Z) = fd_1 + (1 - fd_1)[pR(p) + (1 - p)r] - (1 - p)Z. \tag{13}$$

In this case, only early diers withdraw at $t = 1$ (the first term in the right-hand side of equation (13)), and the dead-weight loss of bank failure Z will arise only if the bank's asset risk realizes (the third term). The second term captures the expected date-2 payoff from the bank's assets.

If a bank run occurs at $t = 1$ upon the signal realization $s = l$, social welfare is

$$\begin{aligned} W_R(p, q, Z) = pq[fd_1 + (1 - fd_1)R(p)] + (1 - p)(1 - q)[fd_1 + (1 - fd_1)r - Z] \\ + [p(1 - q) + (1 - p)q][1 - (1 - \frac{1}{d_1})fX - Z] \end{aligned} \quad (14)$$

where the three terms on the right-hand side capture the welfare effects, respectively, if the bank does not fail, if it fails due to the realization of its asset risk at $t = 2$, and if it fails due to the realization of its liquidity risk at $t = 1$.

From Proposition 1, in equilibrium we have

$$W(q, Z) \equiv W(p^*(q), q, Z) = \begin{cases} W_N(p_B, Z) & \text{if } q \leq q_N, \\ W_N(p_l^{Run}(q), Z) & \text{if } q \in (q_N, q_R), \\ W_R(p_B, q, Z) & \text{if } q > q_R. \end{cases} \quad (15)$$

Thus, at the low levels of transparency where $q \leq q_N$, the social welfare $W(q, Z) = W_N(p_B, Z)$ is independent of q.

At the intermediate levels of transparency ($q \in (q_N, q_R)$) where the bank in equilibrium chooses $p_l^{Run}(q)$, the behavior of the social welfare function $W(\cdot, Z) = W_N(p_l^{Run}(\cdot), Z)$ is more complicated. Define $q_N^W(Z) \equiv \arg\max_{q \in [0.5,1]} W_N(p_l^{Run}(q), Z)$, i.e., $q_N^W(Z)$ is the level of transparency which maximizes welfare when the bank chooses the asset risk level $p_l^{Run}(q)$ to prevent excessive deposit outflows at $t = 1$. We can establish the following result:

Lemma 4. *$q_N^W(Z) \in (q_N, 1]$ and it increases with Z. For sufficiently high levels of Z, $q_N^W(Z) > q_R$.*

Lemma 4 implies that at the intermediate levels of transparency where $q \in$

(q_N, q_R), the welfare-maximizing level of transparency is either interior or, if the dead-weight loss Z is sufficiently high, social welfare $W_N(p_l^{Run}(\cdot), Z)$ is increasing on the whole range $q \in (q_N, q_R)$. The optimal level of transparency $q_N^W(Z)$ increases with Z since $p_l^{Run}(q)$ increases with q (Lemma 1) and, from the welfare point of view, an increase in p reduces the probability that the dead-weight loss Z will be incurred. Since $q_N^W(Z)$ increases with Z whereas q_R is independent of Z, for sufficiently high levels of Z, $q_N^W(Z) > q_R$

In the high levels of transparency where $q > q_R$, equation (15) implies that $W(q, Z) = W_R(p_B, q, Z)$, so from equation (14) we get after some algebra that

$$\frac{\partial W_R}{\partial q} = (1 - fd_1)[p_B(R(p_B) - 1) + (1 - p_B)(1 - r)] \\ + (2p_B - 1)(1 - \frac{1}{d_1})fX + p_B Z. \quad (16)$$

From equation (16), sufficient conditions for $\partial W_R/\partial q > 0$ include (i) a sufficiently large Z, (ii) $p_B > 0.5$, i.e., the bank is more likely to be solvent than insolvent, and (iii) $(1 - 1/d_1)fX < (1 - fd_1)(1 - r)$, i.e., a bank run improves welfare if the bank is insolvent.[13] Because of these sufficient conditions for $\partial W_R/\partial q > 0$ when $q > q_R$ appear reasonable, we make the following assumption:

Assumption 3. $\frac{\partial W_R}{\partial q} > 0$.

Using the above insights we can characterize the behavior of the social welfare

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[13] We may also rewrite the right-hand side of equation (16) as

$$p_B\Big[(1 - fd_1)(R(p_B) - 1) + (1 - \frac{1}{d_1})fX + Z\Big] + (1 - p_B)\Big[(1 - fd_1)(1 - r) - (1 - \frac{1}{d_1})fX\Big].$$

The term in the first square-brackets is positive. In the latter square-brackets, $(1 - 1/d_1)fX$ is the expected utility loss suffered by early diers in a bank run and $(1 - fd_1)(1 - r)$ is the gain from liquidating the assets of an insolvent bank at date 1.

function $W(\cdot, Z)$.

Proposition 4. *The social welfare $W(q, Z)$ is independent of the level of transparency if $q \leq q_N$, increases with the level of transparency if $q \in (q_N, \min\{q_N^W(Z), q_R\})$ or if $q > q_R$, and decreases with the level of transparency if $q \in (\min\{q_N^W(Z), q_R\}, q_R]$.*

Proposition 4 has two policy implications. First, transparency regulation can be welfare improving: If the bank were unregulated, it would choose some level of transparency $q \leq q_N$ (Proposition 2). Since $W(q, Z)$ is continuous at $q = q_N$, Proposition 4 suggests that welfare can for sure be improved by increasing q to some level $q \in (q_N, \min\{q_N^W(Z), q_R\})$. In our model, enhanced transparency can improve welfare because it both makes bank runs more efficient mechanism to liquidate insolvent banks ex post and increases the threat of a bank run, which steers the bank towards safer assets to avoid the run ex ante. Therefore, our results hold even if a bank run reduces social welfare.

Second, Proposition 4 also suggests that "too much" transparency may also reduce welfare. For example, the social welfare function $W(\cdot, Z)$ experiences a downward jump at $q = q_R$, since the bank becomes vulnerable to runs and changes its asset choice from $p_l^{Run}(q_R)$ to riskier p_B (Proposition 1). Another case of too much transparency occurs if $q_N^W(Z) < q < q_R$. In that case, to prevent late diers from withdrawing early, the bank becomes too conservative from the welfare point of view, and a decrease in q will increase welfare by allowing the bank to take more risk. Although excessive risk taking by banks is always a concern for bank regulation, to foster economic growth and serve as value-creating financial intermediaries, banks have to take risk. There are situations where banks seem to be too conservative. For example, banks are often criticized as being reluctant to extend loans to new, innovative firms (see, e.g., Hall and Lerner, 2010, for a survey), which may slow down productivity growth, or even to more established firms during economic downturns, which may worsen the recessions (a classic reference is Bernanke et al., 1996; for more recent evidence, see, e.g., Blattner et al., 2023 and Maneresi and Pierri, 2024). In such circumstances, the stability-maximizing level of bank transparency q_R is not optimal, and a lower level of transparency is required to encourage the bank to take appropriate risk.

Figure 3 illustrates Proposition 4 by displaying the relationship between social welfare and q using our numerical example with $Z = 0.04$. As shown in the figure, social welfare is first independent of the level of transparency when $q \leq q_N = 0.671$. If the bank could choose, it would like the level of transparency be in this region. When q increases from q_N to $q_N^W(0.04) = 0.885$, social welfare increases, and then decreases when q increases further to $q_R = 0.974$. There is a drastic downward jump in welfare at $q = q_R$, after which welfare again increases with q.

Building on Proposition 4 we can shed light on the welfare-maximizing transparency policy for all feasible q. In the region $q \in [0.5, q_R)$ where $W(q, Z)$ is continuous and bank runs are absent, Proposition 4 suggests that the regulatory agency should choose the intermediate level of bank transparency of $q = \min\{q_N^W(Z), q_R\} > q_N$, which is more stringent than the one preferred by the bank – cf. Figure 3. Intuitively, if the bank is not exposed to runs, it is optimal to choose either q_R which induces the bank to choose the safest possible asset that can be obtained via transparency regulation, or a somewhat lower level of transparency $q_N^W(Z)$ to encourage the bank to take more risk.

In the region $q > q_R$ where bank runs are possible, Proposition 4 implies that

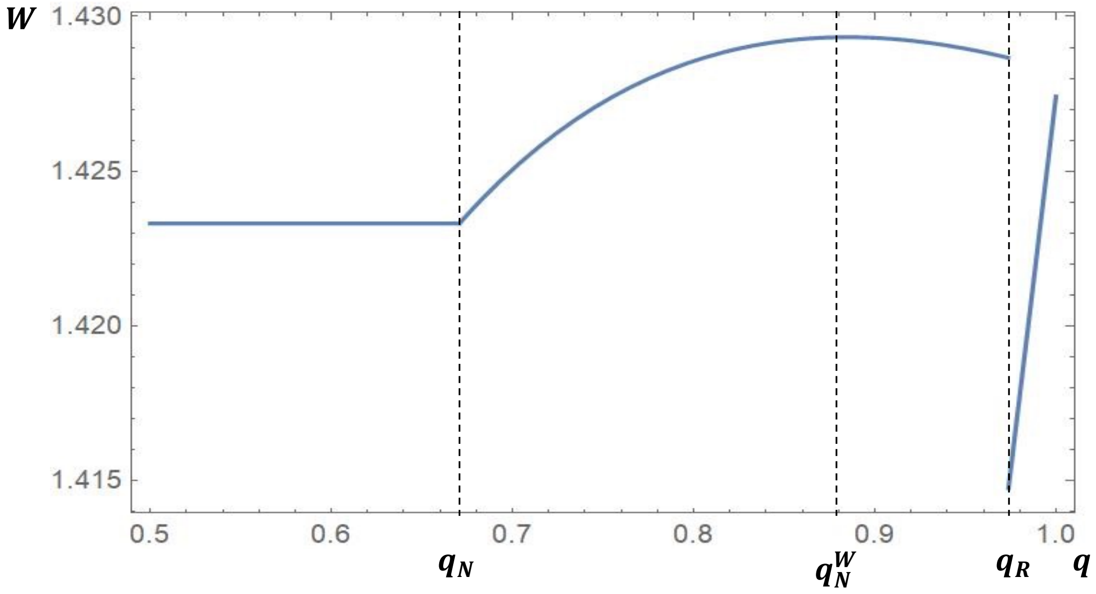

Figure 3: Bank Transparency and Welfare

Notes: This figure shows the relation between social welfare $W(q)$ (in the vertical axis) and the level of bank transparency q (in the horizontal axis) when $f = 0.2$, $\delta = 1.02$, $d_2 = 1.04$, $y = 0.2$, $r = 0.95$, $R(p) = r + 1.4(p^{NPV} - p/2)$, $X = 3$, and $Z = 0.04$

implementing the perfect transparency of $q = 1$ maximizes welfare for all Z – cf. Figure 3 where welfare increases with q when $q > q_R$. Intuitively, if the bank is exposed to runs, it is optimal to eliminate inefficient runs arising from misleading bad news.

Therefore, to characterize the socially optimal bank transparency, we need to compare whether the perfect transparency of $q = 1$ or the intermediate level of transparency of $q = \min\{q_N^W(Z), q_R\}$ yields higher welfare. The following result elucidates why it may not be socially optimal to implement the perfect bank transparency of $q = 1$ even if it were feasible.

Corollary 1. *The higher is the dead-weight loss Z of a bank failure, or the early* *diers' utility loss X from a low consumption in a bank run, the more likely that welfare is maximized at the intermediate level of transparency of $q = \min\{q_N^W(Z), q_R\}$ rather than at the perfect level of $q = 1$. For sufficiently high levels of Z, the welfare-maximizing level of q equals the stability-maximizing level q_R.*

Corollary 1 suggests that the social costs of bank failures – the early diers' utility loss X and the dead-weight loss Z – tend to make the intermediate level of bank transparency preferable to the perfect level. The utility loss X is only incurred in the case of a bank run. Because no bank run occurs when $q = \min\{q_N^W(Z), q_R\}$, and a bank run will be triggered by $s = l$ when $q = 1$, social welfare is likely to be higher when $q = \min\{q_N^W(Z), q_R\}$ than when $q = 1$ – cf. the welfare functions of equations (13) and (14).

The dead-weight loss Z is incurred upon both a bank run and an asset-risk taking failure. Thus, the probabilities that Z is incurred with $q = 1$ and with $q = \min\{q_N^W(Z), q_R\}$ are $1 - p_B$ and $1 - p_l^{Run}\big(\min\{q_N^W(Z), q_R\}\big)$, respectively. Because $p_B < p_l^{Run}\big(\min\{q_N^W(Z), q_R\}\big)$, the dead-weight loss Z is incurred more likely when $q = 1$ than when $q = \min\{q_N^W(Z), q_R\}$. Moreover, both $p_l^{Run}(\cdot)$ and $q_N^W(\cdot)$ are increasing and, for sufficiently high levels of Z, $q_N^W(Z) > q_R$ (Lemmas 1 and 4). Therefore, the higher Z, the more likely that the intermediate level of transparency of $q = \min\{q_N^W(Z), q_R\}$ maximizes welfare and, for sufficiently high levels of Z, the welfare is maximized at the stability-maximizing level of q_R. Intuitively, stability maximization approximates welfare maximization if the dead-weight loss of bank failure is sufficiently large.

Lemma 2 suggests another reason making the intermediate level of bank transparency desirable from the welfare point of view: the bank takes too much risk even without a concern for social costs of bank failures. In the Appendix we establish the following condition for the optimality of the intermediate bank transparency for all $Z \geq 0$:

$$(1 - fd_1)\big(V(p^{NPV}) - V(p_B)\big) > (1 - p_B)\big[(1 - fd_1)(1 - r) - \big(1 - \frac{1}{d_1}\big)fX\big] \quad (17)$$

The left-hand side of the condition (17) gives the difference in the net present value of the bank's assets in the absence of a bank run when $q = q_N^W(0)$ and $q = 1$: In the Appendix we show that when $Z = 0$, the intermediate level of transparency of $q = q_N^W(0)$ results in the asset risk choice p^{NPV} which maximizes $V(p)$, the net present value of the bank's assets. In contrast, the perfect transparency of $q = 1$ results in the bank's preferred asset risk choice p_B and, therefore, $V(p^{NPV}) > V(p_B)$.[14]

The right-hand side of the condition (17) displays the efficiency gain of liquidating an insolvent bank at $t = 1$ via a bank run rather than allowing it to fail at $t = 2$, i.e., the condition (iii) for Assumption 3. If the value r of the bank's assets in an insolvency or if the early diers' loss X in a bank run is sufficiently large, the date-2 insolvency is preferable to the date-1 run and the condition (17) unambiguously holds.

Going beyond our model, striving for perfect transparency is likely in practice associated with very large costs of information gathering and disclosure for the regulatory agency or the bank (see, e.g., Hyytinen and Takalo, 2002; Wei and Zhou, 2021; Moreno and Takalo, 2023). It can be prohibitively costly to obtain

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[14] The condition (17) holds for $q_N^W(0) < q_R$. When $q_N^W(0) > q_R$ the value-maximizing asset risk choice p^{NPV} cannot be implemented via transparency regulation – the highest possible asset value is reached at $q = q_R$ with $p_B < p_l^{Run}(q_R) < p^{NPV}$, i.e., the left-hand side of the condition (17) should be expressed as $(1 - fd_1)\big(V(p_l^{Run}(q_R)) - V(p_B)\big)$, which is also positive – see the Appendix.

perfect transparency as to a bank's asset returns, which are affected by its borrowers' actions, its various high-frequency transactions, security trading, exposures to counterparty risks, and so on.[15] The existence of such regulatory and compliance costs should also render the intermediate level of bank transparency preferable to perfect transparency.

We can thus conclude that setting $q^*(Z) = q_R$ maximizes the banking sector stability and, if $q_R < q_N^W(Z)$ due to large dead-weight losses of bank failures, welfare as well. If the dead-weight losses of bank failures are more moderate so that $q_R \geq q_N^W(Z)$, setting $q^*(Z) = q_N^W(Z)$ maximizes welfare. In our numerical example, the dead-weight loss is modest, and welfare is maximized at $q_N^* = q_N^W(Z) = 0.885 < q_R = 0.974 < 1$ – see Figure 3. More loosely, it may be desirable to choose an intermediate level of transparency ($q \in (q_N, q_R)$), which forces the bank to be more transparent than it would prefer but which maintains sufficient opaqueness to eliminate excessive deposit outflows which may fail a solvent bank.

5 Extensions

This section discusses possible extensions of the model. Section 5.1 studies how macroeconomic conditions and deposit insurance coverage affects the optimal bank transparency. Section 5.2 investigates the consequences of relaxing Assumption 2. In Section 5.3, we discuss the assumptions related to the observability of the

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[15] Stress tests disclosures provide an example of limitations in obtaining perfect transparency: In a couple of months after passing the initial 2010 European stress tests, Allied Irish and Bank of Ireland were on the verge of bankruptcy, as were Bankia and Dexia after passing the 2011 stress tests. In June 2017, the collapse of Banco Popular in Spain, after passing its 2016 stress test, led the *New Your Times* (June 13, 2017)) to note: "... there is much for investors to learn ... Lesson No. 1: Don't trust bank stress-test results". The Federal Reserve's stress tests of 2022 and 2023 did not even consider a scenario of sharply increasing interest rates such as that of early 2023 that led to the failure of several midsize banks.

bank's asset risk choice by depositors and the pricing of deposits, and elaborate the relation of our equilibrium concept to the one used in the global game literature.

5.1 Transparency, Deposit Insurance, and Business Cycles

It has been frequently pointed out that banking crises are not random events but related to the interaction of business cycle with depositors' information (see, e.g., Allen and Gale, 1998; Dang et al., 2020). Our result concerning the prevalence of bank runs (Proposition 1) may also be interpreted as supporting this view. But how should bank regulators adjust banks' disclosure requirements when changing economic conditions also change banks' vulnerability to both asset and liquidity risks?

To examine the relationship between the optimal bank transparency level and business cycle, we make the following modifications of the model: Assume that for each dollar of the bank's investment, the date-2 return is αR when it succeeds and is αr when it fails, and the dead-weight loss of a bank failure is αZ, where $\alpha \in (0, 1/r)$. All the remaining assumptions are kept unchanged. Under this setting, α is a scaling variable, and can be interpreted as the degree of prosperity of the economy. The higher the α, the stronger is the economy.[16] The modified model setting allows us to study the relation between the socially optimal bank transparency and business cycle stages. Simultaneously, we can study how deposit insurance coverage y affects the optimal bank transparency level. As shown in the following proposition, banks should be less transparent when the economy is worse

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[16] That the dead-weight loss Z is proportional to α is debatable but assumed for simplicity. We may consider the dead-weight loss to be lower in recessions, since governments often prefer banks not to cut loans to borrowers in recessions, and holding more loans in recessions means banks have higher asset risk. On the other hand, if a failure of one bank leads to contagion more easily in recessions than in booms, then the dead-weight loss may be higher in recessions.

off or deposit insurance coverage is smaller.

Proposition 5. *The socially optimal level of bank transparency* $q^*(\alpha, y) = \min\{q_N^W(\alpha, y), q_R(\alpha, y)\}$ *increases with* α *and* y.

To explain Proposition 5, note first that under this modified setting, equation (4) should be rewritten as

$$v_F(\alpha, y) \equiv \frac{1 - fd_1)\alpha r}{1 - f} + \left[1 - \frac{(1 - fd_1)\alpha r}{(1 - f)d_2}\right] y. \tag{18}$$

Since $v_F(\alpha, y)$ increases with both α and y, equation (5) implies that $p_l^{Run}(q, \alpha, y)$ decreases with both α and y. Intuitively, when economic conditions or deposit insurance coverage are better, late diers are more willing to rollover, and the bank can take more asset risk without a concern for a bank run when $s = l$. To counteract this increased risk appetite, the regulatory agency should increase the level of transparency to steer the bank's risk taking towards safer assets: the regulatory agency should choose q to keep the level of $p_l^{Run}(q, \alpha, y)$ constant at the desired level when α or y changes.

One implication of Proposition 5 is that bank regulators should relax disclosure requirements for banks in economic crises, reinforcing the message of Proposition 4. Intuitively, in economic crises, depositors are more eager to respond to pessimistic information about banks, so bank regulators should reduce the precision of bank information to lower depositors' incentive to start a bank run. For example, according to Anderson and Copeland (2023), the New York state bank regulator suspended the rendering and publication of call reports for state-charter banks during the Great Depression due to the concern for bank runs.

Proposition 5 also suggests the complementarity between bank transparency and deposit insurance coverage. Deposit insurance has the familiar effects in our model: it makes deposits stickier which encourages the bank to take more risk. To offset this moral hazard, the banking regulators should increase the level of transparency and make depositors more sensitive to news about weak bank performance.

5.2 Panicky Depositors: When Assumption 2 Does Not Hold

Assumption 2 stipulates that $p_B > p_0^{Run}$. Let us analyze the relation between the bank's choice of p and the transparency level q when this assumption is violated. In this case, depositors panic easily and withdraw unless they obtain sufficiently reliable good news about the bank's performance. The results for this case are shown in the following proposition.

Proposition 6. *Suppose that $p_B < p_0^{Run}$, and that depositors deposit at date 0. In this case, there is a unique $q'_R \in (0.5, 1)$ such that the bank sets $p^*(q) = p_l^{Run}(q)$ if $q < q'_R$, and sets $p^*(q) = \max\{p_B, p_h^{Run}(q)\}$ if $q > q'_R$. There are no bank runs if $q < q'_R$ or if $s = h$.*

Proposition 6 suggests that the bank's asset risk choice is similar irrespectively of whether Assumption 2 holds or not. If the level of transparency is not too high (that is, $q < q'_R$), the bank chooses p to eliminate bank runs. If q is sufficiently high, eliminating the bank runs is too costly for the bank, so it allows a bank run to occur when $s = l$. Since the bank's behavior does not change much when Assumption 2 is relaxed, our main results should be qualitatively similar if Assumption 2 is relaxed.

When Assumption 2 fails to hold, however, $p^*(q)$ must be no lower than $p_h^{Run}(q)$: if $p < p_h^{Run}(q)$, a bank run would always occur at date 1 and depositors would not lend their money to the bank at date 0. If the bank chooses $p_B < p_0^{Run}$, late diers roll over at date 1 only if the signal is h and sufficiently precise (so that $p_h^{Run}(q) < p_B$). Thus, if $p_B < p_0^{Run}$, a sufficiently high level of transparency is a necessary condition to make banking feasible. Yet, when $p_B < p_0^{Run}$, it may still be difficult to satisfy the depositors' participation constraint.

5.3 Other Assumptions

In this subsection, we discuss three further features of the model: the observability of bank's choice of asset risk p by depositors, exogeneity of deposit pricing, and our equilibrium selection criterion. First, from, e.g., Freixas and Rochet (2008) and Vives (2016), who discuss both the observable and unobservable asset risk cases, we can infer that the observability of the bank's choice of p by depositors may be critical to some of our results. If, alternatively, we assume that p is unobservable to depositors, depositors need to have a conjecture on the p chosen by the bank, which extends the set of possible (Nash) equilibria. However, using our perfect Bayesian Pareto dominance criterion we may restrict depositors' conjectures. Since choosing p_B maximizes both $\pi_N(p)$ and $\pi_R(p, q) = q\pi_N(p)$, the depositors' only reasonable conjecture of p satisfying the perfect Bayesian Pareto dominance criterion is p_B. Therefore, when p is unobservable, the only possible equilibrium for any feasible q is that the bank sets $p = p_B$ if depositors make deposits at date 0.

In this case, bank transparency would have no impact on the riskiness of bank assets and the region $q \in (q_N, q_R]$ where $p^*(q) = p_l^{Run}(q)$ would vanish. As a result, there would be runs upon $s = l$ if $q \geq q_N$ and a stability-maximizing regulator should set q to any level less or equal to q_N. Under Assumption 3, welfare maximization would amount to comparing $W_R(p_B, 1, Z)$ to $W_N(p_B, Z)$. From equations (13) and (14), we then obtain that the sign of $W_R(p_B, 1, Z) - W_N(p_B, Z)$ is given by the sign of $(1 - fd_1)(1 - r) - (1 - 1/d_1)fX$. Thus, if the sufficient condition (iii) for Assumption 3 holds, setting $q = 1$ maximizes welfare in this case. Otherwise, choosing some $q \leq q_N$ would be welfare-maximizing, too. Intuitively, if the bank transparency affects only the bank's liquidity risk, welfare effects of bank transparency depend on the efficiency of bank runs: When $(1 - 1/d_1)fX < (1 - fd_1)(1 - r)$, a bank run improves welfare if the bank is insolvent, and setting $q = 1$ makes sure that there are runs only if the bank is insolvent. In contrast, if early diers' utility loss X in the case of a bank run is so large that insolvency is preferable to runs, it is optimal to make the banking system opaque ($q \leq q_N$) to avoid runs.

Whether or not p is observable may be case specific. In the case of bank failures of 2023, for example, it is quite clear that the asset risk level of Silicon Valley Bank was observable to those who wanted to look. However, probably very few people outside of Credit Suisse knew what had been hidden in its balance sheets and derivatives. As Lowenstein (2000) discussion of the demise of Long-Term Capital Management, a prominent hedge fund, concludes: "If the long-term episode proved anything, it is that...investors have a pretty good idea of balance-sheet risks [of financial intermediaries]; they are completely befuddled with regard to derivative risks" (Lowenstein, 2000, p. 231).

Another debatable simplifying assumption, while also used in the literature, is that the deposit interest rates are exogenously given. To see how our results may change when the pricing of deposits becomes endogenously determined, suppose that the deposit interest rates are determined by the bank. To provide liquidity, d_1 must be no lower than δ. On the other hand, the bank has no incentive to set d_1 higher than δ because doing so would increase both its interest expenses and the depositors' incentive to start a bank run. Therefore, the optimal d_1 for the bank is indeed δ.

The bank encounters tradeoffs when it determines d_2. An increase in d_2 has several effects on the bank. First, an increase in d_2 raises the bank's interest expenses and thus reduces its payoff. Second, the increased debt burden induces the bank to take more risk, thus $p_B(d_2)$ decreases with d_2. Third, by raising the late diers' payoff to rolling over, an increase in d_2 reduces $p_l^{Run}(q)$.[17] As a result, bank transparency regulation would have complex effects on the bank's asset risk taking if it also affects d_2. Thus, some of our results may change if the deposit interest rates are endogenously determined, especially if deposit interest rates could be contingent on bank transparency and the realization of the signal S. However, we see seldom such contingent deposit contracts in practice. We can also interpret our analysis as a study of bank creditors' rollover decisions when interest rate payments to withdrawing and rolling over are predetermined.

Finally, we discuss the relation of our equilibrium concept with the one used in the global game literature. Let us assume there is no public information ($q = 0.5$) for brevity. In such global-game settings p would be a random variable with realizations from which depositors would obtain private signals – see, e.g., Rochet and

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[17] From equations (5) and (6), an increase in d_2 has two effects on $p_l^{Run}(q, d_2, v_F(d_2))$. First, $\partial p_l^{Run}/\partial d_2 < 0$. Second, $(\partial p_l^{Run}/\partial v_F)(\partial v_F/\partial d_2) < 0$. Therefore, $p_L^{Run}(q, d_2, v_F(d_2)))$ decreases with d_2. As to $p_B(d_2)$, it decreases with d_2, since $R(p) + pR'(p)$ in equation (9) is decreasing by Assumption 1.

Vives (2004), Goldstein and Pauzner (2005), Bouvard et al. (2015), Iachan and Nenov (2015), and Moreno and Takalo (2016). In the absence of public information, the threshold p_0^{Run} defined in Lemma 1 would correspond to the threshold of a lower dominance region of those settings. Finding another threshold for an upper dominance region, say $p_1^{Run} \in (p_0^{Run}, 1)$, and using iterated elimination of strictly dominated strategies, we could pin down a threshold level $\bar{p} \in (p_0^{Run}, p_1^{Run})$ such that late diers would rollover if their private signals were above $\bar{p}$ and withdraw otherwise. In our setting, late diers coordinate to rollover immediately if they observe a p above p_0^{Run} and withdraw otherwise. Thus, in the case of an exogenous p, in our setting the threshold level for withdrawing and rolling over is somewhat lower than in a global game setting, and either all or a fraction f of depositors withdraw, whereas in a global game setting, a fraction of depositors whose signal is above the threshold rollover and the rest withdraw.

6 Conclusions

We study optimal bank transparency regulation when it affects both sides of a bank's balance sheet. We show how, on the one hand, an opaque banking system is not vulnerable to a liquidity crisis arising from excessive deposit outflows. As a result, banks prefer opaqueness which allows them to choose risky assets with a less concern for liquidity shortfalls. On the other hand, a more transparent banking system allows banks' creditors to better separate weak and strong banks, and may lead to bank runs if news about a bank are bad. Through increasing this threat of bank runs, enhanced bank transparency can induce banks to lower asset risk to prevent such runs. Optimal bank transparency regulation must balance these tradeoffs: An optimally set bank transparency is at an intermediate level, which is larger than the level preferred by banks but lower than the level which would prompt excessive deposit outflows in the case of bad news.

Since banks can take too much or too little risk from the welfare point of view, one policy implication of the paper is that bank disclosure requirements should be stricter during booms when banks may take too much risk but bank creditors may pay less attention to news, and should be looser during recessions when banks are likely to be too conservative and their creditors are more sensitive to bad news. We also find that bank transparency complements deposit insurance: Broader deposit insurance coverage makes deposits stickier, which encourages the bank to take more risk. To combat this moral hazard, the bank should be forced to disclose more information to depositors.

In a desire to study the interaction of bank transparency, banks' asset and liquidity risks, we have abstracted from a number of important considerations that should be addressed in future research. First, our assumption of an exogenous deposit pricing is awkward. According to the literature, bank transparency can provide market discipline as it forces riskier banks to pay more for their funding. Nonetheless, even in the presence of exogenous deposit pricing, we find a similar market discipline effect operating via the threat of a liquidity crisis.

Second, we do not consider bank capital regulation. The model can be extended to analyze the optimal combination of bank capital and transparency regulation as in Orlov et al. (2023). We expect that capital and transparency regulation are complementary policy tools, like deposit insurance and transparency regulation in our setting. In such a case, the government should require banks to be more transparent when they are better capitalized. We also assume that the bank chooses its asset risk level. Alternatively, we can modify the model so that the bank chooses the proportion of risky loans in its assets. The more risky loans it holds, the higher is its asset risk. The policy implication that too much transparency may be especially harmful during recessions will become more reasonable under this setting. More generally, a future work could model more rigorously the way the banking regulation is affected by business cycles.

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Appendix

Proof of Lemma 1

Setting $q = 0.5$ and $q = 1$ in equations (5) and (6) implies $p_l^{Run}(0.5) = p_h^{Run}(0.5) = (d_1 - v_F)/(d_2 - v_F)$, $p_l^{Run}(1) = 1$, and $p_h^{Run}(1) = 0$. A straightforward differentiation of $p_l^{Run}(q)$ and $p_h^{Run}(q)$ in equations (5) and (6) shows that $\partial p_l^{Run}/\partial q > 0$ and $\partial p_h^{Run}/\partial q < 0$. These results imply that $p_l^{Run}(q) \geq p_h^{Run}(q)$ with the inequality being strict for $q \in (0.5, 1]$. The claims concerning the occurrence of bank runs in part (b) then follow from the definitions of $p_l^{Run}(q)$ and $p_h^{Run}(q)$. ■

Proof of Lemma 2

As implied by equation (2) and Assumption 1, $p^{NPV} \in (0, 1)$ and satisfies $R(p) + pR'(p) = r$, whereas equation (9) implies that p_B satisfies $R(p) + pR'(p) = ((1 - f)d_2)/(1 - fd_1)$. Assumption 1 implies that $((1 - f)d_2)/(1 - fd_1) > 1 > r$ and that $R(p) + pR'(p)$ decreases with p. As a result, $p_B < p^{NPV}$. Moreover, $p_B > 0$: because $R'(p)$ is bounded by Assumption 1, at $p = 0$, $R(p) + pR'(p)$ equals $R(0) = \bar{R} > ((1 - f)d_2)/(1 - fd_1)$, where the inequality follows from Assumption 1. Finally, since equation (9) contains no q, p_B is independent of q. ■

Proof of Lemma 3

Given that (i) $\partial p_l^{Run}/\partial q > 0$ (Lemma 1), (ii) $p_l^{Run}(0.5) = p_0^{Run}$ and $p_l^{Run}(1) = 1$ (Lemma 1), (iii) $p_0^{Run} < p_B < p^{NPV} < 1$ (Assumption 2 and Lemma 2), and (iv) p_B is independent of q (Lemma 2), there is a unique $q_N \in (0.5, 1)$ such that

$p_l^{Run}(q_N) = p_B$. Moreover, $p_l^{Run}(q) < p_B$ for $q \in [0.5, q_N)$ and $p_l^{Run}(q) > p_B$ for $q \in (q_N, 1]$.

We next show that there is a unique $q_R \in (q_N, 1)$ such that $\pi_R(p_B, q_R) = \pi_N(p_l^{Run}(q_R))$. Since $\pi_R(p_B, q) = q\pi_N(p_B)$ (equation (8)) and since p_B is independent of q (Lemma 2), $\pi_R(p_B, \cdot)$ is increasing. From the facts that (i) $\partial p_l^{Run}/\partial q > 0$, (ii) $\pi_N(\cdot)$ is concave and is maximized at p_B, and (iii) $p_l^{Run}(q_N) = p_B$, we know that $\pi_N(p_l^{Run}(q))$ increases with q on $[0.5, q_N)$ and decreases with q on $(q_N, 1]$. Also, since $q_N < 1$, $\pi_R(p_B, q_N) = q_N\pi_N(p_B) < \pi_N(p_B) = \pi_N(p_l^{Run}(q_N))$, whereas at $q = 1$, $\pi_R(p_B, 1) = \pi_N(p_B) > \pi_N(p_l^{Run}(1)) = \pi_N(1)$ where the inequality follows from the definition of p_B and Lemma 2 implying $p_B < 1$.

Since we have established that (i) $\pi_R(p_B, q) - \pi_N(p_l^{Run}(q))$ increases with q on $(q_N, 1)$ and (ii) $\pi_R(p_B, q_N) - \pi_N(p_l^{Run}(q_N) < 0$, whereas $\pi_R(p_B, 1) - \pi_N(p_l^{Run}(1)) > 0$, there is a unique $q_R \in (q_N, 1)$ which satisfies $\pi_R(p_B, q_R) = \pi_N(p_l^{Run}(q_R))$. In addition, $\pi_R(p_B, q) < \pi_N(p_l^{Run}(q))$ for $q \in [q_N, q_R)$, and $\pi_R(p_B, q) > \pi_N(p_l^{Run}(q))$ for $q \in (q_R, 1]$. ■

Proof of Proposition 1

Recall from Lemma 3 that q_N and q_R are uniquely determined, and $0.5 < q_N < q_R < 1$. Lemmas also 3 implies that if $q \in [0.5, q_N]$, $p_l^{Run}(q) \leq p_B$, so choosing p_B does not trigger bank runs (Lemma 1 and Assumption 2) and by definition maximizes the bank's payoff $\pi_N(p)$. By Lemma 2, p_B is independent of q.

If $q > q_N$, $p_l^{Run}(q) > p_B$, so choosing p_B triggers a bank run upon $s = l$ (Lemmas 1 and 3, and Assumption 2). The bank needs to compare whether choosing p_B and allowing the bank run to take place upon $s = l$ or choosing $p_l^{Run}(q)$ to prevent bank runs yields higher profits. Lemma 3 implies that $\pi_R(p_B, q) < \pi_N(p_l^{Run}(q))$ for $q \in (q_N, q_R)$ and $\pi_R(p_B, q) > \pi_N(p_l^{Run}(q))$ for $q \in (q_R, 1]$, so the bank will set $p = p_l^{Run}(q) > p_B$ if $q \in (q_N, q_R)$, and will set $p = p_B < p_l^{Run}(q)$ if $q > q_R$. At $q = q_R$, $\pi_R(p_B, q_R) = \pi_N(p_l^{Run}(q_R))$ by definition, so the bank is indifferent between choosing p_B and $p_l^{Run}(q_R)$. By Lemmas 1 and 2, $p_l^{Run}(q)$ increases with q and p_B is independent of q.

Since the bank's asset risk choice is either p_B which prevents bank runs upon $s = h$ (Lemma 1 and Assumption 2), or it is $p_l^{Run}(q)$ which prevents bank runs for both $s = h$ and $s = l$ (Lemma 1), no bank run occurs if $s = h$. Moreover, by Lemma 1, no bank run can occur if the bank chooses some p such that $p \geq p_l^{Run}(q)$, which we have established to happen if $q < q_R$. ■

Proof of Proposition 2

Equation (10) shows that the bank's expected profit $\pi^*(q)$ is $\pi_N(p_B)$ if $q \leq q_N$, is $\pi_N(p_l^{Run}(q))$ if $q \in (q_N, q_R)$, and is $\pi_R(p_B, q)$ if $q > q_R$. By definition, $\pi_N(p_B) = \pi_N(p_l^{Run}(q_N))$ and $\pi_R(p_B, q_R) = \pi_N(p_l^{Run}(q_R))$.

Since $\pi_N(p)$ and p_B are independent of q, the bank's payoff $\pi_N(p_B)$ is independent of q if $q \leq q_N$. Also, because $\pi_R(p_B, q) = q\pi_N(p_B)$ for all p, the bank's payoff $\pi_R(p_B, q)$ increases with q for $q > q_R$. Moreover, $\pi_R(p_B, 1) = \pi_N(p_B)$. For $q \in (q_N, q_R)$, the bank's payoff $\pi_N(p_l^{Run}(q))$ decreases with q as established in the proof of Lemma 3. Given $\pi_N(p_B) = \pi_N(p_l^{Run}(q_N))$ and $\pi_R(p_B, q_R) = \pi_N(p_l^{Run}(q_R))$, the bank's expected profit $\pi^*(q)$ is maximized when $q \leq q_N$ or when $q = 1$, and minimized when q_R. ■

Proof of Proposition 3

Because, by Proposition 1, no bank run will occur if $q < q_R$ and a bank run will occur when $s = l$ if $q > q_R$, bank stability (the probability that the bank does not fail) is the p chosen by the bank if $q \leq q_R$, and is the p chosen by the bank multiplied by q if $q \geq q_R$. By Proposition 1, bank stability is then p_B if $q \leq q_N$, is $p_l^{Run}(q)$ if $q \in (q_N, q_R)$, and is qp_B if $q > q_R$. At $q = q_R$, the bank stability is either $q_R p_B$ or $p_l^{Run}(q_R)$ in which $p_l^{Run}(q_R) > p_B > q_R p_B$. From the facts that (i) p_B is independent of q, (ii) $\partial p_l^{Run}/\partial q > 0$, and (iii) $p_L^{Run}(q_N) = p_B$, bank stability is independent of q if $q \leq q_N$ and increases with q if $q \in (q_N, 1] \backslash \{q_R\}$.

From these results, bank stability is p_B for $q \in [0.5, q_N]$ and, for $q \in (q_R, 1]$, the highest bank stability is p_B (when $q = 1$). For $q \in (q_N, q_R)$, bank stability is $p_l^{Run}(q)$. Since $p_l^{Run}(q) > p_B$ for $q > q_N$ by Lemma 3, bank stability is higher when $q \in (q_N, q_R)$ than otherwise. Moreover, since $\partial p_l^{Run}/\partial q > 0$, the highest bank stability, obtained by setting $q = q_R$, is $p_l^{Run}(q_R)$. Since the bank is indifferent between choosing p_B and $p_l^{Run}(q_R)$ at $q = q_R$ by Proposition 1, maximal stability can alternatively be achieved by choosing q below but arbitrarily close to q_R. ■

Proof of Lemma 4

Let us use equation (1) to rewrite equation (13) as

$$W_N(p,Z) = fd_1 + (1-fd_1)(V(p)+1) - (1-p)Z \tag{A1}$$

Evaluating this equation (A1) at $p = p_l^{Run}(q)$ and taking derivatives yield

$$\frac{dW_N(p_l^{Run}(q),Z)}{dq} = \big[(1-fd_1)V'(p_l^{Run}(q)) + Z\big]\frac{\partial p_l^{Run}}{\partial q}.$$

Since $\partial p_l^{Run}/\partial q > 0$ by Lemma 1, the sign of $dW_N(p_l^{Run}(q),Z)/dq$ is given by the sign of

$$\frac{\partial W_N(p_l^{Run}(q),Z)}{\partial p_l^{Run}} = (1-fd_1)V'(p_l^{Run}(q)) + Z. \tag{A2}$$

Recall that Assumption 1 implies that $V(\cdot)$ is strictly concave, bounded, $V'(0) > 0$, and $V'(1) < 0$, whereas Lemma 1 verifies that $\partial p_l^{Run}/\partial q > 0$ and $p_l^{Run}(1) = 1$. These properties of $V(\cdot)$ and $p_l^{Run}(\cdot)$, and equation (A2) imply that for $Z < -(1-fd_1)V'(1)$, $q_N^W(Z) < 1$ is a unique solution to

$$(1-fd_1)V'(p_l^{Run}(q_N^W)) + Z = 0 \tag{A3}$$

from where we get

$$\frac{dq_N^W}{dZ} = -\frac{1}{(1-fd_1)V''(p_l^{Run}(q))\frac{\partial p_l^{Run}}{\partial q}} > 0,$$

whereas for $Z \geq -(1-fd_1)V'(1)$, $q_N^W(Z) = 1 > q_R$. Thus, for sufficiently high Z, $q_N^W(Z) > q_R$.

For $Z = 0$, equations (A3) and (2) imply that $q_N^W(0)$ satisfies $p_l^{Run}(q_N^W(0)) = p^{NPV}$. Since $p^{NPV} > p_B$ by Lemma 2, $p_l^{Run}(q_N) = p_B$ by definition, and $\partial p_l^{Run}/\partial q > 0$ by Lemma 1, $q_N^W(0) > q_N$. Since $q_N^W(\cdot)$ is increasing, $q_N^W(Z) > q_N$ for all Z. ■

Proof of Proposition 4

For $q \leq q_N$, equation (15) shows that $W(q, Z) = W_N(p_B, Z)$. Because p_B is independent of q, $W_N(p_B, Z)$ is independent of q.

For $q \in (q_N, q_R)$, equation (15) shows that $W(q, Z) = W_N(p_l^{Run}(q), Z)$. If $q_N^W(Z) < q_R$, then $q_N^W(Z) \equiv \arg\max_{q\in[0.5,1]} W_N(p_l^{Run}(q), Z) \in (q_N, q_R)$ is the unique solution to equation (A3). Thus, if $q \in (q_N, q_N^W(Z))$, $W_N(p_l^{Run}(q), Z)$ increases with q and, if $q \in (q_N^W(Z), q_R)$, $W_N(p_l^{Run}(q), Z)$ decreases with q. If $q_N^W(Z) > q_R$, $q_N^W(Z) \equiv \arg\max_{q\in[0.5,1]} W_N(p_l^{Run}(q), Z)$ is either the unique solution to equation (A3) in which case $q_N^W(Z) \in (q_R, 1)$ and $W_N(p_l^{Run}(q), Z)$ increases with q for all $q \in [0.5, q_N^W(Z))$ or $q_N^W(Z) = 1$ in which case $W_N(p_l^{Run}(q), Z)$ increases with q for all $q \in [0.5, 1]$.

For $q > q_R$, equation (15) shows that $W(q, Z) = W_R(p_B, q, Z)$. By Assumption 3, $\partial W_R(p_B, q, Z)/\partial q > 0$ for all $q \in [0.5, 1]$. ■

Proof of Corollary 1

We break the proof into three steps.

Step 1. Let $q_R^*(Z) \equiv \arg\max_{q\in(q_R,1]} W_R(p_B, q, Z)$ and $q_N^*(Z) \equiv \arg\max_{q\in[0.5,q_R]} W_N(p, Z)$, i.e., $q_R^*(Z)$ and $q_N^*(Z)$ are the transparency levels that maximize welfare when, respectively, there are runs and there are no runs in equilibrium. Assumption 3 implies $q_R^*(Z) = 1$ for all Z.

To determine $q_N^*(Z)$, note first that setting $q \leq q_N$ cannot be optimal: Proposition 4 implies that $W(q, Z) = W_N(p_B, Z)$ is independent of q if $q \leq q_N$, and $W(q, Z) = W_N(p_l^{Run}(q), Z)$ increases with q if $q \in (q_N, q_R)$. Since $p_l^{Run}(q_N) = p_B$ by definition, $W(\cdot, Z)$ is continuous on $[0.5, q_R)$.

For $q \in (q_N, q_R]$, there are two possible solutions for $q_N^*(Z)$ which arise from Proposition 4: If $q_N^W(Z) < q_R$, $q_N^*(Z) = q_N^W(Z)$. On the other hand, if $q_N^W(Z) \geq q_R$, $W_N(p_l^{Run}(q), Z)$ increases with q on $(q_N, q_R]$, implying that $q_N^*(Z) = q_R$. Therefore, $q_N^*(Z) = \min\{q_N^W(Z), q_R\}$, with Lemmas 3 and 4 implying that $\min\{q_N^W(Z), q_R\} > q_N$.

Step 2. Step 1 proves that $q_R^*(Z) = 1$ and $q_N^*(Z) = \min\{q_N^W(Z), q_R\} > q_N$. Hence, to find out the optimal policy $q^*(Z)$, we only need to compare whether choosing $q_R^*(Z) = 1$ or $q_N^*(Z) = \min\{q_N^W(Z), q_R\}$ yields higher welfare. Note from equation (15) that if $q_N^*(Z) = \min\{q_N^W(Z), q_R\}$ is optimal, the resulting maximal welfare is $W_N(p_l^{Run}(q_N^*(Z)), Z)$ since $\min\{q_N^W(Z), q_R\} > q_N$. Similarly, if $q_R^*(Z) = 1$ is optimal, the resulting maximal welfare is $W_R(p_B, 1, Z)$. Equations (A1) and (14) imply that

$$W_N(p_l^{Run}(q_N^*(Z)), Z) = fd_1 + (1 - fd_1)\big[V\big(p_l^{Run}(q_N^*(Z))\big) + 1\big] \\ - \big(1 - p_l^{Run}(q_N^*(Z))\big)Z, \quad \text{(A4)}$$

and

$$W_R(p_B, 1, Z) = p_B\big[fd_1 + (1 - fd_1)R(p_B)\big] \\ + (1 - p_B)\big[1 - (1 - \frac{1}{d_1})fX - Z\big]. \quad \text{(A5)}$$

Step 3. Equation (A4) shows that welfare in the absence of bank runs is independent of X, whereas equation (A5) shows that welfare in the presence of bank runs decreases with X. Therefore, the higher is X, the more likely that the welfare-maximizing q is $\min\{q_N^W(Z), q_R\}$, which prevents bank runs, rather than 1, which allows bank runs to take place when $s = l$.

Similarly, we show that an increase in Z has a larger negative impact on $W_R(p_B, 1, Z)$ than on $W_N(p_l^{Run}(q_N^*(Z)), Z)$. Consider first the case where $q_N^W(Z) \geq q_R$ implying that $q_N^*(Z) = q_R$ is independent of Z. Then, taking derivatives in equation (A4) gives

$$\frac{\partial W_N(p_l^{Run}(q_R), Z))}{\partial Z} = -(1 - p_l^{Run}(q_R)). \quad \text{(A6)}$$

Next, consider the case where $q_N^W(Z) < q_R$ implying that $q_N^*(Z) = q_N^W(Z)$. Note from equations (A2) and (A3) that in this case $q_N^W(Z)$ is a solution to

$$\frac{\partial W_N\big(p_l^{Run}(q_N^W(Z)), Z\big)}{\partial p_l^{Run}} = 0. \quad \text{(A7)}$$

Using equation (A7) in differentiating equation (A4) gives

$$\frac{dW_N(p_l^{Run}(q_N^W(Z)), Z)}{dZ} = -\big(1 - p_l^{Run}(q_N^W(Z))\big). \quad \text{(A8)}$$

Similarly, taking derivatives in equation (A5) gives

$$\frac{\partial W_R(p_B, 1, Z))}{\partial Z} = -(1 - p_B). \tag{A9}$$

Both $p_l^{Run}(q_R)$ and $p_l^{Run}(q_N^W(Z))$ are strictly larger than p_B by Lemmas 3 and 4. Moreover, $p_l^{Run}(q_N^W(Z))$ increases with Z (Lemmas 1 and 4). Therefore, from equations (A6), (A8) and (A9) we observe that

$$\frac{\partial W_R(p_B, 1, Z)}{\partial Z} < \frac{dW_N(p_l^{Run}(q_N^*(Z)), Z)}{dZ} < 0 \tag{A10}$$

for all Z, irrespective of whether $q_N^*(Z) = q_N^W(Z)$ or $q_N^*(Z) = q_R$.

Moreover, q_R is independent of Z but, by Lemma 4, $q_N^W(\cdot)$ is increasing and for sufficiently high values of Z, $q_N^W(Z) > q_R$. Thus, for sufficiently high values of Z, $q_N^*(Z) = q_R$. In that case, we get from equations (A6) and (A9) that

$$\frac{\partial W_N(p_l^{Run}(q_R, Z)}{\partial Z} - \frac{\partial W_R(p_B, 1, Z)}{\partial Z} = p_l^{Run}(q_R) - p_B,$$

where the right-hand side is a strictly positive constant (recall Lemma 3). Therefore, for sufficiently high values of Z, $W_N(p_l^{Run}\big(q_N^W(Z)), Z\big) = W_N(p_l^{Run}(q_R), Z) > W_R(p_B, 1, Z)$ and thus, welfare is maximized when $q = q_R$. Alternatively, since $p^*(q) = p_B$ is also an equilibrium at q_R, we may think that q should be chosen below but arbitrarily close to q_R. ■

Proof of the condition (17)

From equations (A4) and (A5) we get that the condition $W_N(p_l^{Run}(q_N^*(0)), 0) > W_R(p_B, 1, 0)$ is equivalent to

$$(1 - fd_1)\big[V\big(p^{Run}(q_N^*(0))\big) + 1 - p_B R(p_B)\big] > (1 - p_B)\big[1 - fd_1 - (1 - \frac{1}{d_1})fX\big].$$

Using equation (1) to rearrange this inequality yields after some algebra

$$\begin{aligned}(1-fd_1)\big[V\big(p_l^{Run}(q_N^*(0))\big)-V(p_B)\big]&\\ >(1-p_B)\big[(1-fd_1)(1-r)-(1-\frac{1}{d_1})fX\big].&\quad \text{(A11)}\end{aligned}$$

The right-hand side of inequality (A11) equals the right-hand side of inequality (17). Recall next from the proof of Lemma 4 that $q_N^*(0)=\min\{q_N^W(0),q_R\}$ where $q_N^W(0)$ satisfies $p_l^{Run}(q_N^W(0))=p^{NPV}$. Hence, if $q_N^W(0)<q_R$, then $V\big(p_l^{Run}(q_N^*(0))\big)=V(p^{NPV})$, i.e., also the left-hand side of inequality (A11) equals the left-hand side of inequality (17).

To prove that the left-hand side of inequality (A11) is strictly positive, note first that $V(p^{NPV})>V(p_B)$ by the definition of $p^{NPV}\equiv\arg\max_{p\in[0,1]}V(p)$ and Lemma 2. If $q_N^W(0)>q_R$, then Lemmas 2 and 3 imply that $p_B<p_l^{Run}(q_R)<p_l^{Run}(q_N^W(0))=p^{NPV}<1$. Then the definition of p^{NPV} and Assumption 1 (implying $V''(p)<0$) imply that $V(p_l^{Run}(q_R))>V(p_B)$. Thus, irrespective of whether $q_N^*(0)=q_N^W(0)$ or $q_N^*(0)=q_R$, $V\big(p_l^{Run}(q_N^*(0))\big)>V(p_B)$. (We have $1>fd_1$ by assumption). ■

Proof of Proposition 5

In Section 4.2, we establish that the intermediate level of bank transparency maximizes welfare. For this modified setting, this optimal level of bank transparency can be written as $q^*(\alpha,y)=\min\{q_N^W(\alpha,y),q_R(\alpha,y)\}$. Consider first the case where $q_N^W(\alpha,y)<q_R(\alpha,y)$ so that $q^*(\alpha,y)=q_N^W(\alpha,y)$. When $q_N^W(\alpha,y)$ is chosen, there are no bank runs. From equation (A1), we get that in this modified setting, social welfare in the absence of runs is given by

$$W_N(p,\alpha)=fd_1+\alpha[(1-fd_1)\left(V(p)+1\right)-(1-p)Z]. \qquad \text{(A12)}$$

Define $p_N^W\equiv\arg\max_{p\in[0,1]}W_N(p)$ where $W_N(p)$ is given by equation (A1). Comparing equations (A1) and (A12) shows how this p_N^W that maximizes $W_N(p)$ of equation (A1) must equal the p that maximizes $W_N(p,\alpha)$ of equation (A12). Hence p_N^W is independent of α and y. Moreover, $q_N^W(\alpha,y)\equiv\arg\max_{q\in[0.5,1]}W_N(p_l^{Run}(q,\alpha,y),\alpha)$ must be a solution to $p_l^{Run}(q_N^W,\alpha,y)=p_N^W$. Since $p_l^{Run}(q,\alpha,y)$ increases with q but decreases with α and y (see the main text after the proposition), $q_N^W(\alpha,y)$ must increase with both α and y.

If $q_N^W(\alpha, y) > q_R(\alpha, y)$, $q^*(\alpha, y) = q_R(\alpha, y)$ where $q_R(\alpha, y)$ solves $\pi_R(p_B(\alpha), q_R, \alpha) = \pi_N(p_l^{Run}(q_R, \alpha, y), \alpha)$. We have

$$\pi_R(p_B(\alpha), q_R, \alpha) = p_B(\alpha) q_R \big[(1 - fd_1)\alpha R(p_B(\alpha)) - (1 - f)d_2\big] \tag{A13}$$

and

$$\pi_N(p_l^{Run}(q_R, \alpha, y), \alpha) = p_l^{Run}(q_R, \alpha, y)\big[(1 - fd_1)\alpha R(p_l^{Run}(q_R, \alpha, y)) - (1 - f)d_2\big], \tag{A14}$$

where equation (5) suggests that

$$p_l^{Run}(q_R, \alpha, y) = \frac{1}{1 + \frac{(1-q_R)(d_2-d_1)}{q_R(d_1-v_F(\alpha,y))}} \tag{A15}$$

with $v_F(\alpha, y)$ being increasing in α and y – recall (equation (18)). Note also that $p_B(\alpha)$ is a solution to

$$\frac{\partial \pi_R}{\partial p} = (1 - fd_1)\alpha(R(p) + pR'(p)) - (1 - f)d_2 = 0.$$

Hence, $p_B(\alpha)$ increases with α, given that $R(p) + pR'(p)$ decreases with p by Assumption 1.

Since $\pi_R(p_B(\alpha), q_R, \alpha) = q_R \pi_N(p_B(\alpha), \alpha)$ by equation (8), we may write the condition $\pi_R(p_B(\alpha), q_R, \alpha) = \pi_N(p_l^{Run}(q_R, \alpha, y), \alpha)$ as

$$q_R \pi_N(p_B(\alpha), \alpha) - \pi_N(p_l^{Run}(q_R, \alpha, y), \alpha) = 0. \tag{A16}$$

Differentiating equation (A16) with respect to q_R and y gives

$$\frac{dq_R}{dy} = \frac{\frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial p_l^{Run}} \frac{dp_l^{Run}}{dy}}{\pi_N(p_B(\alpha), \alpha) - \frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial p_l^{Run}} \frac{\partial p_l^{Run}}{\partial q_R}} > 0 \tag{A17}$$

where the sign follows since $dp_l^{Run}/dy < 0$ and $\partial p_l^{Run}/\partial q_R > 0$ (see equations (18) and (A15)), and since $\partial \pi_N(p_l^{Run}(q_R, \alpha, y), \alpha)/\partial p_l^{Run} < 0$ by the definition of $p_B(\alpha) \equiv \arg\max_{p\in[0,1]} \pi_N(p,\alpha)$ and since Lemmas 1 and 3 apply so that $1 > p_l^{Run}(q_R,\alpha,y) > p_B(\alpha)$. Thus, both the numerator and denominator of the right-hand side of equation (A17) are positive.

Similarly, differentiating equation (A16) with respect to q_R and α using the Envelope Theorem gives

$$\frac{dq_R}{d\alpha} = \frac{-q_R \frac{\partial \pi_N(p_B(\alpha),\alpha)}{\partial \alpha} + \frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial \alpha} + \frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial p_l^{Run}} \frac{dp_l^{Run}}{d\alpha}}{\pi_N(p_B(\alpha),\alpha) - \frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial p_l^{Run}} \frac{\partial p_l^{Run}}{\partial q_R}}. \tag{A18}$$

In the right-hand side of equation (A18) the denominator and the last term

$$\frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial p_l^{Run}} \frac{dp_l^{Run}}{d\alpha}$$

in the numerator are positive as in the case of equation (A17). As to the two first terms in the numerator of the right-hand side of equation (A18), we get from equations (A13) and (A14) that

$$\begin{aligned}
&\frac{\partial \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)}{\partial \alpha} - q_R \frac{\partial \pi_N(p_B(\alpha),\alpha)}{\partial \alpha} \\
&\qquad = (1 - f d_1)\left[p_l^{Run}(q,\alpha,y) R(p_l^{Run}(q,\alpha,y)) - q_R p_B(\alpha) R(p_B(\alpha))\right] \\
&\qquad\qquad = \frac{1}{\alpha}(1-f) d_2 \left[p_l^{Run}(q,\alpha,y) - p_B(\alpha) q_R\right] > 0
\end{aligned}$$

where the second equality follows after substitution of equations (A13) and (A14) for the condition $\pi_R(p_B(\alpha), q_R, \alpha) = \pi_N(p_l^{Run}(q_R,\alpha,y),\alpha)$. The inequality follows since Lemmas 1 and 3 imply $1 > p_l^{Run}(q_R,\alpha,y) > p_B(\alpha) > q_R p_B(\alpha)$. As a result, the numerator of the right-hand side of equation (A18) is positive, too, and we have $dq_R/d\alpha > 0$ as claimed.

In sum, as both $q_N^W(\alpha,y)$ and $q_R(\alpha,y)$ increase with α and y, $q^*(\alpha,y) = \min\{q_N^W(\alpha,y), q_R(\alpha,y)\}$ increases with α and y. ■

Proof of Proposition 6

Suppose that Assumption 2 is violated so that $p_B < p_0^{Run}$. By Lemma 1, the function $p_h^{Run} : [0.5, 1] \rightarrow [p_0^{Run}, 0]$ is strictly decreasing. Because $p_B > 0$ is independent of q, there thus exists a unique $q'_N \in (0.5, 1)$ that satisfies $p_h^{Run}(q'_N) = p_B$. In addition, $p_h^{Run}(q) > p_B$ if $q \in [0.5, q'_N)$ and $p_h^{Run}(q) < p_B$ if $q \in (q'_N, 1]$.

First consider the case where $q \in [0.5, q'_N)$, implying that $p_B < p_h^{Run}(q) < p_l^{Run}(q)$. The bank has two choices. It can either set $p = p_h^{Run}(q)$ so that a bank run will occur if and only if $s = l$, or set $p = p_l^{Run}(q)$ to eliminate bank runs. Setting $p = p_B$ is not optimal for the bank in this case, because it would allow a bank run to occur irrespective of the realization of the signal S. The bank will set $p^*(q) = p_h^{Run}(q)$ and receive $\pi_R(p_h^{Run}(q), q)$ if $\pi_R(p_h^{Run}(q), q) > \pi_N(p_l^{Run}(q))$, and will set $p^*(q) = p_l^{Run}$ and receive $\pi_N(p_l^{Run}(q))$ otherwise.

Next consider the case where $q \in (q'_N, 1]$. In this case, $p_h^{Run}(q) < p_B < p_l^{Run}(q)$. This case is familiar from the main setting in which Assumption 2 holds. The bank has two choices: It can either set $p = p_B$ so that a bank run will occur if and only if $s = l$, or set $p = p_l^{Run}(q)$ to eliminate bank runs. The bank will set $p^*(q) = p_B$ and receive $\pi_R(p_B, q)$ if $\pi_R(p_B, q) > \pi_N(p_l^{Run}(q))$, and will set $p^*(q) = p_l^{Run}(q)$ and receive $\pi_N(p_l^{Run}(q))$ otherwise.

Combining these two cases, the bank sets $p^*(q) = \max\{p_h^{Run}(q), p_B\}$ if

$$\pi_R(\max\{p_h^{Run}(q), p_B\}, q) > \pi_N(p_l^{Run}(q)),$$

and $p^*(q) = p_l^{Run}(q)$ otherwise. Note that $\pi_R(\max\{p_h^{Run}(q), p_B\}, q)) = q\pi_N(\max\{p_h^{Run}(q), p_B\})$ increases with q: if $p_B \geq p_h^{Run}(q)$, $\pi_N(p_B)$ is independent of q, and if $p_B < p_h^{Run}(q)$,

$$\frac{d\pi_N(p_h^{Run}(q))}{dq} = \frac{\partial \pi_N}{\partial p_h^{Run}} \frac{\partial p_h^{Run}}{\partial q} > 0,$$

since $\partial \pi_N / \partial p_h^{Run} < 0$ by the definition of p_B and $\partial p_h^{Run} / \partial q < 0$ by Lemma 1. Also, $\pi_N(p_l^{Run}(q))$ decreases with q because $\partial p_l^{Run} / \partial q > 0$ by Lemma 1 and $\partial \pi_N / \partial p_l^{Run} < 0$ since $p_B < p_l^{Run}(q)$.

In addition, if $q = 0.5$,

$$\begin{aligned}\pi_N(p_l^{Run}(0.5)) = \pi_N(p_0^{Run}) &> \pi_R(p_0^{Run}, 0.5) \\ &= \pi_R(p_h^{Run}(0.5), 0.5) = \pi_R(\max\{p_h^{Run}(0.5), p_B\}, 0.5)\end{aligned}$$

since when Assumption 2 fails to hold, $p_B < p_0^{Run} = p_h^{Run}(0.5)$. By the continuity of

$\pi_N(p_l^{Run}(\cdot))$ and $\pi_R(\max\{p_h^{Run}(\cdot), p_B\}, \cdot)$, we have $\pi_N(p_l^{Run}(q)) > \pi_R(\max\{p_h^{Run}(q), p_B\}, q)$ for any q sufficiently close to 0.5.

If $q = 1$,

$$\begin{aligned}\pi_N(p_l^{Run}(1)) = \pi_N(1) < \pi_N(p_B) = \pi_R(p_B, 1) \\ = \pi_R(\max\{p_h^{Run}(1), p_B\}, 1) = \pi_R(\max\{0, p_B\}, 1).\end{aligned}$$

By the continuity of $\pi_N(p_l^{Run}(\cdot))$ and $\pi_R(\max\{p_h^{Run}(\cdot), p_B\}, \cdot)$, we have $\pi_N(p_l^{Run}(q)) < \pi_R(\max\{p_h^{Run}(q), p_B\}, q)$ for any q sufficiently close to 1.

From the results that (i) $\pi_R(\max\{p_h^{Run}(q), p_B\})$ increases with q on $(0.5, 1)$, (ii) $\pi_N(p_l^{Run}(q))$ decreases with q on $(0.5, 1)$, (iii) $\pi_N(p_l^{Run}(q)) > \pi_R(\max\{p_h^{Run}(q), p_B\}, q)$ for any q sufficiently close to 0.5, and (iv) $\pi_N(p_l^{Run}(q)) < \pi_R(\max\{p_h^{Run}(q), p_B\}, q)$ for any q sufficiently close 1, there is a unique $q'_R \in (0.5, 1)$ such that the bank's optimal risk choice is $p^*(q) = p_l^{Run}(q)$ if $q < q'_R$, and is $p^*(q) = \max\{p_B, p_h^{Run}(q)\}$ if $q > q'_R$. When $p^*(q) = p_l^{Run}(q)$ there are no bank runs in equilibrium and when $p^*(q) = \max\{p_B, p_h^{Run}(q)\}$ a bank run arises upon $s = l$. ■

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