

Transparency in the Financial System: Rollover Risk and Crises

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Abstract

We present a theory of optimal transparency when financial institutions are exposed to rollover risk. Transparency enhances the stability of the financial system during crises but has destabilizing effects in normal times. The regulator should therefore provide more information to investors during crises. Under such policy, however, information disclosure signals a deterioration of fundamentals, which gives the regulator ex-post incentives to withhold information. Thus, the regulator faces a commitment problem and lacks the ability to implement an ex-ante optimal disclosure policy. The theory also relates optimal transparency to cross-exposures between financial institutions, and to investors' ability to evaluate financial institutions.

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Financial crises are often associated with demands for an increase in the transparency of the financial system. Indeed, following the 2008 financial crisis, regulators have periodically been performing and disclosing stress tests on the largest financial institutions. This practice, however, has been the subject of much debate. For instance, Fed Chairman Ben Bernanke cautioned that “*when the stress assessment was getting started, some observers had warned that the assessment and, in particular, the public disclosure of the results might backfire*”. [Speech at the Federal Reserve Bank of Chicago, Illinois on May 6th, 2010.] Moreover, the accuracy and actual informativeness of these tests have been questioned, emphasizing the credibility issues that regulators face when adjusting their disclosure policy. This paper studies the trade-offs faced by regulators when using instruments such as stress tests to set the level of transparency in the financial system.

We develop a stylized model of financial intermediation with rollover risk, in which financial institutions –banks– have exclusive access to a long-term investment technology that is illiquid. Banks are ex-ante identical but they differ ex-post in the quality of their investment technology, and hence, in the quality of their balance sheets. Furthermore, the quality of banks in the financial system is affected by aggregate shocks. While investors may have information about these shocks, and therefore, about the ex-post average quality of banks, they do not observe the idiosyncratic component of each bank’s balance sheet. By contrast, the regulator has access to this bank-specific information and can choose to communicate it to the public.

In the baseline case in which investors observe aggregate shocks and therefore know the average quality of banks in the financial system, we show that the optimal disclosure policy depends on the realization of these shocks. When the average quality is high enough that investors are willing to rollover their credit, it is optimal not to disclose bank-specific information as transparency may expose lower-quality banks to a run. On the contrary,

when a negative shock pushes the average quality below a threshold, the regulator switches to transparency, that is, discloses the idiosyncratic component of each bank's balance sheet. Otherwise, if investors knew that the average quality was low but could not tell which banks were of higher relative quality, there would be a run on the entire system.¹ This result relies on the properties of the bank run equilibrium, in which the mass of withdrawals is a non-linear function of a bank's expected return. Specifically, under good economic conditions, pooling the most profitable banks with a few lower-quality banks has little effect on the rollover risk of the former, while it significantly reduces the probability of runs on the latter.

We turn next to the case in which the regulator also has private information about aggregate shocks to the financial system. In this case, an optimal disclosure policy has an additional benefit: by committing to disclose information when average bank quality falls below a threshold, the disclosure policy provides insurance not only against bank-specific shocks but now also against moderate aggregate shocks. Under this disclosure policy, however, no news –opacity– is good news (since investors perceive information disclosure as evidence of a negative shock), so that the regulator has incentives to renege on that commitment ex-post and withhold information.² Therefore, while the presence of private information about aggregate shocks increases the potential benefits of an optimal disclosure policy, it also creates a commitment problem that makes its implementation more difficult.

We show that if the regulator is unable to commit, he still follows a state-contingent policy in which the system becomes transparent following a negative aggregate shock, pro-

¹Recent empirical evidence supports the view that stress tests provided useful information to market participants during the recent crises, despite the credibility issues that we discuss below. See for instance, Bayazitova and Shivdasani (2012), Ellahie (2013), Greenlaw et al. (2012), and Peristiani et al. (2010).

²This commitment problem is consistent with the concerns raised about the leniency of some of the stress tests. For instance, while all banks had passed the 2010 stress test performed by the Committee of European Banking Supervisors, the 2011 stress tests conducted on Irish banks (largely by outside independent advisors) revealed a total capital need of €24 billions. (See Schuermann, 2013.)

vided that investors receive sufficiently precise -yet imperfect- information about aggregate economic conditions. However, because of his incentive to withhold information ex-post, the regulator keeps the system opaque in more states than is ex-ante optimal, which increases the probability of a systemic run. We also show that if the regulator is unable to commit but can credibly disclose aggregate information without disclosing bank-specific information, his private information about aggregate shocks tends to unravel, which underscores the fundamentally different economic principles that lead to the release of aggregate and bank-specific information. In equilibrium, transparency still increases as fundamentals deteriorate, but now the regulator loses the ability to provide insurance against aggregate shocks, and there is a gradation in the release of information. While a large negative shock triggers the disclosure of both aggregate and bank-specific information, the regulator discloses aggregate information without bank-specific information following a moderate shock.³

In a first approach we take each bank's rollover risk as independent. In practice, however, banks have cross-exposures (*e.g.*, Allen and Gale, 2000; Dasgupta, 2004), and hence, runs on a subset of banks may adversely affect other banks. To understand how the possibility of contagion interacts with the regulator's disclosure policy, we extend the model to allow for a run on a bank to increase the vulnerability of other banks to runs. In this setting, while the regulator still discloses information on bank types following a negative aggregate shock, he now also discloses information on bank cross-exposures when the negative aggregate shock is sufficiently severe. Moreover, the analysis also suggests that as the banking system becomes more integrated, information on cross-exposures becomes a more frequent component of an optimal transparency policy.

³This prediction is consistent with the policy of U.S. regulatory authorities who released bank-specific information in the midst of the financial crisis (SCAP stress tests in 2009) but only disclosed macro-scenarios without bank-level results following the 2011 CCAR stress tests (Schuermann, 2013).

Finally, we study the robustness of the model's predictions to investors and the regulator having imperfect bank-specific information. In this framework, transparency still increases following negative aggregate shocks. In addition, the analysis shows that the regulator may restrict information disclosure to a set of banks that are perceived as more vulnerable by the market.

This paper builds on seminal models by Byrant (1980) and Diamond and Dybvig (1983) where strategic complementarities between depositors may trigger runs and lead to the early liquidation of solvent but illiquid banks. Because these models typically have several equilibria, which makes the impact of public policies difficult to assess, we use the global games approach (Carlsson and van Damme, 1993; Morris and Shin, 1998, 2003) to obtain equilibrium uniqueness. Our paper is therefore related to Morris and Shin (2000) and Goldstein and Pauzner (2005) who use global games techniques to refine models of bank runs. Within this literature, we introduce heterogeneity among banks, which makes the release of bank-specific information by the regulator a relevant issue.⁴

Our paper belongs to the literature on transparency in the banking system. [See Landier and Thesmar (2011) and Goldstein and Sapra (2012) for a review of the trade-offs related to transparency in financial systems.] A common theme in this literature is that transparency allows investors to better monitor financial institutions, thereby enhancing market discipline and improving allocation efficiency. This literature, however, has pointed out that information disclosure can also be associated with important costs. For instance, the re-

⁴See also Morris and Shin (2004), Morris and Shin (2009) for models of rollover risk using global games. Eisenbach (2013) also introduces heterogeneity among financial institutions and studies the optimality of short-term debt in the presence of aggregate risk. Plantin (2009) studies bond pricing when investors' concerns about secondary market liquidity create strategic complementarities among them. Chen et al. (2010) and Hertzberg et al. (2011) provide empirical evidence consistent with the existence of strategic complementarities between investors in financial institutions.

lease of public information reinforces coordination concerns, which can generate multiple self-fulfilling equilibria (Rochet and Vives, 2004) and may lead market participants to put insufficient weight on private information (Morris and Shin, 2002; Angeletos and Pavan, 2007). Moreover, public information crowds out private incentives to acquire information, which may prevent inefficient runs (He and Manela, 2013) but can also adversely affect the ability of the government to learn from market prices (Bond et al., 2010; Goldstein et al., 2011; Bond and Goldstein, 2012). We contribute to this literature by showing that the contingent release of bank-specific information can improve the stability of the banking sector by insuring banks against idiosyncratic as well as aggregate shocks, and by studying the regulator’s commitment problem when attempting to implement such ex-ante optimal contingent disclosure policy.⁵

The paper proceeds as follows. Section 1 presents the baseline model. Section 2 analyses the equilibrium and derives the optimal transparency policy. Section 3 introduces cross-exposures and imperfect information. Section 4 concludes. All proofs are in the Appendix.

1 Model

Consider a risk neutral economy with one consumption good, three periods, $t = 0, 1, 2$, and no discounting. There is a continuum $[0, 1] \times [0, 1]$ of investors, each endowed with one unit of the consumption good. At $t = 0$ investors can invest their unit in a financial institution or store it. Financial institutions, which we will call banks hereafter, have exclusive access to a long-term investment technology that generates a gross return of $1 + r_i$ per unit of

⁵This central role of idiosyncratic information is reminiscent of Hirshleifer (1971), where the early knowledge of future realizations of uncertainty prevents individuals from sharing risk efficiently through transactions. The Hirshleifer effect underlies the analysis of Goldstein and Leitner (2013), who, in a recent paper, study the impact of information disclosure on the ability for banks to share risk in financial markets.

consumption good at $t = 2$. Each active bank invests a mass 1 of the consumption good at $t = 0$, and there is free entry in the banking industry. Thus if all investors were to deposit their goods in banks, there would be a continuum $[0, 1]$ of banks each with a continuum $[0, 1]$ of investors.⁶

The net return of the long-term technology, r_i , is stochastic. Specifically, $r_i = \mu + \eta_i$ where μ is a parameter common to all banks that captures the expected return of the banking sector, and η_i is a bank-specific component that captures the relative quality of bank i . The bank-specific component η_i can take values $\Delta_\eta > 0$ (for high-quality banks) and $-\Delta_\eta$ (for low-quality banks) with probability p and $1 - p$, respectively. The proportion p of high-quality banks is drawn from a uniform distribution on $(0, 1)$, so that ex-ante, $\mathbb{E}(\eta_i) = 0$ for all i . The realization of p is interpreted as an aggregate shock to the expected return of the banking system, μ .

Investors who invest in banks at $t = 0$ can either leave their good in the bank or withdraw it at $t = 1$. Thus, banks face rollover risk and the possibility of early liquidation. Liquidation is costly because the technology is illiquid: if a proportion l_i of the resources invested in the long-term technology is withdrawn at $t = 1$, the per-unit return at $t = 2$ is reduced to $r_i - cl_i$. For instance, if half of the bank's investors withdraw, each of them gets one unit of the consumption good back at $t = 1$ and the other half gets $1 + r_i - \frac{c}{2}$ at $t = 2$. This investment technology is similar to the one in Morris and Shin (2000) and, in essence, models rollover risk as a coordination problem among investors.

We assume that early liquidation is inefficient –the net expected return of the long-term technology is greater than zero– and that, when banks' types are disclosed, low-quality banks

⁶While throughout the paper we refer to the continuum $[0, 1]$ of banks as the financial or banking system, it can be interpreted more generally as a subset of banks within the banking system that investors perceive as homogenous. Section 3.2 suggests that this subset would typically consist of banks that can be perceived as vulnerable by investors.

face the risk of early liquidation while high-quality banks do not. As will be clear in the analysis below (Section 2), this boils down to the following assumption on the parameters of the model:⁷

$$0 < -\Delta_\eta + \mu < \frac{c}{2} < \Delta_\eta + \mu. \quad (1)$$

At $t = 1$, before making their withdrawal decision, investors learn p , the proportion of high-quality banks in the financial system. While investors do not know the quality of each bank, the financial system is supervised by a regulator who has access to this information. Specifically, at $t = 1$ the regulator learns $\{\eta_i\}_{i \in [0,1]}$ and decides whether to disclose this information to investors. The objective of the regulator is to maximize total output, that is, the sum of what investors who withdraw early receive at $t = 1$ and what investors who rollover their investment receive at $t = 2$. Notice that this objective is equivalent to maximizing the aggregate expected return of the banking system or to maximizing total consumption.⁸

We finish the presentation of the model by describing two assumptions that we maintain throughout the analysis. First, we assume that investors have the right to withdraw at $t = 1$, that is, financial institutions borrow short-term and face rollover risk. A feature of the 2008 financial crisis has been the sudden freeze in the credit market which led to the collapse of financial institutions that relied on the rollover of short-term debt in the asset-backed commercial paper and overnight secured repo markets (Acharya et al., 2011; Gorton and

⁷This assumption is mainly for expositional reasons; it allows to focus the paper on the more interesting cases. In Appendix B, we allow for efficient runs, and show that the policy recommendations remain qualitatively the same, under reasonable assumptions about the impact of negative shocks on the distribution of returns across banks (i.e., a monotone likelihood ratio property).

⁸In the model, the only alternative to investing with banks is the storage technology that delivers a net return of 0. Therefore, investors who withdraw at $t = 1$ consume one unit of the consumption good, whether they consume at $t = 1$ or storage their unit and consume at $t = 2$.

Metrick, 2012). Thus, our paper studies the optimal level of transparency in the financial system given the presence of rollover risk, that is, under the implicit assumption that while banks may try to ameliorate rollover risk, they will not be able to eliminate it. From a theoretical point view, rollover risk can be micro-founded through depositors' demands for insurance against idiosyncratic liquidity shocks as in Diamond and Dybvig (1983).⁹ Goldstein and Pauzner (2005) show that while demand deposit contracts, i.e., short-term debt, trade off the benefits of risk sharing against the costs of bank runs, these contracts are still desirable even when their destabilizing effect is taken into account.¹⁰

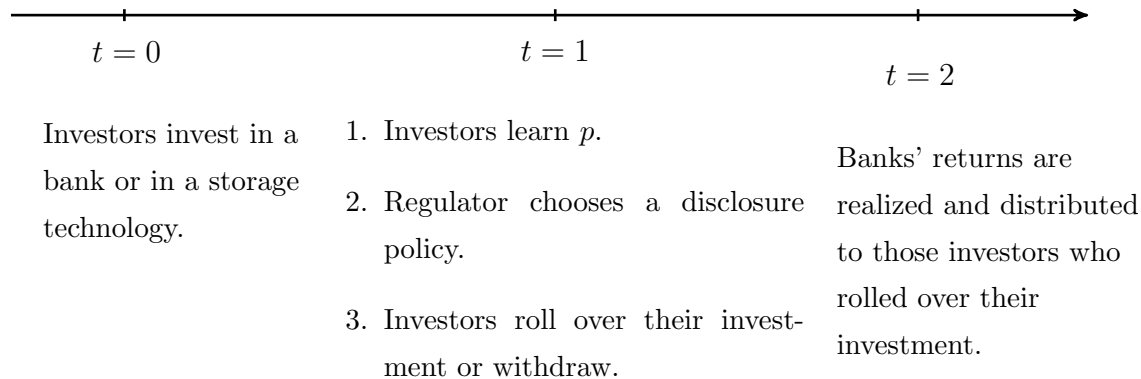
Second, the analysis implicitly assumes that banks cannot credibly disclose their information while the regulator can. That banks cannot credibly disclose soft information is straightforward: low-quality banks do not have any incentives to disclose information that would lead them to cease operations due to a credit run. The regulator, however, who is concerned about the long-term viability of the entire banking system rather than the viability of a single bank, has incentives to disclose information truthfully when he chooses a transparent regime. Indeed, when disclosing $\{\eta_i\}_{i \in [0,1]}$, the regulator communicates relative performance when individual banks can only communicate absolute performance. Chakraborty and Harbaugh (2007, 2010) show that an expert with information on multiple variables may be able to credibly communicate a ranking of these variables in cases where communication about a single variable is impossible. Intuitively, comparative statements have the property of being

⁹See also Stein (2011) for a different modelling of the demand for short-term debt. Alternatively, theories of debt maturities build on agency problems to show that short-term liabilities, which expose borrowers to rollover risk, limit risk-shifting (Barnea et al., 1980) and discipline managers by submitting them to regular market scrutiny (Calomiris and Kahn, 1991).

¹⁰In Appendix B, we allow banks to adjust their exposure to rollover risk through asset diversification or by increasing the liquidity of their balance-sheets. While this richer setting generates some additional insights, it does not qualitatively change the equilibrium disclosure policy of the main text.

simultaneously positive along one dimension and negative along another dimension.¹¹

Figure 1: Timeline of the baseline model



2 Analysis

In this section we start by characterizing the rollover decision at $t = 1$. Then, we study the regulator's optimal disclosure policy in the baseline model described above in which the aggregate shock, p , is common knowledge. Finally, we study the general case in which the regulator has private information about p .

¹¹Note that when p is common knowledge, disclosing a full ranking is equivalent to disclosing $\{\eta_i\}_{i \in [0,1]}$. In such a case, the only way the regulator could misrepresent a low-quality bank as being of high quality without investors immediately knowing that he is not being truthful, is by misrepresenting a high-quality bank as being of low quality at the same time. This, however, would result in a welfare loss, as a high-quality bank would be liquidated instead of a low-quality one. More generally, our setting satisfies the supermodularity conditions in Chakraborty and Harbaugh (2007) under which a complete ranking can be credibly communicated.

2.1 Rollover Equilibrium

Consider an investor who invests in bank i at $t = 0$. At $t = 1$, he can either withdraw his unit of the consumption good or roll over his investment. An investor who rolls over at $t = 1$ receives a random payoff of $1 + r_i - cl_i$ at $t = 2$. Hence, an investor's willingness to withdraw depends on l_i , that is, on the withdrawal decisions of all other investors in the bank. As Diamond and Dybvig (1983) pointed out, these strategic complementarities typically lead to multiple equilibria. In one equilibrium, investors roll over their investment and banks' assets pay off at $t = 2$. Another equilibrium, however, involves a bank run in which all investors demand early withdrawal, causing fundamentally solvent banks to recall loans, to terminate productive investments, and eventually to fail.

The literature on global games has shown that this equilibrium multiplicity is a by-product of the common knowledge assumption which allows perfect coordination among investors. [See Carlsson and van Damme (1993) and Morris and Shin (1998) for two seminal contributions.] We apply this insight to our rollover game. Specifically, we introduce dispersed private information among investors through two modifications of our initial setup. First, instead of considering that the common component in the return of the banking industry is a known parameter μ , we introduce uncertainty by assuming that it is equal to a random variable $\tilde{\mu}$, which is normally distributed with mean μ and precision h_μ . Second, we assume that between $t = 0$ and $t = 1$, each investor j receives a noisy signal $s_j = \tilde{\mu} + \varepsilon_j$, where ε_j is normally distributed with mean 0 and precision h_ε , and independent across investors.

We let ρ_j denote the expectation of $\tilde{\mu}$ conditional on s_j ,

$$\rho_j \equiv \frac{h_\mu \mu + h_\varepsilon s_j}{h_\mu + h_\varepsilon}, \quad (2)$$

and let $\mathbb{E}_1(\eta_i)$ denote the expected value of η_i given investors' information at $t = 1$. Note that $\mathbb{E}_1(\eta_i)$ depends on the disclosure policy of the regulator. For instance, under transparency,

$\mathbb{E}_1(\eta_i) = \eta_i$; under opacity, $\mathbb{E}_1(\eta_i) = p\Delta_\eta - (1-p)\Delta_\eta$.¹² Finally, we define

$$\gamma \equiv \frac{h_\mu^2 (h_\mu + h_\varepsilon)}{h_\varepsilon (h_\mu + 2h_\varepsilon)}. \quad (3)$$

Using standard global game techniques (see the Appendix for details), the following result obtains.

Proposition 1. *If $\gamma \leq \frac{2\pi}{c^2}$, there is a unique equilibrium. In this equilibrium, at $t = 1$, every investor j in bank i rolls over his investment if and only if $\rho_j \geq \rho_i^*$, where ρ_i^* is the unique solution to*

$$\rho_i^* = c \times \Phi(\sqrt{\gamma}(\rho_i^* - \mu)) - \mathbb{E}_1(\eta_i), \quad (4)$$

and $\Phi(\cdot)$ is the standard normal cumulative distribution function.

From Proposition 1, the rollover (sub)game has a unique equilibrium, provided the precision of investors' private signals, h_ε , is high enough relative to the precision of the prior distribution of $\tilde{\mu}$, h_μ (i.e., γ is small enough). In this equilibrium, investors follow a threshold strategy, that is, they withdraw if and only if their posterior belief, ρ_j , is strictly lower than a threshold ρ_i^* .¹³ Note that the properties of this equilibrium are economically sensible in that the probability of a bank run is related to the bank's underlying fundamentals. (Thus, bank runs are not sun-spot phenomena). In particular, bank runs are more likely if the two components of the bank's expected return, μ and $\mathbb{E}_1(\eta_i)$, are lower, and if the strength of the negative externality that early withdrawals exert on investors who roll over, c , is higher.

Another well-known feature of global games is that equilibrium properties carry over to the limit in which signals become infinitely precise. In particular, consider the case in which

¹²Section 2.3 considers the general case in which p is not common knowledge at $t = 1$. In such a case, $\mathbb{E}_1(\eta_i)$ depends on investors' beliefs about p under opacity. Note however that the analysis of the rollover subgame can accommodate any specific way investors form beliefs about η_i before making rollover decisions, as we study strategies taking $\mathbb{E}_1(\eta_i)$ as given.

¹³To simplify the exposition we assume that if an investor is indifferent between rolling over and withdrawing his investment, he will roll it over.

both h_μ and h_ε go to $+\infty$ and the ratio $\frac{h_\mu^2}{h_\varepsilon}$ goes to zero, that is, let the prior belief on $\tilde{\mu}$ become very precise but the private signals on $\tilde{\mu}$ become even more precise. In this limit case, the model with dispersed private information that was introduced in this section converges to the original model described in section 1, in which μ is common knowledge. However, the equilibrium retains the properties of Proposition 1.

Corollary 1. *Let $h_\mu \rightarrow +\infty$ and let $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$. Then, at $t = 1$, every investor in bank i rolls over his investment if and only if*

$$\mu + \mathbb{E}_1(\eta_i) \geq \frac{c}{2}. \quad (5)$$

This limit equilibrium is well defined and preserves the economic properties of the non-limit case, while avoiding some of its technical complexities.¹⁴ Specifically, in the unique equilibrium, investors are more willing to roll over their investment the higher the expected return, $\mu + \mathbb{E}_1(\eta_i)$, and the lower the liquidation costs, c . In the rest of the paper, we will focus on this limit case, as it allows to study the optimal disclosure policy in a simple and tractable framework.

2.2 Disclosure Policy in the Baseline Case

We start the analysis of the optimal transparency policy with the basic case in which information about aggregate shocks is common knowledge. That is, at $t = 1$, before the rollover decision is made, investors learn p , the proportion of high-quality banks in the financial

¹⁴Note that if one takes the limit of h_μ to $+\infty$ without taking the limit of h_ε to $+\infty$ at a fast enough rate, the model would revert to multiple equilibria. In a model of credit risk, Morris and Shin (2004) consider a similar case where both the precision of the prior distribution, h_μ , and the precision of the private signals, h_ε , go to infinity. In models of global games, it is customary to assume, for tractability, that h_ε goes to infinity. The additional assumption that h_μ goes to infinity simplifies the exposition further. We show in Appendix B that the optimal transparency policy (as characterized in Proposition 2 below) takes the same form when $h_\mu < +\infty$ as when $h_\mu \rightarrow +\infty$.

system. Investors, however, cannot distinguish on their own between high- and low-quality banks, i.e., between $\eta_i = \Delta_\eta$ and $\eta_i = -\Delta_\eta$. The regulator has access to this information and must decide whether or not to disclose it to investors. Consider first the case in which the regulator decides to be transparent and discloses the quality of each individual bank. In that case, bank i 's investors roll over their investment if and only if $\mu + \eta_i \geq \frac{c}{2}$, which, given the assumption in (1), implies that investors roll over their investment if and only if the bank is of high quality, $\eta_i = \Delta_\eta$. Hence, the aggregate net returns generated by the banking system under a policy of transparency are $p(\mu + \Delta_\eta)$.

Alternatively, consider the case in which the regulator decides to be opaque and does not disclose information at $t = 1$. Then, $\mathbb{E}_1(\eta_i) = (2p - 1)\Delta_\eta$ and investors roll over their investment if and only if $\mu + (2p - 1)\Delta_\eta \geq \frac{c}{2}$. Hence, the net returns of the banking system under a policy of opacity are

$$\begin{cases} \mu + (2p - 1)\Delta_\eta & \text{if } \mu + (2p - 1)\Delta_\eta \geq \frac{c}{2}, \\ 0 & \text{if } \mu + (2p - 1)\Delta_\eta < \frac{c}{2}. \end{cases} \quad (6)$$

The next proposition follows from this discussion:

Proposition 2. *The regulator follows a policy of transparency if and only if $p < p^*$ where*

$$p^* \equiv \frac{1}{2\Delta_\eta} \left(\frac{c}{2} - \mu \right) + \frac{1}{2}.$$

From Proposition 2, the optimal disclosure policy is contingent on p , the proportion of high-quality banks in the financial system. If the financial system suffers a negative shock and p falls below some threshold p^* , then it becomes optimal to disclose information about the quality of each individual bank. Otherwise, it is optimal for the regulator to be opaque and not disclose information. This result relies on the properties of the bank run equilibrium, in which the mass of withdrawals is a non-linear function of a bank's expected return. Specifically, under good economic conditions, pooling the most profitable banks with a few

lower-quality banks has little effect on the rollover risk of the former, while it significantly reduces the probability of runs on the latter.¹⁵ This pooling equilibrium without bank runs is sustainable as long as the proportion of high-quality banks in the financial system, p , is large enough. Otherwise, pooling leads to runs on all banks (both high- and low-quality).

The disclosure policy in Proposition 2 is consistent with the heightened disclosure of information via stress tests during the recent financial crises. Indeed, Governor D. Tarullo from the Federal Reserve Board of Governors argued that the publication of stress tests performed on U.S. banks helped stabilize the financial system during the 2008-09 crisis. “*This departure from the standard practice of keeping examination information confidential was based on the belief that greater transparency of the process and findings would help restore confidence in U.S. banks at a time of great uncertainty.*” [Keynote speech at the Federal Reserve Board International Research Forum on Monetary Policy, Washington, D.C., 26 March 2010.] Recent empirical evidence supports the view that stress tests provided useful information to market participants, despite some credibility issues (particularly in the European case, as we discuss in Section 2.3 below). Bayazitova and Shivdasani (2012) find evidence of a certification effect from the Supervisory Capital Assessment Program (SCAP) implemented in the U.S. in 2009: excess returns averaged 7.3% for those banks subject to the SCAP around the official announcement of the test results. Peristiani et al. (2010) confirm that although the market had correctly anticipated which banks would have a capital gap, the SCAP was informative about the size of the gap. Finally, Ellahie (2013) finds that information asymmetry declined for tested banks following the disclosure of the 2011 stress test results in Europe. Consistent with our specification of information disclosure, Hirtle et al. (2009) and Peristiani et al. (2010) also point out that the 2009 SCAP was especially suited to determining banks’ relative value due to its horizontalism. Indeed, the SCAP banks were subject to simulta-

¹⁵This non-linearity is not particular to our setting. See, e.g., Goldstein and Pauzner (2005).

neous examinations with the same underlying assumptions about economic conditions and loan losses, and the same quantitative techniques.¹⁶

We conclude this section by briefly discussing the assumption that disclosure policy involves either full transparency or full opacity. If the proportion of high-quality banks is below p^* , the regulator could, in principle, disclose information (and cause a run) on a subset of low-quality banks only, rather than disclose information on all banks and cause a run on every low-quality bank. Notice that under this alternative disclosure rule, there would still be an increase in disclosure during financial crises and the purpose of disclosure would again be to prevent a run on the whole banking system. However, implementing a policy of selective disclosure can be difficult in situations in which the regulator has private information about the average quality of banks in the financial system. As the analysis in the next section shows, the regulator then faces a commitment problem which makes disclosure policies that give him extensive discretion more difficult to implement.

2.3 Disclosure with Asymmetric Information about Aggregate Risk

In the previous section, we assumed that p was common knowledge at $t = 1$. While investors can indeed learn about the economy and the financial system as a whole from a wide variety of sources, in many instances the regulator also has some private information about aggregate shocks to the financial system. In this section, we consider the optimal disclosure policy when the regulator has private information about p .

¹⁶The usefulness of stress test results for market participants relates to a recent literature on opacity in financial systems that suggests that bank claims are designed to limit investors' incentives to acquire information (see, e.g., Gorton and Ordoñez, forthcoming; Dang et al., 2013). Morgan (2002) investigates the relative opacity of banks using disagreement between the major bond-rating agencies as a proxy for uncertainty, and finds that raters split substantially more often over the bank issues than over other issues. The author interprets this finding as evidence that banking firms are more opaque than other sorts of firms.

The following proposition characterizes the optimal disclosure policy if investors do not observe p and the regulator can commit to a disclosure policy as a function of p .

Proposition 3. *If the regulator can commit to a disclosure policy as a function of p , then he discloses information $\{\eta_i\}_{i \in [0,1]}$ if and only if p is below some threshold p^C such that*

- if $\mu \geq \frac{c}{2}$, $p^C = 0$, that is, information $\{\eta_i\}_{i \in [0,1]}$ is never disclosed;
- if $\mu < \frac{c}{2}$, p^C is the unique solution to $\mathbb{E}(p|p > p^C) = p^*$.

As in the case in which investors observe p , the optimal disclosure policy is such that the system becomes transparent following a negative aggregate shock. Consider first the case where $\mu \geq \frac{c}{2}$, that is, the case in which investors rollover their investments if they cannot distinguish between banks and do not update their beliefs on p . Since a policy of unconditional opacity does not convey any information on p , it prevents bank runs and is therefore optimal. Turn now to the case where $\mu < \frac{c}{2}$. Then, since runs are inefficient, the optimal disclosure policy maximizes the mass of states in which the regime is opaque, subject to the constraint that investors do not run, i.e., subject to the constraint that the probability of a high-quality bank conditional on opacity is larger than p^* (as defined in Proposition 2). This yields a threshold p^C which is the unique solution to $\mathbb{E}(p|p > p^C) = p^*$. Notice that asymmetric information about p leads to less information disclosure by the regulator: $p^C < p^*$. Intuitively, there can now be pooling not only between high- and low-quality banks, but also across different states of the economy (i.e., realizations of p).

The equilibrium in Proposition 3 relies on the ability of the regulator to commit to a disclosure policy as a function of his private information on p . While factors such as reputation could help sustaining the optimal policy with commitment as an equilibrium, it is also plausible that the regulator may have incentives to renege on his commitment in some

instances.¹⁷ The following proposition characterizes the regulator’s disclosure policy when he cannot commit.

Proposition 4. *If the regulator cannot commit to a disclosure policy as a function of p , there is no equilibrium with a p -contingent transparency policy. There always exists a fully transparent equilibrium, and if $\mu \geq \frac{\epsilon}{2}$, there also exists a more efficient equilibrium which is fully opaque.*

Proposition 4 illustrates the difficulties of credibly implementing a state-contingent disclosure policy. Suppose there exists a non-empty p -region $O \subset (0, 1)$, in which the regulator chooses opacity. Then, it must be that runs do not occur if $p \in O$, that is, $\mathbb{E}[p|p \in O] \geq p^*$, otherwise, the regulator would be better off switching to transparency and saving the high-quality banks. But then, for any $p' \notin O$, switching from transparency to opacity increases total expected surplus from $p'(\mu + \Delta_\eta)$ to $p'(\mu + \Delta_\eta) + (1 - p')(\mu - \Delta_\eta)$, so that the regulator has ex-post incentives to deviate and also choose opacity for all $p \notin O$. Hence the only possible equilibrium featuring some opacity is, in fact, a fully opaque equilibrium. However, if $\mu < \frac{\epsilon}{2}$, a fully opaque equilibrium without runs is not sustainable, and the only equilibrium involves full transparency. Intuitively, if the regulator could commit, it would be optimal to disclose information only when the average quality p is low. Under this policy, however, no news is good news and therefore, an increase in transparency would lead investors to revise their expectation of p downwards. This creates an incentive for the regulator to withhold information ex-post, which undermines his credibility and precludes any p -contingent equilibrium policy.

Overall, Proposition 4 raises two issues. First, under asymmetric information, the lack of commitment ability may prevent the regulator from implementing a p -contingent disclosure

¹⁷Morrison and White (2011) and Shapiro and Skeie (2012) study how the regulator’s reputational concerns may affect his disclosure policy.

policy, as is optimal in Propositions 2 and 3. Second, there is some indeterminacy regarding the regulator's disclosure policy, as equilibria with full transparency and full opacity may coexist. We show next that while the regulator indeed faces a commitment problem, the inability to implement a p -contingent disclosure policy and the multiplicity of equilibria are driven by two assumptions. Namely, that investors do not learn anything about aggregate shocks to the financial system, p , and that the regulator cannot credibly disclose p without also disclosing bank specific information $\{\eta_i\}_{i \in [0,1]}$. We explore the impact of these two assumptions in the remainder of this section.

We enrich the model by allowing investors to observe a noisy signal z about p at $t = 1$, after the regulator has chosen a disclosure policy but before investors' rollover decision. Specifically,

$$z = p + u,$$

where u is uniformly distributed on $[-\frac{\delta}{2}, +\frac{\delta}{2}]$. The parameter δ provides a continuous measure of the degree of asymmetric information between the regulator and the investors. This specification nests the cases in which p is common knowledge (i.e., $\delta \rightarrow 0$), and in which investors do not receive any signal about aggregate shocks to the financial system (i.e., $\delta \rightarrow +\infty$). Note that under opacity, investors' posterior belief about p now depends on the signal z as well as on their belief about the regulator's equilibrium disclosure policy. The only restriction we impose on investors' out-of-equilibrium beliefs is that they must be consistent with the signal z , that is, when observing z , investors believe that $p \in [z - \frac{\delta}{2}, z + \frac{\delta}{2}]$.¹⁸

We first consider the equilibrium disclosure policy under the same conditions as in Propo-

¹⁸If we let $O^* \subset (0, 1)$ be the set of ps in which the regulator chooses opacity in equilibrium, then, when $[z - \frac{\delta}{2}, z + \frac{\delta}{2}] \cap O^*$ is non-empty and the regulator chooses opacity, investors update their belief about p using Bayes' rule. Out of equilibrium, that is, when $[z - \frac{\delta}{2}, z + \frac{\delta}{2}] \cap O^*$ is empty and the regulator deviates and chooses opacity, we only impose that the support of investors' posterior belief about p is a subset of $[z - \frac{\delta}{2}, z + \frac{\delta}{2}]$. (See Angeletos et al. (2006) for a similar restriction on out-of-equilibrium beliefs.)

sition 4, that is, when the regulator cannot commit to a disclosure policy nor credibly disclose p without disclosing $\{\eta_i\}_{i \in [0,1]}$.¹⁹

Proposition 5. *If $\delta < \min\{p^*, 1 - p^*\}$ there is a unique equilibrium in which the regulator follows a policy of transparency if and only if $p < p^{NC}(\delta)$. The disclosure threshold $p^{NC}(\delta)$ is such that $0 < p^{NC}(\delta) < p^*$, and decreases in δ .*

Proposition 5 shows that if $\delta < \min\{p^*, 1 - p^*\}$, there is a unique equilibrium in which the regulator increases transparency following a negative shock to the financial system (i.e., a low realization of p). The condition $\delta < 1 - p^*$ guarantees the existence of a p -region in which runs do not occur under opacity. Indeed if $p > p^* + \delta$, even the smallest possible signal that investors can receive, $z = p - \frac{\delta}{2}$, reveals that p is larger than p^* , i.e., $p - \frac{\delta}{2} > p^* + \frac{\delta}{2}$. Hence for $p > p^* + \delta$, opacity allows to save all banks with probability one, and is therefore the regulator's best response to investors' equilibrium strategy in the rollover subgame, for any beliefs investors may hold about the disclosure policy. Notice that this upper dominance region $[p^* + \delta, 1)$ can be arbitrarily small provided it exists. That is, Proposition 5 only requires the existence of states of the economy, however unlikely, in which the fundamentals are strong enough so that the financial system does not face the risk of a systemic run. Similarly, condition $\delta < p^*$ guarantees that for small enough realizations of p , transparency is optimal as investors can infer from z that p is smaller than p^* . Again, this lower dominance region $(0, p^* - \delta)$ can be arbitrarily small. Once these two regions exist, the unique equilibrium is a threshold equilibrium as indicated in Proposition 5.

While the optimal disclosure policy in Proposition 5 is similar to the ones in Propositions 2 and 3 (that is, disclosure takes places when p falls below some threshold), there is an important economic difference between them. Namely, in Proposition 5, runs can occur

¹⁹To simplify the exposition we assume that if the regulator is indifferent between disclosing and not disclosing information, then he does not disclose information.

under opacity in equilibrium. Specifically, one can show that in any equilibrium in which opacity is followed for some realizations of p , investors run under opacity if their signal z falls below some (endogenously determined) threshold z^* (see Appendix). Hence, for each p , the regulator faces a trade-off between a transparent regime with frequent runs that affect only a few banks, and an opaque regime in which runs are less frequent but can affect the entire banking system. This trade-off also provides the intuition for Proposition 5. The existence of an upper dominance region guarantees that the regulator chooses opacity for high enough realizations of p . Then, given that the regulator chooses opacity in this upper dominance region, it becomes optimal to choose opacity for realizations of p close to that region from below. However, as p decreases, the probability that z falls below z^* increases, and so does the probability of a run on the entire system under opacity. Hence, the opacity region spreads from the top until the regulator becomes indifferent between opacity and transparency, which determines $p^{NC}(\delta)$.²⁰ The existence of a lower dominance region guarantees that the probability of a systemic run under opacity increases fast enough as p decreases, so that $p^{NC}(\delta) > 0$.

Finally, Proposition 5 also shows that under the optimal disclosure policy, $p^{NC}(\delta) < p^*$. That is, even without the ability to commit, there is some pooling across different states of the economy (i.e., realizations of p). Interestingly, however, the regulator's inability to commit to a p -contingent disclosure policy ex-ante is still costly:

Corollary 2. *If $\delta < \min\{p^*, 1 - p^*\}$ and the regulator can commit to a disclosure policy ex-ante, it is optimal to be opaque above a threshold that is below p^* but above $p^{NC}(\delta)$.*

That is, the regulator would like to commit to disclose more information (i.e., to a higher

²⁰Two forces play in the same direction here. First, for a fixed z^* , a lower p increases the probability that $z = p + u$ falls below z^* . In addition, as the opacity region spreads from the top, z^* increases because opacity becomes in itself a weaker signal of a high realization of p .

disclosure threshold), but because no news is good news, he has ex-post incentives to be opaque down to $p^{NC}(\delta)$. Intuitively, once p is realized, the regulator does not internalize that decreasing the disclosure threshold $p^{NC}(\delta)$ increases z^* , and hence, increases the ex-ante probability of a run for every p in which the system is opaque. (Investors run under opacity if their signal z falls below z^* .) Therefore, the regulator has an excessive tendency to withhold information: he chooses to be opaque ex-post in some states in which it would be ex-ante optimal to choose transparency, which increases the probability of a systemic run. This commitment problem is consistent with the ambiguous reaction to the disclosure of the 2011 European stress tests results. For instance, Ellahie (2013) finds that, following the disclosure of the results, information asymmetry declined gradually, but also that information uncertainty increased significantly. The author interprets this finding as suggesting that while the revealed information enabled investors to sort banks, uncertainty worsened either due to low test credibility and unresolved bank capital plans, or due to negative signals about fundamentals.²¹

Overall, Proposition 5 shows that a p -contingent transparency policy is robust to asymmetric information provided that mistakes by investors cannot lead to runs under the best possible economic conditions or prevent runs under the worse possible ones. As one would expect (the models are nested), when δ is large enough, the optimal disclosure policy is as in Proposition 4:

Corollary 3. *If $\delta > 1 - p^*$ there always exists a fully transparent equilibrium. In addition when $\mu \geq \frac{c}{2}$, there also exists a more efficient equilibrium that is fully opaque if $\delta > \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta}$.*

Hence, like in Proposition 4, the signalling effect of the disclosure policy may generate

²¹There is also evidence pointing to the European regulatory authorities withholding information during the crisis. For instance, the 2011 stress tests on Irish banks conducted largely by outside independent advisors (BlackRock) revealed a total capital need of €24 billions while all banks had previously passed the 2010 stress test performed by the Committee of European Banking Supervisors. See Schuermann (2013).

multiple equilibria when δ is large, that is, when investor's information about p is very imprecise. Notice, however, that investors can acquire information about the economy as a whole -about p - from a wide variety of sources (e.g., stock market, consumption and investment expenditures, unemployment, etc.), and hence, it seems reasonable to assume that investors learn p with a certain degree of precision.

While credibility issues can make selective disclosure difficult to implement in practice, we close this section with the case in which the disclosure of aggregate information can be decoupled from the disclosure of bank-specific information. This last case emphasizes the differences between the release idiosyncratic and aggregate information. Specifically, while we still assume that the regulator lacks the ability to commit to a disclosure policy, we now allow for the possibility of credibly disclosing p without disclosing $\{\eta_i\}_{i \in [0,1]}$.

Proposition 6. *For any finite δ , the regulator discloses $\{\eta_i\}_{i \in [0,1]}$ if and only if $p < p^*$, and discloses p for $p \in [p^*, p^{Cr}(\delta))$ with $p^{Cr}(\delta) > p^*$.*

When the regulator can credibly disclose p , even if δ is arbitrarily large, aggregate information unravels and the optimal disclosure policy produces the same economic outcome –runs on low-quality banks if $p < p^*$ – as when p is common knowledge.²² Indeed, when $p \in [p^*, p^{Cr}(\delta))$, the regulator now has an ex-post incentive to disclose p in order to avoid being pooled with lower p -types. From an ex-ante point of view, however, this means that there cannot be any pooling across states. This is another manifestation of the commitment problem that the regulator faces when he possesses private information about p : while the regulator still has the ability to retain bank-specific information and provide insurance across banks for $p \geq p^*$, unravelling of aggregate information prevents him from providing

²²If $\delta = +\infty$ (i.e., investors' signal is uninformative), the equilibrium in Proposition 6 may coexist with another fully opaque equilibrium. However, that second equilibrium is not robust to investors receiving an informative signal z , however imprecise this signal might be, that is, for δ arbitrarily large.

any insurance across different states of the economy (i.e., realizations of p).

In line with previous results, Proposition 6 also suggests an optimal disclosure policy in which transparency increases as fundamentals deteriorate, but introduces a gradation in information release. For p above $p^{Cr}(\delta)$ the regulator follows a policy of opacity, for $p \in [p^*, p^{Cr}(\delta))$ the regulator discloses p but not bank-specific information, and for $p < p^*$ he discloses bank-specific information.²³ This prediction is consistent with the fact that the American stress test of 2009 (SCAP), which was undertaken in the middle of the U.S. financial crisis, disclosed more information than the stress test of 2011 (CCAR). More importantly, while the SCAP disclosed bank-specific information, the CCAR only disclosed the macro-scenario but no bank level results (see Schuermann, 2013).

Note that regulators may differ in their ability to credibly disclose aggregate information. Indeed, Freixas and Laux (2012), Greenlaw et al. (2012) and Schuermann (2013) point out that European regulatory authorities faced greater credibility issues than U.S. authorities. When such credibility issues arise, it might be necessary to expand the scope of information release and disclose bank-specific details to convince investors.²⁴ For instance, stress tests were conducted in 2011 just on Irish banks with a much higher degree of disclosure than the previous 2009 and 2010 tests conducted at the European level. Similarly, the 2011 European

²³For $p \geq p^{Cr}(\delta)$, the regulator is indifferent between disclosing p and opacity as both produce the same outcome –no runs–, and hence, any arbitrarily small cost of disclosing information would lead the regulator to choose opacity. Intuitively, when p is large enough (i.e., $p \geq p^{Cr}(\delta)$), there is no enough overlap between the set signals z that can be generated from $p \geq p^{Cr}(\delta)$ and from $p < p^*$, and therefore, the regulator has no incentive to deviate to opacity when p is below p^* .

²⁴Note that, as in the baseline model, the communication of relative information about banks by the regulator is always credible (Chakraborty and Harbaugh, 2007). Kamenica and Gentzkow (2010) also shows that persuasion –inducing a change in beliefs– depends crucially on the design of a signal-generating mechanism (e.g., stress tests) and on the understanding of this mechanism by information receivers. Building on this idea, Gick and Pausch (2012) show that credible communication of stress test results might require disclosing both the signal and the signal generating process.

wide stress tests conducted by the European Banking Authority (EBA) also disclosed more information than the earlier European tests. Schuermann (2013) argues that this level of details was necessary to make information release credible.²⁵ Nonetheless, Propositions 5 and 6 combined suggest an equilibrium disclosure policy where transparency increases in bad economic times, whether the regulator has the ability to credibly disclose aggregate information or not.

In summary, this section highlights the conditions under which the regulator still follows a p -contingent disclosure policy -as in the baseline model- even when he has private information about aggregate shocks, p . First, if the regulator can commit ex-ante to a p -contingent transparency policy, a policy of opacity in good times is optimal, not only as an insurance mechanism across banks, but also as an insurance against (moderate) aggregate shocks to the financial system. Second, if the regulator is not able to commit but can credibly disclose aggregate information on p without disclosing idiosyncratic information on $\{\eta_i\}_{i \in [0,1]}$, private information on p unravels and, in equilibrium, withdrawals decisions are identical to the case in which p is public information. Finally, if in addition to his commitment problem, the regulator cannot credibly disclose p without disclosing $\{\eta_i\}_{i \in [0,1]}$, the unique equilibrium strategy is still to increase transparency in bad times as long as investors have access to accurate enough –yet imperfect– information about aggregate shocks. Importantly, while the regulator may still be able to use the contingent disclosure of bank-specific information to provide insurance against idiosyncratic shocks, his inability to commit prevents him from providing insurance against aggregate shocks in a way that is ex-ante optimal.

²⁵ “*This is precisely what was done in the Irish bank stress test of 2011, an acute case of loss of confidence (and subsequent regaining), as well as the 2011 EBA stress test. Because credibility of European supervisors was rather low by that point, only with very detailed disclosure, bank by bank, of their exposures by asset class, by country, by maturity bucket, could the market do its own math and arrive at its own conclusions.*” (Schuermann, 2013)

This section of the paper is related to Angeletos et al. (2006), who show that a policy maker’s action can signal aggregate information in a coordination game between agents, in a similar way as the disclosure policy conveys aggregate information in the current paper. The equilibrium multiplicity we obtain in Propositions 4 (and Corollary 3) is reminiscent of the self-fulfilling “policy traps” that constitute the focus of their paper. However, Angeletos et al. (2006) feature a signalling game in which the policy-maker can take a costly action –a policy– that directly affects the agents’ payoff from taking an action that is detrimental to the policy-maker, e.g., a currency attack or a bank run. By contrast, the regulator’s action in the current paper, disclosing information, is costless and only affects investors’ expected payoffs through an information channel. Moreover, because our game is one of information disclosure, it allows to study the different economic principles that lead to the release of aggregate and bank-specific information. The central role of idiosyncratic information also distinguishes our paper from earlier contributions on the role of public information in coordination games. As in Angeletos and Pavan (2007), in our model, agents (investors) exert payoff externalities on each other, and therefore, information can have a positive or a negative social value. However, in Angeletos and Pavan (2007) agents learn about a common aggregate component, and hence, public information is socially valuable to the extent that it brings agents closer to the socially optimal coordination level (see also Morris and Shin, 2002, and Metz, 2002). By contrast, in our model, agents learn about a continuum of idiosyncratic components, and hence, information is simultaneously positive in one dimension and negative in another one. As a result, information disclosure leads some investors to coordinate on the socially efficient action (rollover) and some other investors to coordinate on the socially inefficient one (withdraw). The overall social value of information depends on the relative importance of these two effects.

3 Cross-Exposures and Imperfect Information

In this section we enrich the model by allowing for the possibility of cross-exposures and imperfect information. Indeed, one of the salient features of the financial system is that banks are interconnected, and hence, liquidity problems in a subset of banks are likely to have contagion effects across the whole financial system. Section 3.1. studies the optimal disclosure policy in the presence of cross-exposures. A second simplifying assumption made in the previous section is that the regulator learns each bank's type perfectly while investors do not receive any bank-specific information. In practice, however, the regulator's information is not perfect and investors –the markets– do have some ability to discriminate between banks on their own. Section 3.2. studies the optimal disclosure policy when both investors and the regulator have imperfect bank-specific information.

3.1 Optimal Disclosure with Cross-Exposures

Until now, we have assumed that the early liquidation of assets by a bank has no direct impact on other banks in the financial system. In other words, by withdrawing at $t = 1$, an investor in bank i alters the long-term payoffs of other investors in the same bank but has no effect on the payoffs of investors in other banks $j \neq i$.

In this section, we explore the possibility that banks' interconnectedness creates externalities between investors' rollover decisions, not only within banks but also across banks. These cross-exposures can be caused by a pecuniary externality: if the market has a limited capacity to absorb asset sales at $t = 1$, liquidations by some banks may have an impact on market prices, as in Allen and Gale (2004). This, in turn, can make capital requirements binding for other banks in the system, forcing them to liquidate assets and lowering long-term returns for investors (Brunnermeier and Pedersen, 2009). Externalities between banks

may also be the result of direct cross-exposures. In a system where banks refinance each other, a run on one bank dries up a source of liquidity for the other banks (Allen and Gale, 2000; Dasgupta, 2004).²⁶

We introduce cross-exposures in the model by assuming that the payoff at $t = 2$ of a bank- i investor who chooses to rollover at $t = 1$ is

$$1 + \tilde{\mu} + \eta_i - c \left[(1 - \alpha_i)l_i + \alpha_i \int_{z \neq i} \frac{\alpha_z}{\int_{j \neq i} \alpha_j dj} l_z dz \right], \quad (7)$$

where, as earlier, l_i is the mass of withdrawals from bank i , $\int_{z \neq i} \frac{\alpha_z}{\int_{j \neq i} \alpha_j dj} l_z dz$ is the weighted average of withdrawals from all other banks in the system, and $\alpha_i \in [0, 1]$ parametrizes the strength of liquidity externalities between bank i and other banks in the system. Indeed, when α_i increases, investors in bank i become more exposed to rollover decisions in the rest of the system. Symmetrically, when α_i increases, the rollover decisions of investors in bank i have a relatively higher impact on the liquidity of the rest of the system.²⁷ This specification presents several advantages. First, it nests the original model (i.e., $\alpha_i \rightarrow 0$ for all i) and can therefore be seen as a generalization as well as a robustness check. Second it takes a neutral stance on the overall impact of interconnectedness between banks: as α_i increases, the magnitude of the externality that each investor exerts on other investors remains constant, but progressively shifts from being mostly concentrated on investors in the same bank to investors in other connected banks. In other words, α_i affects the degree of cross-exposure without making strategic complementarities intrinsically stronger. This is in line with the idea that interconnections between banks bring benefits (e.g., diversified

²⁶Banks may also have direct cross-exposures through OTC derivative contracts or simply through customary trading relationships that are difficult and costly to replace if severed (Babus, 2009).

²⁷While this symmetry seems a natural assumption, an alternative specification in which the impact of bank j on bank i does not depend on the exposure of bank j to the system, that is, long-term return is $1 + \tilde{\mu} + \eta_i - c \left[(1 - \alpha_i)l_i + \alpha_i \int_{z \neq i} l_z dz \right]$, produces qualitatively similar results.

sources of funding, cross-insurance), as well as contagion effects.

Note also that α_i is bank-specific, that is, we allow for banks to vary along the cross-exposure dimension, in addition to the return dimension, η_i . To keep the exposition simple, we assume that there are two types of banks as far as cross-exposures are concerned. A mass q of banks have a positive and symmetric exposure to the system, $\alpha_i = \alpha$, and a mass $1 - q$ of banks have no exposure, $\alpha_i = 0$. We also assume that η_i and α_i are independent.²⁸ At $t = 1$, the regulator has private information about both bank-idiosyncratic shocks, $\{\eta_i\}_{i \in [0,1]}$, and cross-exposures, $\{\alpha_i\}_{i \in [0,1]}$. That is, we assume that p and q are common knowledge but investors cannot distinguish on their own between high- and low-quality banks and between banks with and without cross-exposures.²⁹ Hence, the bank-idiosyncratic information that investors have about the system before their rollover decision (which we denote σ) depends on the regulator's disclosure policy: if the system is fully opaque, $\sigma = \{\emptyset\}$; if the regulator discloses idiosyncratic shocks without disclosing cross-exposures, $\sigma = \{\eta_i\}_{i \in [0,1]}$; and if the regulator discloses both idiosyncratic shocks and cross-exposures, $\sigma = \{\eta_i, \alpha_i\}_{i \in [0,1]}$. Note that the regulator could in principle disclose cross-exposures, $\{\alpha_i\}_{i \in [0,1]}$, without disclosing shocks, $\{\eta_i\}_{i \in [0,1]}$. However, this would generate the same rollover decisions as full opacity. Intuitively, when the regulator does not disclose shocks, investors perceive banks as identical in terms of long-term returns. Therefore, for an investor in bank i , forming beliefs about the behavior of investors in other banks $z \neq i$ is not different from forming beliefs about investors in his own bank i . Hence, whatever the strength of the liquidity externalities between banks, $\{\alpha_i\}_{i \in [0,1]}$, the rollover game is not fundamentally different from one in which each investor only cares about rollover decisions within his own bank. In other words, cross-exposures

²⁸A specification in which η_i and α_i are imperfectly correlated delivers the same insights

²⁹The idea that investors are uncertain about banks' cross-exposures is central in Caballero and Simsek (forthcoming).

matter only to the extent that investors perceive differences in fundamentals –in long-term returns– across banks.

When the regulator discloses long-term returns, the presence of cross-exposures modifies the nature of the rollover game (relative to the one in Section 2.1). For instance, consider the case in which the system is fully transparent, that is, the case in which the regulator discloses both idiosyncratic shocks and cross-exposures. In such a case, an investor in a connected bank has to form beliefs not only about the actions of other investors in the same bank, but now also about the actions of investors in all other connected banks. Hence, in equilibrium, the strategy of investors in connected low-quality banks feeds back into the strategy of investors in connected high-quality banks (and vice-versa) so that their withdrawal thresholds have to be jointly determined. Nonetheless, since the game is still one of strategic complementarities between investors within and across banks, the main intuitions of the global games analysis still apply. In particular, if we let

$$\xi \equiv \frac{h_\mu^2(h_\mu + h_\varepsilon)(2h_\varepsilon + h_\mu)}{h_\varepsilon^3},$$

the following lemma shows that provided that $\xi < \frac{2\pi}{c^2}$, the unique equilibrium of the rollover game is a threshold equilibrium in which the threshold for each bank i depends on the disclosure policy.

Lemma 1. *If $\xi < \frac{2\pi}{c^2}$, the rollover game has a unique equilibrium in which every investor in bank i withdraws if and only if his posterior belief ρ_j is strictly lower than a threshold $\rho_i^*(\sigma)$.*

As in Section 2, the limit case in which the prior distribution of $\tilde{\mu}$ and private signals become infinitely precise provides economic intuitions in the simplest possible form. One can then characterize equilibrium withdrawal decisions in closed forms as a function of investors information, σ , and the magnitude of the aggregate shock, p .

Lemma 2. There exist five ordered thresholds, $p_\Delta < p_{\Delta,\alpha} < p^* < p_{-\Delta,\alpha} < p_{-\Delta}$, such that

1. If the system is completely opaque ($\sigma = \{\emptyset\}$), investors rollover if and only if $p \geq p^*$, where p^* is defined as in Proposition 2
2. If the regulator discloses idiosyncratic shocks but not cross-exposures ($\sigma = \{\eta_i\}_{i \in [0,1]}$), investors rollover if and only if $p \geq p_\Delta$ in banks where $\eta_i = \Delta_\eta$ and if and only if $p \geq p_{-\Delta}$ in banks where $\eta_i = -\Delta_\eta$.
3. If the regulator discloses idiosyncratic shocks and cross-exposures ($\sigma = \{\eta_i, \alpha_i\}_{i \in [0,1]}$), investors in bank i always rollover if $\eta_i = \Delta_\eta$ and $\alpha_i = 0$; never rollover if $\eta_i = -\Delta_\eta$ and $\alpha_i = 0$; rollover if and only if $p \geq p_{\Delta, \alpha}$ in banks where $\eta_i = \Delta_\eta$ and $\alpha_i = \alpha$; and rollover if and only if $p \geq p_{-\Delta, \alpha}$ in banks where $\eta_i = -\Delta_\eta$ and $\alpha_i = \alpha$.

Because banks are interconnected, investors' rollover decisions in the interim period now depend on the aggregate shock, p , even when idiosyncratic shocks, $\{\eta_i\}_{i \in [0,1]}$, are public information. As a result, if the system is always fully transparency, $\sigma = \{\eta_i, \alpha_i\}_{i \in [0,1]}$, cross-exposures have an ambiguous effect on banks' stability. On the one hand, a bank that is known by investors to be of high-quality might not be safe as it can be contaminated by liquidations in other banks when aggregate conditions deteriorate ($p < p_{\Delta, \alpha}$). On the other hand, a connected bank that is known by investors to be of low-quality benefits from the liquidity in the rest of system and hence might survive a moderate aggregate shock ($p \geq p_{-\Delta, \alpha}$). If the regulator can implement a contingent transparency policy, his optimal strategy follows directly from Lemma 2.

Proposition 7. *In the presence of cross-exposures, the optimal transparency policy is to be fully opaque for $p \geq p^*$, to disclose idiosyncratic shocks, $\{\eta_i\}_{i \in [0,1]}$, but not cross-exposures, $\{\alpha_i\}_{i \in [0,1]}$, for $p_\Delta \leq p < p^*$, and to disclose both idiosyncratic shocks and cross-exposures for $p < p_\Delta$.*

As in the baseline model, if $p \geq p^*$, a policy of opacity prevents any runs and hence is optimal. When fundamentals deteriorate, that is, if $p_\Delta \leq p < p^*$, then disclosing only

idiosyncratic shocks, $\{\eta_i\}_{i \in [0,1]}$, is enough to prevent runs on high-quality banks. In such case, disclosing also cross-exposures would result in a strictly inferior outcome if $p_\Delta \leq p < p_{\Delta, \alpha}$ as it would create runs on the fraction of high-quality banks that are connected. In other words, keeping cross-exposures opaque allows pooling within the subset of high-quality banks. Finally, when fundamentals deteriorate further, that is, if $p < p_\Delta$, disclosing both idiosyncratic shocks and cross-exposures allows to save those high-quality banks that are not exposed to the rest of the financial system. Overall, Proposition 7 shows that a disclosure policy in which transparency increases in bad economic times is robust to the introduction of bank cross-exposures. In fact, the presence of these interlinkages creates a gradation in the implementation of transparency which is in line with empirical evidence. As pointed out in Schuermann (2013) and Bischof and Daske (2012), the aggravation of the European financial crises was associated with an increased disclosure, and more importantly, following the stress tests in 2011, the European Banking Authority not only issued information about each of the participating banks' simulation results, but also about their type of exposures, such as financial institutions, real estate, sovereign debt, etc. The analysis also has implications for the relative importance of idiosyncratic shocks and cross-exposures in the regulator's disclosure policy:

Corollary 4. *p_Δ is an increasing function of α and q . Furthermore, if $2\Delta_\eta < \frac{cq\alpha}{2}$, then $p_\Delta = p^*$ and the regulator always discloses cross-exposures when $p < p^*$.*

From Corollary 4, if cross-exposures are stronger, either because a larger fraction of banks are interconnected (q is high), or because the banks that are interconnected have stronger ties (α is high), then the region in which the regulator keeps cross-exposures opaque (above p_Δ) shrinks. Moreover, if $2\Delta_\eta < \frac{cq\alpha}{2}$, that is if interlinkages are strong relative to idiosyncratic differences in long-term returns, it is never possible to separate banks without disclosing cross-exposures, $\{\alpha_i\}_{i \in [0,1]}$. Indeed, in this case, if only $\{\eta_i\}_{i \in [0,1]}$ disclosed, investors with-

draw from every bank, irrespective of its quality, as soon as $p < p^*$. In other words, the strategic complementarities that go through interlinkages between banks create contamination effects that are strong enough to overcome differences in long-term expected returns. This suggests that in highly connected financial systems, the disclosure of information about cross-exposures becomes an important tool through which the regulator can manage rollover risk in the system

As a final remark on the results in this section, note that in the model, investors can learn about the extent of banks' exposure to other banks in the financial system, which seems consistent with the disclosure of banks' exposures by industry in the 2011 European stress tests. We have also considered a variant of the model in which banks are matched into pairs, and exert liquidity externalities on each other within each pair. The regulator can then disclose not only the idiosyncratic shocks $\{\eta_i\}_{i \in [0,1]}$, but also the identity of each bank's counterpart. Hence, under a fully transparent regime, investors learn about the long-term return of their own bank as well as the long-term return of the bank to which their bank is exposed. In this alternative set up, we obtain the same predictions as in Proposition 7 above, that is, when liquidations in low-quality banks can contaminate high-quality banks, the regulator discloses long-term returns but not cross-exposures following moderate aggregate shocks, and long-term returns with cross-exposures after larger aggregate shocks (see Appendix B).

3.2 Imperfect Information

The analysis in Section 2 assumes that the regulator learns banks' type, $\{\eta_i\}_{i \in [0,1]}$, perfectly while investors do not receive any bank-specific information. This section explores the optimal disclosure policy when these two assumptions are relaxed. In particular, we assume that at $t = 1$, investors not only learn p , but now also receive a set of public signals $\{\zeta_i^I\}_{i \in [0,1]}$

about the quality of each individual bank. This information $\{\varsigma_i^I\}_{i \in [0,1]}$ captures the possibility that investors –the market– may have different priors for different banks. Similarly, the regulator receives a set of private signals $\{\varsigma_i^R\}_{i \in [0,1]}$ about $\{\eta_i\}_{i \in [0,1]}$, that is, the regulator has private bank-specific information, albeit imperfect. Each signal ς_i^A , where $A \in \{I, R\}$, can take two values: h and l (high and low). The probability that a high-quality bank generates a signal h is $\Pr(\varsigma_i^A = h | p, \eta_i = \Delta_\eta) = \theta^A + (1 - \theta^A)p$, and the probability that a low-quality bank generates a signal l is $\Pr(\varsigma_i^A = l | p, \eta_i = -\Delta_\eta) = \theta^A + (1 - \theta^A)(1 - p)$, where the parameter $\theta^A \in (0, 1)$ measures the informativeness or quality of the signal.³⁰ Notice that for any θ^A , this probability distribution always generates a proportion p of h signals and proportion $(1 - p)$ of l signals, *i.e.*, $\Pr(\varsigma_i^A = h | p) = p$. That is, since there is a proportion p of high-quality banks in the financial system, the signal classifies a proportion p of banks as high-quality (*i.e.*, a proportion p of banks generate a signal h) and a proportion $1 - p$ of banks as low-quality (*i.e.*, a proportion $1 - p$ of banks generate a signal l). Therefore, the quality θ^A of the signal just determines the extent of misclassifications, that is, the number of high-quality banks that are classified as low-quality banks and vice versa. At $t = 1$, the regulator decides his disclosure policy, which can be contingent on all public information, *i.e.*, p and $\{\varsigma_i^I\}_{i \in [0,1]}$. That is, a disclosure policy is a function $d(p, \varsigma^I) \rightarrow (T, O)$ that for each p can take four different values: full transparency, *i.e.*, $d(p, h) = d(p, l) = T$; full opacity, *i.e.*, $d(p, h) = d(p, l) = O$; transparency for banks that are perceived by investors as low-quality only, *i.e.*, $d(p, h) = O$ and $d(p, l) = T$; transparency for banks that are perceived by investors as high-quality only, *i.e.*, $d(p, h) = T$ and $d(p, l) = O$.

Let $\mathbb{E}_1(\eta_i | \sigma_i)$ be the expectation of η_i given investors' information σ_i about bank i at

³⁰If $\theta^A \rightarrow 1$, all high-quality banks generate a signal h and all low-quality banks generate a signal l , so the signal is perfectly informative. Alternatively, if $\theta^A \rightarrow 0$, both a high-quality bank and a low-quality bank generate a signal h with probability p , so the signal does not contain any bank-specific information. Moreover, the limit case $\theta^R \rightarrow 1$ and $\theta^I \rightarrow 0$ corresponds to the baseline model.

$t = 1$. ($\sigma_i = \{p, \varsigma_i^I, \emptyset\}$ if the regulator does not disclose ς_i^I and $\sigma_i = \{p, \varsigma_i^I, \varsigma_i^R\}$ if he does). This expectation satisfies the following two properties: $\frac{\partial \mathbb{E}_1(\eta_i|\sigma_i)}{\partial p} > 0$, and $\mathbb{E}_1(\eta_i|p, h, \emptyset) > \mathbb{E}_1(\eta_i|p, l, \emptyset)$, that is, the expectation of η_i is higher if there is a greater proportion of high-quality banks p , and if investors observe a high signal h rather than a low signal l . From Corollary 1, investors run on bank i if and only if $\mu + \mathbb{E}_1(\eta_i|\sigma_i) < \frac{c}{2}$. Hence, if we define \bar{p}^* as $\mathbb{E}_1(\eta_i|\bar{p}^*, l, \emptyset) \equiv \mu - \frac{c}{2}$, then it is optimal to disclose information when $p < \bar{p}^*$ for banks that are perceived by investors as low-quality (i.e., $\varsigma_i^I = l$). Similarly, if we define \underline{p}^* as $\mathbb{E}_1(\eta_i|\underline{p}^*, h, \emptyset) \equiv \mu - \frac{c}{2}$, then it is optimal to disclose information when $p < \underline{p}^*$ for banks that are perceived by investors as high-quality (i.e., $\varsigma_i^I = h$). Furthermore, the two aforementioned properties imply that $\bar{p}^* > \underline{p}^*$. The following proposition summarizes this discussion and characterizes the optimal disclosure policy.

Proposition 8. *There are two thresholds \underline{p}^* and \bar{p}^* , where $\bar{p}^* > p^* > \underline{p}^*$, such that (i) for $p \geq \bar{p}^*$, it is optimal to follow a policy of full opacity (i.e., $d(p, h) = d(p, l) = \text{O}$); (ii) for $p \in [\underline{p}^*, \bar{p}^*)$, it is optimal to disclose information on banks that are perceived as low-quality by investors (i.e., $d(p, h) = \text{O}$ and $d(p, l) = \text{T}$); and (iii) for $p < \underline{p}^*$, it is optimal to follow a policy of full transparency (i.e., $d(p, h) = d(p, l) = \text{T}$).*

The optimal disclosure policy in Proposition 8 implies that as fundamentals worsen, transparency increases (i.e., lower p 's are associated with more information being disclosed). Specifically, in good times (for $p \geq \bar{p}^*$), the regulator follows a policy of opacity. When fundamentals deteriorate (for $\bar{p}^* > p \geq \underline{p}^*$), the regulator discloses information on banks that investors perceive as low-quality (i.e., $\varsigma_i^I = l$) in an attempt to prevent runs on some of these banks. Finally, in bad times (for $p < \underline{p}^*$), the regulator discloses information on all banks. Notice that the regulator's optimal disclosure policy is not only contingent on p , but also on investors' bank-specific information $\{\varsigma_i^I\}_{i \in [0,1]}$. Overall, Proposition 8 suggests that the regulator may want to confine information release to a subset of "vulnerable" banks.

Indeed, Proposition 8 highlights that the consistent feature of an optimal disclosure policy is that transparency in bad times allows investors to differentiate within a group of banks that would otherwise be perceived as homogenous (whether this group consists of the entire system or a subset of weaker banks). For instance, in the 2010 European stress tests, Greece, that was at the forefront of the European crisis, was among the top three countries by number of banks included in the tests, despite the relatively small size of the Greek economy and financial system.³¹

The existence of an interior solution, i.e., $1 > \bar{p}^* > \underline{p}^* > 0$, requires that investors receive a signal that is not too precise, as measured by θ^I .³² Indeed, at the limit when $\theta^I \rightarrow 1$, there is no role for disclosing information, as investors perfectly learn each bank's quality. More generally, the two thresholds in Proposition 8, \underline{p}^* and \bar{p}^* , depend on θ^I as formalized in the following corollary:

Corollary 5. $\frac{\partial \bar{p}^*}{\partial \theta^I} > 0$ and $\frac{\partial \underline{p}^*}{\partial \theta^I} < 0$, and if $\theta^I \rightarrow 0$, then $\bar{p}^* \rightarrow p^*$ and $\underline{p}^* \rightarrow p^*$.

As θ^I increases and investors' signals become more precise, $\zeta_i^I = h$ (*resp.* $\zeta_i^I = l$) conveys information about bank i that is more positive (*resp.* more negative), which decreases (*resp.* increases) the threshold \underline{p}^* (*resp.* \bar{p}^*) at which the regulator needs to start disclosing information for those banks that are perceived as high-quality (*resp.* low-quality) by investors. Corollary 5 also implies that when investors are uninformed about bank types ($\theta^I \rightarrow 0$), then, even if the regulator's information is imperfect (i.e., for any θ^R), the optimal disclosure policy remains the same as in the baseline model (see Proposition 2). Intuitively, the quality θ^R of the regulator's signal does not affect the disclosure threshold p^* ; it just determines the

³¹See the Committee of European Banking Supervisors' statement on the key features of the 2010 EU-wide stress test. (http://www.eba.europa.eu/documents/10180/15977/ST_followupPR.pdf)

³²If $\bar{p}^* \geq 1$, then it is optimal to disclose information if $s_i^I = l$ for all $p \in (0, 1)$; if $\underline{p}^* \leq 0$, then it is never optimal to disclose information if $s_i^I = h$.

extent to which runs are more or less inefficient when p is below p^* .

4 Conclusion

The recent financial crises have triggered demands for an increase in the transparency of the financial system. Regulatory authorities in Europe and the United States have attempted to enhance transparency by performing stress tests on banks and releasing their results to investors. One stated objective of these measures was to prevent a contagion of investors' distrust to the entire system by providing information on the specific risk exposure of each financial institution. This is consistent with the idea that, partly, the banking crisis was a run on the liability side of banks' balance sheets.³³ In line with this view, this paper studies the risk faced by solvent but potentially illiquid financial institutions. The analysis shows that when banks are exposed to rollover risk, the disclosure of bank-specific information following a negative aggregate shock does indeed increase the stability of the financial system. However, while transparency should ideally be contingent on the state of the financial system, the analysis emphasizes that regulatory authorities face a commitment problem when implementing such a state-contingent policy. Indeed, under this policy, an increase in transparency signals a deterioration of economic fundamentals, which gives ex-post incentives to the regulator to manipulate investors' beliefs by retaining information. As a result, the regulator lacks the ability to fully exploit his private information through an ex-ante optimal disclosure policy.

While this paper focuses on a regulatory measure that has been central in the recent

³³ *The fate of Bear Stearns was the result of a lack of confidence, not a lack of capital. [...] Counterparty withdrawals and credit denials, resulting in a loss of liquidity - not inadequate capital - caused Bear's demise.* (Letter to the Chairman of the Basel Committee on Banking Supervision, dated March 20th 2008, posted on the SEC website on: <http://www.sec.gov/news/press/2008/2008-48.htm>.)

debate on the reform of the financial system, namely, transparency, regulators have several instruments at their disposal to cope with liquidity crises. Among them, the provision of liquidity by central banks or governments, acting as lenders of last resort, has been an emergency recourse for financial institutions during the recent credit crisis.³⁴ There can be interesting interactions between public provision of liquidity to the banking system and transparency. In particular, to the extent that the regulator faces a trade-off between the size and frequency of banks runs when choosing a transparency regime, disclosure policy is likely to have an effect on the magnitude of the liquidity shock that a government or a central bank would have to withstand in times of crisis in order to maintain the financial system afloat. Moreover, disclosing bank-specific information implies putting pressure on the financial system's weakest institutions in an attempt to release pressure from the fittest ones. This suggests that following information disclosure, the regulator should be ready to intervene. For instance, Greenlaw et al. (2012) argue that *"in order for a stress test to alleviate concerns that deleveraging is imminent, the test must either produce a credible private capital-raising program or be accompanied with an adequate government backstop to make sure that wholesale creditors see no risk of suffering losses."* These are interesting avenues for future research in the task of building a more stable financial system.

³⁴The provision of liquidity by the central bank or the government, however, has limitations. Indeed, it creates a well-known moral hazard problem for banks (Freixas and Rochet, 2004). Also, banks are typically reluctant to use the discount window of the central bank as this signals their fragility and may eventually worsen the liquidity dry-up they face. Furthermore, institutions that suffer from a liquidity shortage are not only banks in the strict sense, but also investment vehicles such as conduits and asset-backed securities (the "shadow banking system"), which do not have a direct access to public provision of liquidity. (Investment banks did not have access to the discount window in the 2008 financial crisis.)

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Appendix

Proof of Proposition 1

The proof follows standard global games arguments. (See, e.g., Morris and Shin (2000).)

Suppose there exists a threshold equilibrium in which investor j in bank i rolls over if and only if $\rho_j \geq \rho_i^*$. At the threshold ρ_i^* , an investor must be indifferent between rolling over and withdrawing, hence

$$\rho_i^* + E_1(\eta_i - cl_i | \rho_i^*) = 0, \quad (\text{A.1})$$

where the operator $E_1(\cdot | \rho_j)$ denotes investor j 's expectation given public information about η_i and his private information about $\tilde{\mu}$, captured by the posterior belief ρ_j (which maps one-to-one into the private signal s_j).

Note that $E(l_i | \rho_i^*) = Pr(\rho_j < \rho_i^* | \rho_i^*)$. Using (2),

$$Pr(\rho_j < \rho_i^* | \rho_i^*) = \Phi[\sqrt{\gamma}(\rho_i^* - \mu)], \quad \text{where} \quad \gamma \equiv \frac{h_\mu^2(h_\mu + h_\epsilon)}{h_\epsilon(h_\mu + 2h_\epsilon)}. \quad (\text{A.2})$$

Combining with (A.1), the equilibrium threshold ρ_i^* has to verify

$$\rho_i^* + E_1(\eta_i) = c\Phi[\sqrt{\gamma}(\rho_i^* - \mu)]. \quad (\text{A.3})$$

If $c^2\gamma < 2\pi$, there is only one solution to (A.3), and hence, there exists a unique equilibrium, restricting attention to threshold strategies.

The second part of the proof shows that if $c^2\gamma < 2\pi$, the unique equilibrium is in threshold strategy. The proof is by iterated deletion of dominated strategy and is standard. We only sketch it here.

Suppose $c^2\gamma < 2\pi$, and define $u_i(\rho_j, \hat{\rho})$ as the expected payoff obtained by investor j in bank i at $t = 2$ if he does not withdraw at $t = 1$ given his private information, ρ_j , and given that the strategy of other investors is to withdraw if and only if their conditional expectation of $\tilde{\mu}$ is below a given $\hat{\rho}$.

$$u_i(\rho_j, \hat{\rho}) \equiv 1 + \rho_j + E[\eta_i] - c\Phi\left[\sqrt{\gamma}\left(\hat{\rho} - \mu + \frac{h_\epsilon}{h_\mu}(\hat{\rho} - \rho_j)\right)\right] \quad (\text{A.4})$$

Note that, u_i is strictly increasing in its first argument, and strictly decreasing in its second argument. We refer to this property as the monotonicity of u_i . Note also that $u_i(\rho, \rho) = 1 \Leftrightarrow \rho = \rho_i^*$.

Consider the sequence $\{\underline{\rho}_1, \underline{\rho}_2, \dots, \underline{\rho}_k, \dots\}$ defined as follows,

$$u(\underline{\rho}_1, -\infty) = 1 \quad \text{and} \quad u(\underline{\rho}_{k+1}, \underline{\rho}_k) = 1 \quad \text{for any } k \geq 1. \quad (\text{A.5})$$

The monotonicity of u implies that $\{\underline{\rho}_k\}_k$ is a strictly increasing and that $\rho_k < \rho_i^*$ for any k . Therefore $\{\underline{\rho}_k\}_k$ converges and the continuity of u_i implies $\lim_{k \rightarrow \infty} \underline{\rho}_k = \rho_i^*$.

We prove the following claim by forward induction: the only strategies that survive k rounds of deletion of strictly dominated strategies are such that investors withdraw if $\rho_j < \underline{\rho}_k$.

From the monotonicity of u_i , for any $\rho_j < \underline{\rho}_1$, $u(\rho_j, -\infty) < 1$. Hence, even if other investors were always rolling over, investor j would strictly prefer withdrawing if $\rho_j < \underline{\rho}_1$. Therefore withdrawing is a dominant strategy below $\underline{\rho}_1$. This proves the claim for $k = 1$.

Suppose that investors withdraw if their posterior belief is strictly lower than $\underline{\rho}_k$. For any $\rho_j \in [\underline{\rho}_k, \underline{\rho}_{k+1})$,

$$u_i(\rho_j, \underline{\rho}_k) < u_i(\underline{\rho}_{k+1}, \underline{\rho}_k) = 1.$$

Hence, even if other investors were rolling over any time their belief was higher than $\underline{\rho}_k$, that is, even if they were playing the strategy that maximizes investor j 's incentive to rollover given that they withdraw below $\underline{\rho}_k$, investor j would still strictly prefer withdrawing if $\rho_j \in [\underline{\rho}_k, \underline{\rho}_{k+1})$. Thus, given that investors withdraw below $\underline{\rho}_k$, it is a dominant strategy to withdraw below $\underline{\rho}_{k+1}$. This complete the proof the claim.

Therefore, the only strategies that survive iterated deletion of strictly dominated strategies are such that investors withdraw if $\rho_j < \rho_i^*$. Using a symmetric reasoning, one shows that the only strategies that survive the iterated deletion of strictly dominated strategies are such that investors rollover if $\rho_j > \rho_i^*$. Hence the threshold equilibrium described in Proposition 1 is the unique equilibrium of the rollover game. \square

Proof of Proposition 3

We assume that investors do not observe p but that the regulator can commit to a disclosure policy conditional on p . Consider first the case where $\mu \geq \frac{c}{2}$. Then $\mu + E(2p - 1)\Delta_\eta - \frac{c}{2} = \mu - \frac{c}{2}$, which is positive. In words, investors never run if they can't distinguish between banks and don't update their beliefs on p . Since a policy of unconditional opacity does not convey any information on p , it prevents bank runs and is therefore optimal.

Turn to the case where $\mu < \frac{c}{2}$. Let O denote the states in which the system is opaque (i.e., the set of realizations of p in which the regulator commits not to disclose).

Notice first that O is optimal only if

$$\mu + E(2p - 1|p \in O)\Delta_\eta = \frac{c}{2} \Leftrightarrow E(p|p \in O) = p^*. \quad (\text{A.6})$$

Indeed, if $E(p|p \in O) < p^*$, there is a run on all banks when the system is opaque, which is dominated by $O = \{\emptyset\}$ (i.e., full transparency). If $E(p|p \in O) > p^*$, there exists a set s such that $Pr(p \in s) > 0$, $s \subset (0, 1) \setminus O$ and $E(p|p \in O) = p^*$. Extending opacity from O to $O \cup s$ is then strictly welfare-improving since it allows to save low-quality banks if $p \in s$.

Thus, the optimization program of the regulator writes

$$\begin{aligned} & \max_{O \subset (0,1)} \int_{p \in O} (1-p)[\mu - \Delta_\eta] dp, \\ \text{s.t. } & E(p|p \in O) = p^*. \end{aligned} \tag{A.7}$$

Using (A.7), $\int_{p \in O} (1-p) dp = (1-p^*)Pr[p \in O]$, and the optimization program becomes

$$\begin{aligned} & \max_{O \subset (0,1)} Pr[p \in O] \\ \text{s.t. } & E(p|p \in O) = p^* \end{aligned} \tag{A.8}$$

In words, the optimal transparency policy maximizes the mass of states in which the regime is opaque, subject to the constraint that the probability of a high-quality bank conditional on opacity is larger than p^* .

Let p^C be the unique solution to

$$E[p|p > p^C] = p^* \tag{A.9}$$

Suppose that O is optimal (i.e., is solution to (A.7)).

We show first that $Pr\{p \in [p^C, 1) \cap \bar{O}\} = 0$, where $\bar{O} = (0, 1) \setminus O$. Suppose indeed that $Pr\{p \in [p^C, 1) \cap \bar{O}\} > 0$ and consider two cases. First, if $Pr\{p \in (0, p^C) \cap O\} = 0$, then $Pr(p \in O) < Pr\{p \in [p^C, 1)\}$ and O is strictly dominated by $[p^C, 1)$. Second, if $Pr\{p \in (0, p^C) \cap O\} > 0$, then there exist two subset $s_1 \subset [p^C, 1) \cap \bar{O}$ and $s_2 \subset (0, p^C) \cap O$ such that $Pr(p \in s_1) = Pr(p \in s_2) > 0$. Let $O' \equiv O \cup s_1 \setminus s_2$. By construction, $Pr(p \in O') = Pr(p \in O)$ and $E(p|p \in O') > p^*$. Therefore there exists $O'' \supset O'$ such that $Pr(p \in O'') > Pr(p \in O')$ and $E(p|p \in O'') = p^*$. Thus O cannot be an optimum.

Hence, if $p \in [p^C, 1)$, $Pr\{p \in O\} = 1$. Furthermore,

$$\mathbb{E}\{p|p \in [p^C, 1)\} = Pr\{p \in [p^C, 1) \cap O\} + Pr\{p \in (0, p^C) \cap O\}$$

for any set $s \subset (0, p^C]$ such that $Pr(p \in s) > 0$, $E\{p|p \in [p^C, 1) \cup s\} < p^*$, and therefore if $p \in O$, $Pr\{p \in [p^C, 1)\} = 1$. Thus, the optimal set of opaque states is equal to $[p^C, 1]$ almost everywhere. \square

Proof of Proposition 4

We prove first that there cannot be a p -contingent disclosure policy. Suppose there exists a non-empty subset $O \subset [0, 1]$, in which the regulator chooses opacity. O must be such that

$$E[p|p \in O] \geq p^*. \tag{A.10}$$

Indeed, if $E[p|p \in O] < p^*$, Bayesian updating would lead investors to run on the entire system, and the regulator would then choose transparency for any $p \in O$. Notice next that for any $p \notin O$, switching from

transparency to opacity increases total expected surplus from $p(\mu + \Delta_\eta)$ to $p(\mu + \Delta_\eta) + (1 - p)(\mu - \Delta_\eta)$. Therefore if $O \neq \{\emptyset\}$, $O = (0, 1)$.

Full disclosure is always an equilibrium. It is sustained by (a continuum of) out-of-equilibrium beliefs that $p < p^*$ conditional on opacity.

Full opacity can be an equilibrium only if and only if

$$\mu + E[2p - 1]\Delta_\eta \geq \frac{c}{2} \Leftrightarrow \mu \geq \frac{c}{2}. \quad (\text{A.11})$$

Proof of Proposition 5

We start by introducing notation. Let O denote the set of p 's for which the regulator chooses opacity (hence, O defines the regulator's strategy). O can be split into two distinct sets:

$$O_- \equiv O \cap (0, p^*) \text{ and } O_+ \equiv O \cap [p^*, 1), \quad (\text{A.12})$$

that is, O_+ (respectively, O_-) is the set of p 's that are above (respectively, below) the run threshold p^* and such that the system is opaque. We let Z denote the set of signals under opacity that are consistent with the regulator playing strategy O :

$$Z \equiv \{z : O \cap [z - \frac{\delta}{2}, z + \frac{\delta}{2}] \neq \{\emptyset\}\}. \quad (\text{A.13})$$

In words, for any $z \in Z$, there exists a $p \in O$ that can generate z . Hence, when observing $z \in Z$ under opacity, investors can infer that $p \in O$.

The proof of the Proposition builds on the following Lemma

Lemma A.1. *If $\delta < 1 - p^*$, then O_+ and O_- are non-empty in equilibrium, and there exists a threshold z^* such that investors' strategy under opacity is to withdraw if and only if $z < z^*$.*

Proof. We prove the three components of this Lemma in three steps.

1. O_+ is non empty.

For any p in $[p^* + \delta, 1)$, even under the lowest possible signal, $p - \frac{\delta}{2}$, investors assign probability 1 to $p \geq p^*$. Hence, under opacity the probability of a run is 0 and therefore, choosing opacity is optimal.

2. O_- is non empty.

Suppose that O_- is empty. Then for any $p \in O_+$, the probability of a run is 0 under opacity (i.e., if O_- is empty a policy of opacity reveals that $p \geq p^*$) and the net benefit of opacity (i.e., avoiding runs on low-quality banks) is strictly positive, that is, $(1 - p)(\mu - \Delta_\eta) > 0$. At $p = \inf O_+ - \varepsilon$, for some

small $\varepsilon > 0$, the benefit of deviating to opacity is weakly greater than $(1 - \frac{\varepsilon}{\delta})(1 - \inf\{O_+\} + \varepsilon)(\mu - \Delta_\eta) - \frac{\varepsilon}{\delta}(\inf\{O_+\} - \varepsilon)(\mu + \Delta_\eta)$. [Intuitively, if the regulator deviates to opacity, either the deviation is not detected ($z \in Z$), which happens with probability $1 - \frac{\varepsilon}{\delta}$, and the deviation has the net benefit of saving low-quality banks. Or, the deviation is detected (with probability $\frac{\varepsilon}{\delta}$), and then, in the worst case, there is a run on all banks, so that the net cost of the deviation is the liquidation of high-quality banks.] This expression is strictly positive for ε small enough, and hence, at $p = \inf\{O_+\} - \varepsilon$, opacity is a profitable deviation, a contradiction.

3. There exists a z^* such that all investors withdraw under opacity if and only if $z < z^*$.

Let $p(z) : Z \rightarrow (0, 1)$ be the investors' expectation of p given a signal z and opacity

$$p(z) \equiv E\{p | p \in O \cap [z - \frac{\delta}{2}, z + \frac{\delta}{2}]\}. \quad (\text{A.14})$$

This expectation $p(z)$ is weakly increasing on Z . Indeed, consider $z' < z$. If $z' + \delta < z$, then obviously $p(z') < p(z)$. [That is, if $z' + \frac{\delta}{2} < z - \frac{\delta}{2}$, any p than can generate a signal z is higher than any p' that can generate z' .] If $z' + \delta \geq z$,

$$\begin{aligned} p(z') = E\{p | p \in O \cap [z' - \frac{\delta}{2}, z' + \frac{\delta}{2}]\} &\leq E\{p | p \in O \cap [z - \frac{\delta}{2}, z' + \frac{\delta}{2}]\} \\ &\leq E\{p | p \in O \cap [z - \frac{\delta}{2}, z + \frac{\delta}{2}]\} = p(z). \end{aligned} \quad (\text{A.15})$$

Let $z^* \equiv \inf\{z \in Z : p(z) \geq p^*\}$. That is, z^* is the lower bound of the set of signals such that there is no run under opacity. Note that since O_+ is non empty, this set is non empty as well. Therefore, z^* is well defined.^{A1}

□

The previous Lemma implies that in any equilibrium there is a z^* such that the probability of a run on all banks when the regulator chooses opacity for a given p is $Pr(z < z^* | p)$. Next, we show that in any equilibrium the regulator chooses opacity iff $p \geq p^T$ for some p^T . Consider an equilibrium strategy O . From Lemma A.1, there exists a z^* such that a run occurs under opacity iff $z < z^*$. Since $z \geq p^* + \frac{\delta}{2}$ perfectly reveals $p \geq p^*$, it must be that $z^* \leq p^* + \frac{\delta}{2}$. Similarly, since $z < p^* - \frac{\delta}{2}$ perfectly reveals $p < p^*$, it must be that $z^* \geq p^* - \frac{\delta}{2}$.

^{A1}We can prove the stronger result that there exists a unique signal z^* in Z such that investors are indifferent between withdrawing and rolling over. Hence, for any p , the probability that investors are exactly indifferent is zero and therefore, our result does not hinge on the assumption we made for expositional ease that investors roll over if they are indifferent.

Define the following function for $p \in (0, 1)$,

$$B(p) = Pr(z \geq z^* | p)[\mu + (2p - 1)\Delta_\eta] - p(\mu + \Delta_\eta). \quad (\text{A.16})$$

$B(p)$ represents the net benefit of opacity if the strategy of investors is to run under opacity iff $z < z^*$. Hence, $B(p) \geq 0$ is a necessary condition for $p \in O$.

$B(p)$ has the following properties:

1. for $p \geq z^* + \frac{\delta}{2}$, $Pr(z \geq z^* | p) = 1$ and $B(p) = (1 - p)(\mu - \Delta_\eta)$ which is positive and linearly decreasing in p . Since $z^* \leq p^* + \frac{\delta}{2}$ and $p^* < 1 - \delta$, the interval $[z^* + \frac{\delta}{2}, 1)$ is not empty.
2. for $p \leq z^* - \frac{\delta}{2}$, $Pr(z \geq z^* | p) = 0$ and $B(p) = -p(\mu + \Delta_\eta)$ which is negative and linearly decreasing in p . Since $z^* \geq p^* - \frac{\delta}{2}$ and $\delta < p^*$ the interval $(0, z^* - \frac{\delta}{2}]$ is not empty.
3. for $z^* - \frac{\delta}{2} < p < z^* + \frac{\delta}{2}$, $Pr(z \geq z^* | p) = \frac{1}{2} + \frac{p - z^*}{\delta} \in (0, 1)$, and hence, $B(p)$ is continuous and strictly convex,

$$B''(p) = \frac{1}{\delta} 4\Delta_\eta. \quad (\text{A.17})$$

All of these observations imply that there exists a unique $p^T \in (0, 1)$ such that $B(p^T) = 0$, and $\forall p \in (0, 1)$, $B(p) > 0$ iff $p > p^T$. Since $B(p) \geq 0$ is a necessary condition for $p \in O$, then for $p < p^T$ the regulator chooses transparency in equilibrium. [Note: $B(p) \geq 0$ is a necessary condition for $p \in O$ because $B(p) < 0$ implies that transparency is a profitable deviation if $p \in O$, a contradiction.]

Next we show that $(p^T, 1) \subset O$. Suppose otherwise, that is, that there exists a subset $D \subset (p^T, 1)$ such that $D \cap O = \{\emptyset\}$. Then, since $[p^* + \delta, 1) \subset O$ (i.e., opacity is strictly optimal in $[p^* + \delta, 1)$), there exists a \underline{p} and an $\varepsilon > 0$ arbitrarily small such that $(\underline{p}, 1) \subset O$ and $\underline{p} - \varepsilon \in D$. Consider the incentive of type $\underline{p} - \varepsilon$ to deviate to opacity. Since $(\underline{p}, 1) \subset O$ a sufficient condition for such a deviation not to be detected is $z > \underline{p} - \frac{\delta}{2}$. [i.e., for investors, any signal in $[\underline{p} - \frac{\delta}{2}, \underline{p} - \varepsilon + \frac{\delta}{2}]$ could originate from \underline{p} .] In addition, in case of detection, the worst possible outcome is a run on the entire system, in which case the net cost of opacity is $(\underline{p} - \varepsilon)(\mu + \Delta_\eta)$ (the liquidation of high-quality banks). Therefore the net benefit of deviating to opacity at $\underline{p} - \varepsilon$ is bounded below by

$$Pr(z \geq \max\{z^*, \underline{p} - \frac{\delta}{2}\} | \underline{p} - \varepsilon)[\mu + (2\underline{p} - \varepsilon - 1)\Delta_\eta] - (\underline{p} - \varepsilon)(\mu + \Delta_\eta). \quad (\text{A.18})$$

The expression in (A.18) tends to $B(\underline{p}) > 0$ as $\varepsilon \rightarrow 0$, hence, it is strictly positive for ε small. [Note that $B(p) > 0$ for all $p \in (p^T, 1)$.] Therefore there exists a type $\underline{p} - \varepsilon \in D$ for which the regulator has a profitable deviation to opacity, a contradiction. Hence, the system must be opaque for $p > p^T$. Note finally that at p^T , the regulator is indifferent between opacity and transparency. Indeed, $B(p^T) = 0$ is the net benefit of opacity if $p^T \in O$, but also if $p^T \notin O$ as, because $(p^T, 1) \subset O$, the probability that a deviation to transparency is detected is 0 at p^T . Since $p = p^T$ is a 0-probability event, and the regulator is indifferent between policies, we simply assume that the regulator follows a policy of opacity at p^T .

So far we have shown that in any equilibrium there is a z^* and a corresponding p^T such that the regulator follows a policy of transparency iff $p < p^T$. That is, we have shown that any equilibrium is a threshold equilibrium. Next, we show that the pair (z^*, p^T) is uniquely defined.

Note first that in principle, from the definition of z^* in Lemma A.1., it could be that

$$p(z^*) = E\{p | p \in O \cap [z^* - \frac{\delta}{2}, z^* + \frac{\delta}{2}]\} > p^*$$

however, $O = [p^T, 1)$ and $B(p^T) = 0$ imply $p(z)$ is continuous on $Z = [p^T - \frac{\delta}{2}, 1 + \frac{\delta}{2}]$, strictly increasing and such that $p(\cdot)$ changes sign on Z . Therefore, in equilibrium,

$$p(z^*) = E\{p | p \in [p^T, z^* + \frac{\delta}{2}]\} = p^*,$$

which is equivalent to

$$\frac{p^T + (z^* + \frac{\delta}{2})}{2} = p^* \Leftrightarrow z^* = 2p^* - p^T - \frac{\delta}{2}.$$

Therefore,

$$Pr(z > z^* | p^T) = \frac{1}{2} + \frac{p^T - z^*}{\delta} = 1 - \frac{2}{\delta}(p^* - p^T). \quad (\text{A.19})$$

Plugging this expression into (A.16) yields the following equilibrium requirement which pins down p^T ,

$$f(p^T) \equiv \left[1 - \frac{2}{\delta}(p^* - p^T)\right] [\mu + (2p^T - 1)\Delta_\eta] - p^T(\mu + \Delta_\eta) = 0. \quad (\text{A.20})$$

From Lemma 1, O_- is not empty, which, by definition, implies that $p^T < p^*$. Moreover, $f(p^T)$ is strictly convex, $f(p^*) > 0$, and $f(p) < 0 \forall p \in (0, p^* - \frac{\delta}{2}]$. Therefore, $f(p^T)$ has a unique root $p^{NC}(\delta)$ in $(0, p^*)$ and $p^* > p^{NC} > p^* - \frac{\delta}{2}$.

Finally we prove that $\frac{\partial p^{NC}}{\partial \delta} < 0$. From (A.20) it follows that

$$\frac{\partial p^{NC}}{\partial \delta} = - \frac{\frac{2}{\delta^2}(p^* - p^{NC})[\mu + (2p^{NC} - 1)\Delta_\eta]}{\frac{\partial f(p^{NC})}{\partial p^{NC}}}. \quad (\text{A.21})$$

Since $p^* > p^{NC} > p^* - \frac{\delta}{2}$, $f(p^* - \frac{\delta}{2}) < 0$ and $f(p^*) > 0$, together with f being strictly convex, implies that $\frac{\partial f(p^{NC})}{\partial p^{NC}} > 0$ and hence that $\frac{\partial p^{NC}}{\partial \delta} < 0$. \square

Proof of Corollary 2

The proof uses the same notation as the Proof of Proposition 5. A strategy is a set $O \subset (0, 1)$ in which the system is opaque. As earlier, O can be split into two distinct subsets, $O_+ \equiv O \cap [p^*, 1)$ and $O_- \equiv O \cap (0, p^*)$.

From Lemma A.1, for any strategy O such that O_+ is non-empty, there exists a (signal) threshold $z^*(O)$ such that investors withdraw if and only if their signal z is strictly below $z^*(O)$.

Assume that strategy O is ex-ante optimal.

We first show that O_+ is non empty. If O_+ were empty, investors would always withdraw from low-quality banks so that O would be strictly dominated by $O' = [p^*, 1)$ where investors never withdraw from high-quality banks and withdraw from low-quality banks if and only if $p < p^*$.

Therefore, since O_+ is non empty, the threshold $z^*(O)$ is well defined and for any $p \in (0, 1)$, the net benefit of opacity is

$$B(p, O) = Pr(z \geq z^*(O)|p)[\mu + (2p - 1)\Delta_\eta] - p(\mu + \Delta_\eta).$$

Since O is ex-ante optimal,

$$O \in \operatorname{argmax}_{\tilde{O}} \int_{p \in \tilde{O}} B(p, \tilde{O}) dp$$

Using the same reasoning as in the proof of Proposition 5, there exists a unique $p^T(O)$ in $(0, 1)$ such that $B[p^T(O), O] = 0$, $B(p, O) > 0$ if $p > p^T(O)$ and $B(p, O) < 0$ if $p < p^T(O)$. This has a series of implications:

1. The system is transparent almost everywhere in $(0, p^T(O))$.

Suppose that $S \equiv (0, p^T(O)) \cap O$ has positive measure. Switching to transparency for $p \in S$ both strictly increases welfare for every $p \in S$ (since $B(p, O) < 0$) and (weakly) decreases the probability of a run for every $p \in O \cap [p^T(O), 1)$, a contradiction.^{A2}

2. $p^T(O) \leq p^*$.

Suppose that $p^T(O) > p^*$, then given that the system is transparent almost everywhere below $p^T(O)$, O is strictly dominated by $O' \equiv [p^*, 1)$. Therefore O is not ex-ante optimal, a contradiction.

3. The system is opaque almost everywhere in $[p^*, 1)$.

Suppose that the system is transparent for a set $S \subset [p^*, 1)$ of positive measure. Consider the alternative strategy $O' \equiv O \cup S$

By the law of iterated expectations,

$$\begin{aligned} & \mathbb{E} \left[p | p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O' \right] = \\ & q \mathbb{E} \left[p | p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O \right] + (1 - q) \mathbb{E} \left[p | p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap S \right] \end{aligned}$$

$$\text{where } q = \frac{\int_{p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O} dp}{\int_{p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O'} dp}. \quad \text{A3}$$

^{A2}Intuitively, switching from opacity to transparency for low p s increases investors' expectation of p conditional on opacity. Formally, consider the alternative strategy $O' \equiv O \setminus S$, using a reasoning similar to the one in point 3 below, one can show that $z^*(O') \leq z^*(O)$.

^{A3}One can show $\int_{p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O} dp > 0$, which implies $\int_{p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O'} dp > 0$, and hence q is well defined.

Since, by definition of $z^*(O)$, $\mathbb{E}[p|p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O] \geq p^*$, and $S \subset [p^*, 1)$,

$$\mathbb{E}\left[p|p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O'\right] \geq p^*. \quad (\text{A.22})$$

and therefore, $z^*(O') \leq z^*(O)$.^{A4} This implies in turn, that for any $p \in (0, 1)$, $B(p, O') \geq B(p, O)$. Finally, since $p^T(O) < p^*$ and $S \subset [p^*, 1)$, for any $p \in S$, $B(p, O) > 0$ and hence $B(p, O') > 0$. Therefore, since S has positive measure, $\int_{p \in S} B(p, O') dp > 0$. Finally,

$$\int_{p \in O'} B(p, O') dp = \int_{p \in O} B(p, O') dp + \int_{p \in S} B(p, O') dp > \int_{p \in O} B(p, O) dp,$$

which implies that O is not ex-ante optimal, a contradiction.

4. There exists p_z^C such that the system is opaque almost everywhere on $[p_z^C, 1)$ and transparent almost everywhere on $(0, p_z^C)$.

Suppose such p_z^C does not exist. Then there exist two intervals (p_a, p_b) and (p_c, p_d) such that $p_a < p_b \leq p_c < p_d$, $(p_a, p_b) \subset O$, $(p_c, p_d) \cap O$ is empty, and $p_b - p_a = p_d - p_c$.^{A5}

Note that

- From points 1 and 3 above, $p^T(O) \leq p_a < p_d \leq p^*$.
- $z^*(O) + \frac{\delta}{2} \geq p^*$, by definition of $z^*(O)$, and $p^T(O) + \frac{\delta}{2} \geq z^*(O)$, by definition of $p^T(O)$.
- Hence, $z^*(O) + \frac{\delta}{2} \geq p_d$ and $p_a \geq z^*(O) - \frac{\delta}{2}$, and therefore, $(p_c, p_d) \subset [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}]$ and $(p_a, p_b) \subset [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}]$.
- Finally, $z^*(O) + \frac{\delta}{2} \geq p^*$ implies that $B(p, O)$ is strictly increasing on $[p^T(O), p^*]$ (See Proof of Proposition 5).

Consider the strategy $O' \equiv O \cup (p_c, p_d) \setminus (p_a, p_b)$. Using conditional expectations, and noticing that $O \cup O'$ can be written as the union of the two disjoint sets O and (p_c, p_d) or as the union of the two disjoint sets O' and (p_a, p_b) . Then,

$$\begin{aligned} (1 - q)\mathbb{E}\left[p|p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O'\right] + q\mathbb{E}[p|p \in (p_a, p_b)] = \\ (1 - q)\mathbb{E}\left[p|p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O\right] + q\mathbb{E}[p|p \in (p_c, p_d)], \end{aligned}$$

^{A4}From Lemma A.1., $p(z) = \mathbb{E}[p|p \in [z - \frac{\delta}{2}, z + \frac{\delta}{2}] \cap O']$ is weakly increasing and $z^*(O')$ is by definition the smallest z such that $p(z) \geq p^*$

^{A5}A technical caveat is that we restrict attention to strategies that are unions of countable sets and open intervals. That is, we do not consider strategies containing sets that have positive measure but do not contain any open interval (e.g., set of irrational numbers) which do not appear to be economically relevant.

where

$$q = \frac{p_b - p_a}{\int_{p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap (O \cup O')} dp} = \frac{p_d - p_c}{\int_{p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap (O \cup O')} dp}.$$

Since $\mathbb{E}[p|p \in (p_a, p_b)] < \mathbb{E}[p|p \in (p_c, p_d)]$,

$$\mathbb{E}\left[p|p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O'\right] > \mathbb{E}\left[p|p \in [z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}] \cap O\right] \geq p^*,$$

which in turn implies $z^*(O') \leq z^*(O)$. Hence, for any $p \in (0, 1)$, $B(p, O') \geq B(p, O)$. Furthermore, the strict monotonicity of $B(p, O)$ on $[p^T(O), p^*]$ implies

$$\int_{p \in (p_a, p_b)} B(p, O) dp < \int_{p \in (p_c, p_d)} B(p, O) dp.$$

Therefore,

$$\begin{aligned} \int_{p \in O} B(p, O) dp &= \int_{p \in O'} B(p, O) dp + \int_{p \in (p_a, p_b)} B(p, O) dp - \int_{p \in (p_c, p_d)} B(p, O) dp \\ &< \int_{p \in O'} B(p, O) dp \\ &\leq \int_{p \in O'} B(p, O') dp, \end{aligned}$$

which implies that O is not optimal, a contradiction.

5. $p^{NC} < p_z^C < p^*$.

$p^T(O) \geq z^*(O) - \frac{\delta}{2}$ and $p_z^C \geq p^T(O)$ imply $p_z^C \geq z^*(O) - \frac{\delta}{2}$; $z^*(O) - \frac{\delta}{2} < p^*$ and $p^* < 1 - \delta$ imply $z^*(O) + \frac{\delta}{2} < 1$. Therefore

$$\mathbb{E}\left\{p|p \in \left[z^*(O) - \frac{\delta}{2}, z^*(O) + \frac{\delta}{2}\right] \cap [p_z^C, 1]\right\} = \frac{p_z^C + z^*(O) + \frac{\delta}{2}}{2}. \quad (\text{A.23})$$

Equating this expression to p^* yields^{A6}

$$z^*(O) = 2p^* - \frac{\delta}{2} - p_z^C.$$

If $p \geq 2p^* - p_z^C$, then $z \geq z^*(O)$, and depositors never run. If $p \in [p_z^C, 2p^* - p_z^C]$ (which is non-empty since $p_z^C \leq p^*$) the probability of a run conditional on p is

$$Pr(z < z^*(O)|p) = Pr(u > z^*(O) - p|p) = \int_{z^*(O) - p}^{\frac{\delta}{2}} \frac{1}{\delta} du = 1 - \frac{2p^* - p_z^C - p}{\delta}. \quad (\text{A.24})$$

^{A6}Note that, from Lemma A.1, (A.23) could in principle be strictly greater than p^* . However, $p(z) = E\{p|p \in [z - \frac{\delta}{2}, z + \frac{\delta}{2}] \cap [p_z^C, 1]\}$ is continuous on $[p^* - \frac{\delta}{2}, p^* + \frac{\delta}{2}]$ and $p(p^* - \frac{\delta}{2}) < p^* < p(p^* - \frac{\delta}{2})$. Hence, $p[z^*(O)] = p^*$.

[If $p \leq 2p^* - p_z^C$, then $\min\{z^*(O) - p, -\frac{\delta}{2}\} = \min\{2p^* - \frac{\delta}{2} - p_z^C - p, -\frac{\delta}{2}\} = z^*(O) - p$.]

The regulator's objective function is

$$\int_0^{p_z^C} p(\mu + \Delta_\eta) dp + \int_{p_z^C}^{2p^* - p_z^C} \left(1 - \frac{2p^* - p_z^C - p}{\delta}\right) [\mu + (2p - 1)\Delta_\eta] dp + \int_{2p^* - p_z^C}^1 [\mu + (2p - 1)\Delta_\eta] dp \quad (\text{A.25})$$

Differentiating with respect to p_z^C yields

$$p_z^C(\mu + \Delta_\eta) - \left(1 - \frac{2}{\delta}(p^* - p_z^C)\right) [\mu + (2p_z^C - 1)\Delta_\eta] + \int_{p_z^C}^{2p^* - p_z^C} \frac{1}{\delta} [\mu + (2p - 1)\Delta_\eta] dp. \quad (\text{A.26})$$

The second order derivative is with respect to p_z^C is

$$(\mu + \Delta_\eta) - \frac{2}{\delta} [\mu + (2p_z^C - 1)\Delta_\eta] - 2\Delta_\eta \left(1 - \frac{2}{\delta}(p^* - p_z^C)\right) - \frac{4}{\delta}(p^* - p_z^C)\Delta_\eta. \quad (\text{A.27})$$

Rearranging,

$$(\mu - \Delta_\eta) - \frac{2}{\delta} [\mu + (2p_z^C - 1)\Delta_\eta] < -(\mu - \Delta_\eta) < 0, \quad (\text{A.28})$$

where the last inequality uses $\delta < 1$.

From (A.28) the problem is convex, and therefore, the optimal p_z^C equalizes (A.26) to 0 (FOC).

From (A.20) p^{NC} satisfies

$$\left(1 - \frac{2}{\delta}(p^* - p^{NC})\right) [\mu + (2p^{NC} - 1)\Delta_\eta] - p^{NC}(\mu + \Delta) = 0, \quad (\text{A.29})$$

and hence, evaluating (A.26) at $p_z^C = p^{NC}$ yields:

$$\int_{p^{NC}}^{2p^* - p^{NC}} \frac{1}{\delta} [\mu + (2p - 1)\Delta_\eta] dp > 0,$$

where the last inequality uses $p^{NC} < p^*$ (See Proposition 5)

Evaluating (A.26) at $p_z^C = p^*$ yields:

$$p^*(\mu + \Delta_\eta) - [\mu + (2p^* - 1)\Delta_\eta] < 0 \quad (\text{A.30})$$

It follows that $p^{NC} < p_z^C < p^*$. □

Proof of Corollary 3

The proposition follows from the next two results.

Result 1. *There exists an equilibrium with full transparency if and only if $\delta \geq 1 - p^*$.*

Proof. (Necessary.) Assume that $\delta < 1 - p^*$, then opacity is strictly optimal for all $p \in (p^* + \delta, 1)$ (as for these values of p 's even the lowest possible signal, $p - \frac{\delta}{2}$, reveals that $p \geq p^*$), and hence, full transparency cannot be an equilibrium (*Sufficiency.*) Assume that $\delta \geq 1 - p^*$. Consider the following off-path beliefs in an equilibrium with full transparency (*FT*):

$$\mathbb{E}(p|z, FT) = \min \left\{ z - \frac{\delta}{2}, 0 \right\} \quad (\text{A.31})$$

where $E(p|z, FT)$ is defined as the posterior of p given signal z , and given a policy of opacity in an equilibrium in which the regulator is expected to *always* follow a policy of transparency. (Notice that this off-path beliefs assign the worse feasible expectation of p for a given realization of z .) Then the probability of a run if the regulator deviates and follows a policy of opacity for some p is:

$$\begin{aligned} \Pr \left(z - \frac{\delta}{2} < p^* \right) &= \Pr \left(p + u - \frac{\delta}{2} < p^* \right) = \Pr \left(u < p^* + \frac{\delta}{2} - p \right) = \\ &= \begin{cases} 1 - \frac{p-p^*}{\delta} & \text{if } p > p^* \\ 1 & \text{if } p \leq p^* \end{cases} \end{aligned} \quad (\text{A.32})$$

[Note: For $p > p^*$ we have $p^* + \frac{\delta}{2} - p \geq -\frac{\delta}{2}$ (i.e., even if $p = 1$ then we get $\delta \geq 1 - p^*$ which is satisfied by assumption).] Given those off-path beliefs there is no incentive to deviate if $p \leq p^*$ as there would be a run with probability one. Consider the incentive to deviate to opacity if $p > p^*$:

$$D(p) \equiv \left(\frac{p-p^*}{\delta} \right) (\mu + (2p-1)\Delta_\eta) - p(\mu + \Delta_\eta) \quad (\text{A.33})$$

where the $\frac{p-p^*}{\delta}$ is the probability of avoiding a run on all banks under opacity, $\mu + (2p-1)\Delta_\eta$ is the net output under opacity if there are no runs, and $p(\mu + \Delta_\eta)$ is the net output under transparency. Notice that

$$D(p^*) < 0 \quad (\text{A.34})$$

$$D(1) = \left(\frac{1-p^*}{\delta} \right) (\mu + \Delta_\eta) - (\mu + \Delta_\eta) \leq 0 \quad (\text{A.35})$$

$$\frac{\partial^2 D(p)}{\partial p^2} = \frac{4\Delta_\eta}{\delta} > 0 \quad \text{that is, the function is convex.} \quad (\text{A.36})$$

This implies that $D(p) \leq 0$ for all $p > p^*$, that is, there are no incentives to deviate for any $p > p^*$. Hence we conclude that for $\delta \geq 1 - p^*$ there is an equilibrium with full transparency which is supported by the aforementioned off-path beliefs. □

Result 2. If $\mu < \frac{\epsilon}{2}$ (equivalently, $p^* > \frac{1}{2}$), there is no equilibrium with full opacity. If $\mu \geq \frac{\epsilon}{2}$ (equivalently, $p^* \leq \frac{1}{2}$) and $\delta \geq \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta}$, there exists an equilibrium with full opacity.

Proof. Consider first the case where $p^* > \frac{1}{2}$ and suppose that the equilibrium is fully opaque. Consider a type \hat{p} such that $0 < \hat{p} < 2p^* - 1$. The best signal that can be generated at \hat{p} is $\hat{p} + \frac{\delta}{2}$, and hence, conditional on full opacity and observing a signal z , an investor will hold the belief

$$\mathbb{E}(p|z) \leq \mathbb{E}(p|\hat{p} + \frac{\delta}{2}) = \frac{\max\{0, z - \frac{\delta}{2}\} + \min\{1, z + \frac{\delta}{2}\}}{2} \leq \frac{\hat{p} + 1}{2} < p^*. \quad (\text{A.37})$$

Hence the probability of a run for type \hat{p} is one, and therefore, at \hat{p} the regulator has an incentive to deviate to transparency. Thus, if $p^* > \frac{1}{2}$ there is no equilibrium with full opacity.

Turn now to the case where $p^* \leq \frac{1}{2}$. We proceed in two steps.

Turn now to the case where $p^* \leq \frac{1}{2}$. We proceed in two steps.

1. If $\delta \geq \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta}$ and the equilibrium is fully opaque, investors run if their signal z is strictly lower than $z^* = 2p^* - \frac{\delta}{2}$

Notice first that if $z > \frac{\delta}{2}$, then

$$E(p|z) = \frac{z - \frac{\delta}{2} + \min\{1, z + \frac{\delta}{2}\}}{2} = \frac{\min\{1 + z - \frac{\delta}{2}, 2z\}}{2} \geq \min\left\{\frac{1}{2}, \frac{\delta}{2}\right\} \geq p^*, \quad (\text{A.38})$$

where the last inequality uses $\delta \geq \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta} > 1$ and $p^* \leq \frac{1}{2}$, which implies $\frac{\delta}{2} \geq p^*$. Hence, if $z > \frac{\delta}{2}$, there is no run. Now suppose $z < \frac{\delta}{2}$, then

$$E(p|z) = \frac{0 + \min\{1, z + \frac{\delta}{2}\}}{2} = \min\left\{\frac{1}{2}, \frac{z + \frac{\delta}{2}}{2}\right\}, \quad (\text{A.39})$$

and there is a run if and only if $E(p|z) < p^*$. Therefore, given that $p^* \leq \frac{1}{2}$, there is a run if and only if

$$\frac{z + \frac{\delta}{2}}{2} < p^* \Leftrightarrow z < 2p^* - \frac{\delta}{2}. \quad (\text{A.40})$$

2. If $\delta \geq \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta}$, then there exists an equilibrium with full opacity.

Let $B(p, p^*)$ denote the net benefit of opacity at p for a given p^* . If $p \geq 2p^*$ then, from step 1 above, $z \geq z^* = 2p^* - \frac{\delta}{2}$. This, in turn, implies that the probability of a run is zero and the net benefit of opacity (i.e., avoiding runs on low-quality banks) is positive, that is, $B(p, p^*) = (1 - p)(\mu - \Delta_\eta) > 0$. If $p < 2p^*$, the probability of a run is strictly positive and

$$\begin{aligned} B(p, p^*) &= \frac{p + \frac{\delta}{2} - z^*}{\delta} [\mu + (2p - 1)\Delta_\eta] - p(\mu + \Delta_\eta) = \\ &= \left(1 - \frac{2p^* - p}{\delta}\right) [\mu + (2p - 1)\Delta_\eta] - p(\mu + \Delta_\eta). \end{aligned} \quad (\text{A.41})$$

[Note that $\delta \geq \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta} > 1$ implies $\delta \geq 2p^*$, and hence, $\frac{p + \frac{\delta}{2} - z^*}{\delta} = 1 - \frac{2p^* - p}{\delta} > 0$.] There exists a fully opaque equilibrium if and only if

$$b(p^*) \equiv \min_{p \in (0, 2p^*)} B(p, p^*) \geq 0. \quad (\text{A.42})$$

Notice that from (A.41), $B(p, p^*)$ is linearly decreasing in p^* . Hence, if $B(p, \frac{1}{2}) \geq 0 \forall p \in (0, 1)$, then a fortiori, when $p^* < \frac{1}{2}$, $B(p, p^*) \geq 0 \forall p \in (0, 1)$. This, in turn, implies $b(p^*) \geq 0$. Hence, a sufficient condition for the existence of an equilibrium is $b(\frac{1}{2}) \geq 0$.

Note that $B(p, \frac{1}{2})$ is convex in p and $B(1, \frac{1}{2}) = 0$. Hence, a necessary and sufficient condition for $b(\frac{1}{2}) \geq 0$ is $\frac{\partial B(p, \frac{1}{2})}{\partial p}$ evaluated at $p = 1$ to be negative. This condition is equivalent to

$$\delta \geq \frac{\mu + \Delta_\eta}{\mu - \Delta_\eta}. \quad (\text{A.43})$$

□

Proof of Proposition 6

First, for $p \geq p^*$, disclosing p prevents runs and hence strictly dominates disclosing $\{\eta_i\}_{i \in [0,1]}$ (which would result in runs on low-quality banks). Conversely, for $p < p^*$ disclosing $\{\eta_i\}_{i \in [0,1]}$ strictly dominates disclosing p only (which would result in runs on all banks). The proof of the proposition builds on the following two lemmas. [Note: We refer to opacity as a policy in which the regulator does not disclose any information, neither p nor $\{\eta_i\}_{i \in [0,1]}$.]

Lemma A.2. *In any equilibrium the set of p 's below p^* for which opacity is the equilibrium strategy has measure zero.*

Proof. Assume otherwise and let $p^{O\text{-below}}$ be the smallest p below p^* for which a policy of opacity is followed in equilibrium. Let $p^{O\text{-above}}$ be the smallest p greater or equal to p^* for which a policy of opacity is followed in equilibrium. [Note that if a policy of opacity is followed in equilibrium in a non-measure zero of p 's below p^* , it must be the case that a policy of opacity is followed for some $p \geq p^*$. Otherwise, the probability of a run for those p 's below p^* would be one under opacity, and hence transparency would be optimal $\forall p < p^*$.] Then it must be the case that

$$p^{O\text{-below}} + \frac{\delta}{2} \geq p^{O\text{-above}} - \frac{\delta}{2} \quad (\text{A.44})$$

otherwise the probability of a run at $p^{O\text{-below}}$ would be one under opacity, and hence, the regulator would have an incentive to deviate to transparency.^{A7} However if there is a non-measure zero subset of p 's between $p^{O\text{-below}}$ and p^* , then $p^{O\text{-below}} + \frac{\delta}{2} \geq p^{O\text{-above}} - \frac{\delta}{2}$ implies that the expectation of p given $z = p^{O\text{-above}} - \frac{\delta}{2}$ and given opacity is smaller than p^* . [Intuitively, a signal $z = p^{O\text{-above}} - \frac{\delta}{2}$ under opacity could come from $p^{O\text{-above}}$ or from all the p 's below p^* for which opacity is the equilibrium strategy. If there is a non-measure zero of p 's between $p^{O\text{-below}}$ and p^* then the posterior of p will be below p^* .] However, this implies that the

^{A7}If condition (A.44) does not hold, there is no signal z coming from $p^{O\text{-below}}$ that could have been generated at $p^{O\text{-above}}$ (or at a $p > p^{O\text{-above}}$).

probability of a run under opacity at $p^{O\text{-above}}$ would be greater than zero, which in turn, implies that opacity could not be an equilibrium for $p^{O\text{-above}}$ as it would be strictly dominated by disclosing p , a contradiction. \square

Lemma A.3. *In any equilibrium, there is an interval of p 's above p^* such that the regulator follows a policy of disclosing p only.*

Proof. Let $p^{O\text{-above}}$ be the smallest p greater or equal to p^* for which a policy of opacity is followed in equilibrium. Then the probability of a run on all banks at $p^{O\text{-above}}$ is zero (otherwise the regulator would have an incentive to disclose p). This implies that, in equilibrium, there is a run under opacity iff z is smaller than the lowest signal that can be generated from $p^{O\text{-above}}$, i.e., iff $z < p^{O\text{-above}} - \frac{\delta}{2}$. Then, for any $p < p^*$ the net benefit of following a policy of *transparency* (i.e., a policy of disclosing $\{\eta_i\}_{i \in [0,1]}$) given $p^{O\text{-above}}$ is

$$\begin{aligned} B(p, p^{O\text{-above}}) &= p(\mu + \Delta_\eta) - \Pr\left(u + p \geq p^{O\text{-above}} - \frac{\delta}{2}\right) (\mu + (2p - 1) \Delta_\eta) = \\ &= p(\mu + \Delta_\eta) - \max\left[1 - \frac{p^{O\text{-above}} - p}{\delta}, 0\right] (\mu + (2p - 1) \Delta_\eta) \end{aligned} \quad (\text{A.45})$$

If we set $p^{O\text{-above}} = p^*$ then $B(p^*, p^*) < 0$. This implies that if $p^{O\text{-above}} = p^*$, then there is an interval of p 's just below p^* (that is, $[p^* - \varepsilon, p^*)$ for some $\varepsilon > 0$) in which the regulator would have an incentive to follow a policy of opacity (i.e., $B(p, p^*) < 0$ for all $p \in [p^* - \varepsilon, p^*)$). Since the interval has measure $\varepsilon > 0$, this contradicts Lemma A.2, which implies that $p^{O\text{-above}} > p^*$. \square

Lemma A.3 implies that the regulator discloses p only for $p \in [p^*, p^{Cr}(\delta))$ with $p^{Cr}(\delta) \equiv p^{O\text{-above}} > p^*$. Finally, we show that in equilibrium the regulator follows a policy of transparency for all $p \in (0, p^*)$. First, if $p^{Cr}(\delta) = 1$ (i.e., if the regulator always discloses p when $p \geq p^*$), then the regulator follows a policy of transparency (i.e., of disclosing $\{\eta_i\}_{i \in [0,1]}$) for all $p < p^*$ (as otherwise, there would be a run on all banks). Consider now the case in which $p^{Cr}(\delta) \equiv p^{O\text{-above}} \in (p^*, 1)$. If $1 - \frac{p^{Cr}(\delta) - p^*}{\delta} \leq 0$ then $B(p, p^{Cr}(\delta)) > 0$ (as defined in equation A.45) for all $p < p^*$. If $1 - \frac{p^{Cr}(\delta) - p^*}{\delta} > 0$, then it cannot be that $B(p, p^{Cr}(\delta)) \leq 0$ for some $p \in (0, p^*)$, otherwise there would be some (arbitrarily small) interval of measure $\varepsilon > 0$ for which $B(p, p^{Cr}(\delta)) < 0$, which would contradict lemma A.2. [Note: When $1 - \frac{p^{Cr}(\delta) - p^*}{\delta} > 0$, if $B(\hat{p}, p^{Cr}(\delta)) = 0$ for some $\hat{p} \in (0, p^*)$, then $B(p, p^{Cr}(\delta))$ would be strictly concave at $p = \hat{p}$, and hence, there would be an arbitrarily small interval below or above that \hat{p} (depending on whether $B(p, p^{Cr}(\delta))$ is decreasing or increasing in p at $B(\hat{p}, p^{Cr}(\delta)) = 0$) such that in that interval $B(p, p^{Cr}(\delta)) < 0$.] \square

Proof of Lemmas 1 and 2

Note first that under full opacity, banks are perceived as perfectly symmetric, and hence, one can show that cross-exposures do not matter and the analysis is equivalent to the proof of Proposition 2.^{A8} In particular, when $h_\mu \rightarrow +\infty$ and $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$, investors run if and only if

$$p < p^* = \frac{1}{2\Delta_\eta} \left(\frac{c}{2} - \mu \right) + \frac{1}{2}.$$

Similarly, banks with no interconnection, $\alpha_i = 0$ are identical to the ones in the original model (subsection 2.1). Hence, under full transparency, $\sigma = \{\eta_i, \alpha_i\}_{i \in [0,1]}$, since investors can perfectly distinguish non-connected banks from connected ones, rollover decisions in non-connected banks are identical to the baseline model. In particular, when $h_\mu \rightarrow +\infty$ and $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$, investors withdraw if $\eta_i = -\Delta_\eta$ and rollover if $\eta_i = \Delta_\eta$.

Therefore, we only need to characterize rollover decisions for

1. every bank if the regulator only discloses idiosyncratic shocks, $\sigma = \{\eta_i\}_{i \in [0,1]}$,
2. connected banks, $\alpha_i = \alpha$, if the system is fully transparent, $\sigma = \{\eta_i, \alpha_i\}_{i \in [0,1]}$.

The analyses of these two cases follow the same path, which is the object of the rest of the proof.

We proceed in a way that is similar to subsection 2.1. We first analyze the “dispersed information” game in which investors receive a signal s_j about the common component of returns $\tilde{\mu}$, and we derive the rollover equilibrium. Then, we go back to the original model in with no uncertainty about $\tilde{\mu}$ by studying the limit case in which $h_\mu \rightarrow +\infty$ and $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$.

Conditional on observing signal s_j , investor j believes that $\tilde{\mu}$ is normally distributed with mean

$$\rho_j = \frac{h_\mu \mu + h_\varepsilon s_j}{h_\mu + h_\varepsilon}.$$

and precision $h_\mu + h_\varepsilon$.

^{A8}For brevity, this part of the proof is omitted. The intuition relies on the standard forward induction argument. Assuming that investors always rollover in every bank, it is a dominant strategy to withdraw from every bank for a belief that is below a *common* threshold. Therefore, in the next round of deletion of dominated strategies, bank i 's exposure, α_i , is irrelevant since lower dominance regions, and hence investors' actions in those regions are identical across banks. Iterating this argument yields the same outcome as in Proposition 2.

Suppose that if $\eta_i = +\Delta_\eta$ (respectively, if $\eta_i = -\Delta_\eta$), investors withdraw from bank i if and only if their belief is below ρ_Δ^* (respectively, below $\rho_{-\Delta}^*$).

For an investor with a posterior belief ρ , the expected mass of withdrawal from a η -type bank is

$$l_\eta(\rho) = \Phi \left[\sqrt{\nu} \left(\rho_\eta^* - \frac{h_\mu \mu + h_\varepsilon \rho}{h_\mu + h_\varepsilon} \right) \right],$$

where

$$\nu = \frac{(h_\mu + h_\varepsilon)^3}{h_\varepsilon(2h_\varepsilon + h_\mu)}.$$

Hence, for the *marginal* investor with posterior belief ρ_η^* in a η -type bank, the expected mass of withdrawal from his bank, as well as from other η -type banks reduces to

$$l_\eta(\rho_\eta^*) = \Phi \left[\sqrt{\gamma} (\rho_\eta^* - \mu) \right],$$

where

$$\gamma = \frac{h_\mu^2(h_\mu + h_\varepsilon)}{h_\varepsilon(2h_\varepsilon + h_\mu)}.$$

Hence, noticing that

$$\begin{aligned} \mathbb{E} \left\{ \int_{z \neq i} \frac{\alpha_z}{\int_{j \neq i} \alpha_j dj} l_z dz \right\} &= \int_{z: \alpha_z = \alpha} \frac{1}{q} \mathbb{E}(l_z | \rho) dz \\ &= \int_{z: \alpha_z = \alpha, \eta_z = \Delta_\eta} \frac{1}{q} \mathbb{E}(l_z | \rho, \eta_z = \Delta_\eta) dz + \int_{z: \alpha_z = \alpha, \eta_z = -\Delta_\eta} \frac{1}{q} \mathbb{E}(l_z | \rho, \eta_z = -\Delta_\eta) dz \\ &= pl_\Delta(\rho) + (1-p)l_{-\Delta}(\rho), \end{aligned}$$

the indifference conditions of marginal investors, respectively in high- and low-quality banks write:

$$\begin{aligned} \frac{\rho_\Delta^* + \Delta_\eta}{c} &= \{1 - \hat{q} + \hat{q}[(1 - \alpha) + \alpha p]\} \Phi \left[\sqrt{\gamma} (\rho_\Delta^* - \mu) \right] \\ &\quad + \hat{q} \alpha (1 - p) \Phi \left[\sqrt{\nu} \left(\rho_{-\Delta}^* - \frac{h_\mu \mu + h_\varepsilon \rho_\Delta^*}{h_\mu + h_\varepsilon} \right) \right], \end{aligned} \quad (\text{A.46})$$

$$\begin{aligned} \frac{\rho_{-\Delta}^* - \Delta_\eta}{c} &= \{1 - \hat{q} + \hat{q}[1 - \alpha + \alpha(1 - p)]\} \Phi \left[\sqrt{\gamma} (\rho_{-\Delta}^* - \mu) \right] \\ &\quad + \hat{q} \alpha p \Phi \left[\sqrt{\nu} \left(\rho_\Delta^* - \frac{h_\mu \mu + h_\varepsilon \rho_{-\Delta}^*}{h_\mu + h_\varepsilon} \right) \right], \end{aligned} \quad (\text{A.47})$$

where $\hat{q} = q$ if $\sigma = \{\eta_i\}_{i \in [0,1]}$, and $\hat{q} = 1$ if $\sigma = \{\eta_i, \alpha_i\}_{i \in [0,1]}$. That is, if investors know idiosyncratic shocks $\{\eta_i\}_{i \in [0,1]}$ but don't know cross-exposures they will consider that their bank is exposed to other banks in the system with probability q . If investors know both idiosyncratic shocks and cross-exposures, either $\hat{q} = 0$ for non-connected banks for which the rollover equilibrium is known, or $\hat{q} = 1$ for connected bank, which we study here.

There exists a unique equilibrium in threshold strategies iff the system $\{(A.46), (A.47)\}$ has a unique solution for the couple $\{\rho_{\Delta}^*, \rho_{-\Delta}^*\}$.

Let

$$\xi \equiv \frac{h_{\mu}^2(h_{\mu} + h_{\varepsilon})(2h_{\varepsilon} + h_{\mu})}{h_{\varepsilon}^3},$$

and consider the following condition,

$$\xi < \frac{2\pi}{c^2}. \quad (\text{A.48})$$

Lemma A.4. *If (A.48) is satisfied, there exists a unique equilibrium in threshold strategies.*

Proof. Note that $\gamma < \xi$. Hence, if (A.48) holds, (A.46) yields a unique solution for ρ_{Δ}^* , taking $\rho_{-\Delta}^*$ as given.^{A9} In addition, ρ_{Δ}^* is strictly increasing in $\rho_{-\Delta}^*$ (which, intuitively, reflects strategic complementarities across banks of different types). Hence, there exists a one-to-one mapping $f(\cdot)$ such that $\rho_{\Delta}^* = f(\rho_{-\Delta}^*)$.

Total differentiation of (A.46) with respect to $\rho_{-\Delta}^*$ yields

$$\left[A + \frac{h_{\varepsilon}}{h_{\varepsilon} + h_{\mu}} B \right] f'[\rho_{-\Delta}^*] = B \quad (\text{A.49})$$

where,

$$A = \frac{\partial}{\partial \rho} \left\{ \frac{\rho + \Delta\eta}{c} - \{1 - \hat{q} + \hat{q}[(1 - \alpha) + \alpha p]\} \Phi[\sqrt{\gamma}(\rho - \mu)] \right\}_{\rho=f(\rho_{-\Delta}^*)}$$

and letting ϕ denote the density of a standard normal distribution,

$$B = \hat{q}\alpha(1 - p)\sqrt{\nu}\phi \left[\sqrt{\nu} \left(\rho_{-\Delta}^* - \frac{h_{\mu}\mu + h_{\varepsilon}\rho_{\Delta}^*}{h_{\mu} + h_{\varepsilon}} \right) \right].$$

(A.48) and $\gamma < \xi$ imply $A > 0$. Furthermore, $B > 0$ and hence, (A.49) implies

$$f' < \frac{h_{\varepsilon} + h_{\mu}}{h_{\varepsilon}}. \quad (\text{A.50})$$

Let C denote the total differentiation of the RHS of (A.47) with respect to $\rho_{-\Delta}^*$. Using (A.50),

$$C < \frac{1}{\sqrt{2\pi}} \left\{ \{1 - \hat{q} + \hat{q}[1 - \alpha + \alpha(1 - p)]\} \sqrt{\gamma} + \hat{q}\alpha p \sqrt{\xi} \right\}. \quad (\text{A.51})$$

Hence, using $\gamma < \xi$, $C < \sqrt{\frac{\xi}{2\pi}}$. Hence, if (A.48) is true, then there is a unique $\rho_{-\Delta}^*$ that satisfies (A.47) if $\rho_{\Delta}^* = f(\rho_{-\Delta}^*)$.^{A10} This, in turn, implies that the system $\{(A.46)(A.47)\}$ has a unique solution, $\{\rho_{-\Delta}^*, \rho_{\Delta}^*\}$.^{A11} \square

^{A9}If $\frac{1}{c} > \sqrt{\frac{\gamma}{2\pi}}$, then the function $\frac{\rho + E_1(\eta_i)}{c} - \Phi[\sqrt{\gamma}(\rho - \mu)]$ is strictly increasing in ρ . This property underlies the uniqueness condition in Proposition 2.

^{A10}This relies again on the fact that the LHS of (A.47) minus the RHS of (A.47) is then strictly increasing in $\rho_{-\Delta}^*$

^{A11}Note that (A.48) is sufficient only.

Lemma 1 shows the existence of a unique equilibrium in threshold strategies when $\xi < \frac{2\pi}{c^2}$. The next lemma claims global uniqueness (without restricting attention to threshold strategies)

Lemma A.5. *If $\xi < \frac{2\pi}{c^2}$ is true, then the unique equilibrium of the rollover game is such that investors withdraw from a η -type bank if and only if their posterior belief ρ is smaller than ρ_η .*

Proof. The proof is a slightly modified version of the forward induction argument that is standard in global games, so we only sketch it here.

Let $u_\Delta(\rho, \rho_\Delta, \rho_{-\Delta})$ and $u_{-\Delta}(\rho, \rho_\Delta, \rho_{-\Delta})$ denote the net return of an investor who rolls over, respectively in a high-quality and in low-quality bank, when his belief is ρ and he believes that other investors withdraw from η -type banks if their belief ρ' is smaller than ρ_η .

$$\begin{aligned} u_\Delta(\rho, \rho_\Delta, \rho_{-\Delta}) &= \rho + \Delta_\eta \\ &\quad -c \{1 - \hat{q} + \hat{q}[1 - \alpha + \alpha p]\} \Phi \left[\sqrt{\nu} \left(\rho_\Delta - \frac{h_\mu \mu + h_\varepsilon \rho}{h_\mu + h_\varepsilon} \right) \right] \\ &\quad -c \hat{q} \alpha (1 - p) \Phi \left[\sqrt{\nu} \left(\rho_{-\Delta} - \frac{h_\mu \mu + h_\varepsilon \rho}{h_\mu + h_\varepsilon} \right) \right] \end{aligned} \quad (\text{A.52})$$

$$\begin{aligned} u_{-\Delta}(\rho, \rho_\Delta, \rho_{-\Delta}) &= \rho - \Delta_\eta \\ &\quad -c \{1 - \hat{q} + \hat{q}[1 - \alpha + \alpha(1 - p)]\} \Phi \left[\sqrt{\nu} \left(\rho_{-\Delta} - \frac{h_\mu \mu + h_\varepsilon \rho}{h_\mu + h_\varepsilon} \right) \right] \\ &\quad -c \hat{q} \alpha p \Phi \left[\sqrt{\nu} \left(\rho_\Delta - \frac{h_\mu \mu + h_\varepsilon \rho}{h_\mu + h_\varepsilon} \right) \right] \end{aligned} \quad (\text{A.53})$$

u_η is strictly increasing in its first argument, and strictly decreasing in its second and third argument. Note also that there exists higher and lower dominance region, i.e.,

$$\rho < \eta \Rightarrow u_\eta < 0 \text{ and } \rho > \eta - c \Rightarrow u_\eta > 0.$$

Let $\underline{\rho}_\Delta^1 \equiv -\Delta_\eta$ and $\underline{\rho}_{-\Delta}^1 \equiv \Delta_\eta$, and notice that

$$\lim_{\rho_\Delta \rightarrow -\infty, \rho_{-\Delta} \rightarrow -\infty} u_\Delta(\underline{\rho}_\Delta^1, \rho_\Delta, \rho_{-\Delta}) = 0 \quad \text{and} \quad \lim_{\rho_\Delta \rightarrow -\infty, \rho_{-\Delta} \rightarrow -\infty} u_{-\Delta}(\underline{\rho}_{-\Delta}^1, \rho_\Delta, \rho_{-\Delta}) = 0. \quad (\text{A.54})$$

Next, define $(\underline{\rho}_\Delta^k)_{k>1}$ and $(\underline{\rho}_{-\Delta}^k)_{k>1}$ in the following recursive way,

$$\forall k, u_\Delta(\underline{\rho}_\Delta^{k+1}, \underline{\rho}_\Delta^k, \underline{\rho}_{-\Delta}^k) = 0 \text{ and } u_{-\Delta}(\underline{\rho}_{-\Delta}^{k+1}, \underline{\rho}_\Delta^k, \underline{\rho}_{-\Delta}^k) = 0.$$

Using the monotonicity properties of u , $u_\Delta(\underline{\rho}_\Delta^1, \underline{\rho}_\Delta^1, \underline{\rho}_{-\Delta}^1) < 0$. Hence, $u_\Delta(\underline{\rho}_\Delta^2, \underline{\rho}_\Delta^1, \underline{\rho}_{-\Delta}^1) = 0$ implies $\underline{\rho}_\Delta^2 > \underline{\rho}_\Delta^1$. Likewise, for any k , $\underline{\rho}_\Delta^{k+1} > \underline{\rho}_\Delta^k$ and $\underline{\rho}_{-\Delta}^{k+1} > \underline{\rho}_{-\Delta}^k$.

Finally, for any k , $\underline{\rho}_\Delta^k < \rho_\Delta^*$ (as defined in Lemma A.4) and $\underline{\rho}_{-\Delta}^k < \rho_{-\Delta}^*$. Proof is by forward induction. It is true for $k = 1$. Suppose it is true for $k > 1$. Then, using the monotonicity properties of u ,

$$0 = u(\underline{\rho}_\Delta^{k+1}, \underline{\rho}_\Delta^k, \underline{\rho}_{-\Delta}^k) > u(\underline{\rho}_\Delta^{k+1}, \rho_\Delta^*, \rho_{-\Delta}^*).$$

Since $u_h(\rho_\Delta^*, \rho_\Delta^*, \rho_{-\Delta}^*) = 0$, $\underline{\rho}_\Delta^{k+1} < \rho_\Delta^*$.

$(\underline{\rho}_{-\Delta}^k)_k$ and $(\underline{\rho}_{-\Delta}^k)_k$ are strictly increasing bounded above sequences, hence they converge, respectively to $\underline{\rho}_\Delta$ and $\underline{\rho}_{-\Delta}$. Since u_Δ and $u_{-\Delta}$ are continuous functions, the following conditions must hold,

$$u_\Delta(\underline{\rho}_\Delta, \underline{\rho}_\Delta, \underline{\rho}_{-\Delta}) = 0 \text{ and } u_l(\underline{\rho}_{-\Delta}, \underline{\rho}_\Delta, \underline{\rho}_{-\Delta}) = 0,$$

which implies $\underline{\rho}_\Delta = \rho_\Delta^*$ and $\underline{\rho}_{-\Delta} = \rho_{-\Delta}^*$.

A similar exercise show the existence of strictly decreasing sequences $(\bar{\rho}_\Delta^k)_k$ and $(\bar{\rho}_{-\Delta}^k)_k$ that converge, respectively to ρ_Δ^* and $\rho_{-\Delta}^*$.

The end of the proof is standard. It consist in showing that the only strategies that survive k rounds of deletion of dominated strategies are such that an investor in an η -type bank withdraws if his belief is below $\underline{\rho}_\eta^k$ and rolls over if his belief is above $\bar{\rho}_\eta^k$. Hence, eventually, the only strategy that survives iterated deletion of dominated strategies is such that investors roll over in a η -type bank if and only if their belief is above ρ_η^* . \square

To summarize, we have shown that provided $\xi < \frac{2\pi}{c^2}$, the rollover game has a unique equilibrium. In this equilibrium investors withdraw from bank i if and only if their belief ρ_i is below a threshold that depends on their information about η_i and α_i .

We turn now to the limit case in which $h_\epsilon \rightarrow +\infty$.^{A12} Note first that this implies $\xi \rightarrow 0$ so that the uniqueness condition $\xi < \frac{2\pi}{c^2}$ is still true. Second, it also implies $\gamma \rightarrow 0$. Finally, since from (A.46) and (A.47), ρ_Δ and $\rho_{-\Delta}$ are bounded,

$$\lim_{h_\epsilon \rightarrow \infty} \Phi[\sqrt{\gamma}(\rho_\eta^* - \mu)] = \frac{1}{2}.$$

The analysis of the equilibrium thresholds builds on two lemmas.

Lemma A.6.

$$\lim_{h_\epsilon \rightarrow \infty} (\rho_\Delta^* - \rho_{-\Delta}^*) \leq 0. \tag{A.55}$$

^{A12}Everything we show below for $h_\epsilon \rightarrow +\infty$ also holds if we take limits jointly on h_ϵ and h_μ , that is, if $h_\mu \rightarrow +\infty$ and $\frac{h_\mu}{h_\epsilon} \rightarrow 0$ (which implies $\xi \rightarrow 0$).

Proof. Suppose (A.55) is not true, then

$$\lim_{h_\varepsilon \rightarrow \infty} \Phi \left[\sqrt{\nu} \left(\rho_{-\Delta}^* - \frac{h_\mu \mu + h_\varepsilon \rho_\Delta^*}{h_\mu + h_\varepsilon} \right) \right] = 0$$

and

$$\lim_{h_\varepsilon \rightarrow \infty} \Phi \left[\sqrt{\nu} \left(\rho_\Delta^* - \frac{h_\mu \mu + h_\varepsilon \rho_{-\Delta}^*}{h_\mu + h_\varepsilon} \right) \right] = 1$$

Then, (A.46) and (A.47) imply

$$\lim_{h_\varepsilon \rightarrow \infty} \frac{\rho_\Delta^* - \rho_{-\Delta}^*}{c} = -\frac{2\Delta_\eta}{c} - \frac{\hat{q}\alpha}{2} < 0,$$

a contradiction. □

Lemma A.7. $\lim_{h_\varepsilon \rightarrow \infty} (\rho_\Delta^* - \rho_{-\Delta}^*) = 0$ if and only if $2\Delta_\eta \leq \frac{\hat{q}\alpha}{2}$.

Proof. Suppose $\lim_{h_\varepsilon \rightarrow \infty} (\rho_\Delta^* - \rho_{-\Delta}^*) = 0$, then subtracting (A.47) from (A.46) and using the fact that $0 \leq \Phi(\cdot) \leq 1$,

$$\frac{2\Delta_\eta}{c} \leq \frac{1 - \hat{q} + \hat{q}[1 - \alpha + \alpha p]}{2} + \hat{q}\alpha(1 - p) - \frac{1 - \hat{q} + \hat{q}[1 - \alpha + \alpha(1 - p)]}{2},$$

which, after rearranging, proves $\lim_{h_\varepsilon \rightarrow \infty} (\rho_h^* - \rho_l^*) = 0 \Rightarrow \frac{2\Delta_\eta}{c} \leq \frac{\hat{q}\alpha}{2}$.

Suppose $\lim_{h_\varepsilon \rightarrow \infty} (\rho_h^* - \rho_l^*) \neq 0$. From lemma 2, it implies $\lim_{h_\varepsilon \rightarrow \infty} (\rho_h^* - \rho_l^*) < 0$. Hence,

$$\lim_{h_\varepsilon \rightarrow \infty} \Phi \left[\sqrt{\nu} \left(\rho_l^* - \frac{h_\mu \mu + h_\varepsilon \rho_h^*}{h_\mu + h_\varepsilon} \right) \right] = 1$$

and

$$\lim_{h_\varepsilon \rightarrow \infty} \Phi \left[\sqrt{\nu} \left(\rho_h^* - \frac{h_\mu \mu + h_\varepsilon \rho_l^*}{h_\mu + h_\varepsilon} \right) \right] = 0$$

Then subtracting (A.47) from (A.46),

$$\lim_{h_\varepsilon \rightarrow \infty} \frac{\rho_h^* - \rho_l^*}{c} = -\frac{2\Delta_\eta}{c} + \frac{\hat{q}\alpha}{2},$$

Hence, $\frac{2\Delta_\eta}{c} > \frac{\hat{q}\alpha}{2}$. □

Consider now two cases

1. $2\Delta_\eta \leq \frac{c\hat{q}\alpha}{2}$

Intuitively, this corresponds to the case where the benefit of transparency is likely to be low (high and low-quality banks are not very different (Δ small)). There are strong externalities between banks,

hence every bank is highly dependent from liquidation decisions in all other banks (α and q large) large).

Using

$$\lim_{h_\varepsilon \rightarrow \infty} \sqrt{\nu} \left(\rho_l^* - \frac{h_\mu \mu + h_\varepsilon \rho_h^*}{h_\mu + h_\varepsilon} \right) = \lim_{h_\varepsilon \rightarrow \infty} \frac{h_\varepsilon}{h_\mu + h_\varepsilon} \sqrt{\nu} (\rho_l^* - \rho_h^*) = - \lim_{h_\varepsilon \rightarrow \infty} \sqrt{\nu} \left(\rho_h^* - \frac{h_\mu \mu + h_\varepsilon \rho_l^*}{h_\mu + h_\varepsilon} \right),$$

$p \times (A.46) + (1-p) \times (A.47)$ yields after simplification

$$\lim_{h_\varepsilon \rightarrow \infty} \rho_\Delta^* = \lim_{h_\varepsilon \rightarrow \infty} \rho_{-\Delta}^* = \frac{c}{2} - (2p-1)\Delta_\eta \quad (A.56)$$

Note that in this case, the run threshold is identical across banks with different η_i . Intuitively, cross-exposures create strategic complementarities between banks that are strong enough to overcome differences in long-term returns.

2. $2\Delta_\eta > \frac{c\hat{q}\alpha}{2}$

One gets directly

$$\begin{aligned} \lim_{h_\varepsilon \rightarrow \infty} \rho_\Delta^* &= [1 + \hat{q}\alpha(1-p)] \frac{c}{2} - \Delta_\eta \\ \lim_{h_\varepsilon \rightarrow \infty} \rho_{-\Delta}^* &= [1 - \hat{q}\alpha p] \frac{c}{2} + \Delta_\eta > \lim_{h_\varepsilon \rightarrow \infty} \rho_\Delta^* \end{aligned}$$

Finally, when $h_\mu \rightarrow +\infty$ (and $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$), $\lim_{h_\varepsilon \rightarrow \infty} \rho_\eta^* = \mu$, and hence

- if $2\Delta_\eta \leq \frac{c\hat{q}\alpha}{2}$,

$$p_\Delta = p_{-\Delta} = p_{\Delta,\alpha} = p_{-\Delta,\alpha} = p^*$$

- if $\frac{c\hat{q}\alpha}{2} < 2\Delta_\eta \leq \frac{c\alpha}{2}$,

$$p_{\Delta,\alpha} = p_{-\Delta,\alpha} = p^*,$$

$$p_\Delta = 1 - \frac{1}{q\alpha} \left[\frac{2(\mu + \Delta_\eta)}{c} - 1 \right] \quad \text{and} \quad p_{-\Delta} = \frac{1}{q\alpha} \left[1 - \frac{2(\mu - \Delta_\eta)}{c} \right].$$

- if $\frac{c\alpha}{2} < 2\Delta_\eta$,

$$p_{\Delta,\alpha} = 1 - \frac{1}{\alpha} \left[\frac{2(\mu + \Delta_\eta)}{c} - 1 \right] \quad \text{and} \quad p_{-\Delta,\alpha} = \frac{1}{\alpha} \left[1 - \frac{2(\mu - \Delta_\eta)}{c} \right].$$

$$p_\Delta = 1 - \frac{1}{q\alpha} \left[\frac{2(\mu + \Delta_\eta)}{c} - 1 \right] \quad \text{and} \quad p_{-\Delta} = \frac{1}{q\alpha} \left[1 - \frac{2(\mu - \Delta_\eta)}{c} \right].$$

Proof of Proposition 8

The probability that a bank is of high-quality (i.e., $\eta_i = \Delta_\eta$) given p and given $\varsigma_i^I = h$ is

$$\begin{aligned} \Pr(\eta_i = \Delta_\eta | p, \varsigma_i^I = h) &= \frac{\Pr(\eta_i = \Delta_\eta | p) \Pr(\varsigma_i^I = h | p, \eta_i = \Delta_\eta)}{\Pr(\varsigma_i^I = h | p)} = \\ &= \Pr(\varsigma_i^I = h | p, \eta_i = \Delta_\eta) = \theta^I + (1 - \theta^I)p. \end{aligned} \quad (\text{A.57})$$

[Since $\Pr(\eta_i = \Delta_\eta | p) = \Pr(\theta^I = h | p) = p$.]

Similarly, the probability that a bank is of low-quality (i.e., $\eta_i = \Delta_\eta$) given p and given $\varsigma_i^I = l$ is

$$\Pr(\eta_i = \Delta_\eta | p, \varsigma_i^I = l) = \theta^I + (1 - \theta^I)(1 - p). \quad (\text{A.58})$$

From (A.57) and (A.58), it follows that

$$\mathbb{E}_1(\eta_i | p, h, \emptyset) = [2(\theta^I + (1 - \theta^I)p) - 1] \Delta_\eta \quad \text{and} \quad \mathbb{E}_1(\eta_i | p, l, \emptyset) = [2(1 - \theta^I)p - 1] \Delta_\eta. \quad (\text{A.59})$$

If the regulator does not disclose his bank-specific information on a given bank i , this bank suffers a run if and only if

$$\mu + \mathbb{E}_1(\eta_i | p, \varsigma_i^I, \emptyset) < \frac{c}{2}. \quad (\text{A.60})$$

Define \underline{p}^* and \bar{p}^* as

$$\mathbb{E}_1(\eta_i | \underline{p}^*, h, \emptyset) \equiv \mu - \frac{c}{2} \quad (\text{A.61})$$

$$\mathbb{E}_1(\eta_i | \bar{p}^*, l, \emptyset) \equiv \mu - \frac{c}{2} \quad (\text{A.62})$$

then, since $\frac{\partial \mathbb{E}_1(\eta_i | p, h, \emptyset)}{\partial p} > 0$ and $\frac{\partial \mathbb{E}_1(\eta_i | p, l, \emptyset)}{\partial p} > 0$, a bank such that $\varsigma_i^I = h$ (respectively, $\varsigma_i^I = l$) suffers a run if the regulator does not disclose bank-specific information if and only if $p < \underline{p}^*$ (respectively, $p < \bar{p}^*$). Hence, if $p < \underline{p}^*$ (respectively, $p < \bar{p}^*$) it is optimal for the regulator to disclose its information on banks such that $\varsigma_i^I = h$ (respectively, $\varsigma_i^I = l$).^{A13}

From (A.59), $\mathbb{E}_1(\eta_i | p, h, \emptyset) > \mathbb{E}_1(\eta_i | p, l, \emptyset)$ for any given p . In addition, $\frac{\partial \mathbb{E}_1(\eta_i | p, h, \emptyset)}{\partial p} > 0$ and $\frac{\partial \mathbb{E}_1(\eta_i | p, l, \emptyset)}{\partial p} > 0$. Therefore, $\underline{p}^* < \bar{p}^*$. Finally, $\mathbb{E}_1(\eta_i | p, h, \emptyset) > \mathbb{E}_1(\eta_i | p) > \mathbb{E}_1(\eta_i | p, l, \emptyset)$, with $\mathbb{E}_1(\eta_i | p) = (2p - 1) \Delta_\eta$ and $\frac{\partial \mathbb{E}_1(\eta_i | p)}{\partial p} > 0$, which implies that $\underline{p}^* < p^* < \bar{p}^*$. \square

^{A13}Note that, since $\mathbb{E}_1(\eta_i | p, \varsigma_i^I, l) < \mathbb{E}_1(\eta_i | p, \varsigma_i^I, \emptyset) < \mathbb{E}_1(\eta_i | p, \varsigma_i^I, h)$, disclosing bank-specific information when $\varsigma_i^I = l$ (respectively, $\varsigma_i^I = h$) prevents run for some realizations of p below \underline{p}^* (respectively \bar{p}^*), in which case it is strictly optimal. However, for a low enough p , and provided if θ^R and θ^I are not too large, it might be the case that $\mathbb{E}_1(\eta_i | p, l, h) < \mu - \frac{c}{2}$ (respectively, $\mathbb{E}_1(\eta_i | p, h, h) < \mu - \frac{c}{2}$). In such cases, disclosure is only weakly optimal as runs cannot be prevented by disclosing information

Proof of Corollary 5

Given (A.59), it follows from (A.61) and (A.62) that $\frac{\partial \bar{p}^*}{\partial \theta^I} > 0$ and $\frac{\partial p^*}{\partial \theta^I} < 0$.

Since p^* verifies $\mu + (2p^* - 1) = \frac{c}{2}$ (see Proposition 2), and from (A.59), $\lim_{\theta^I \rightarrow 0} \mathbb{E}_1(\eta_i | p, h, \emptyset) \rightarrow (2p - 1)\Delta_\eta$, it follows that $\lim_{\theta^I \rightarrow 0} \underline{p}^* \rightarrow p^*$. Likewise, one shows $\lim_{\theta^I \rightarrow 0} \bar{p}^* \rightarrow p^*$. \square

Appendix B. Robustness

I. The Case in which h_μ is Finite

The main text provides the analysis of the limit case where $h_\mu \rightarrow +\infty$. We show here that in the more general case where h_μ is finite, the optimal disclosure policy is still one in which transparency is optimal when p is below a threshold p^* . Hence, this section generalizes the result in Proposition 2 of the main text.

Proposition B.1. *For every finite h_μ there exists a threshold $p^*(h_\mu) \in [0, 1]$ such that the regulator follows a policy of transparency if and only if $p < p^*(h_\mu)$.*

Proof. Let $F(\eta)$ denote the net expected return of a bank when investors believe that the idiosyncratic component of returns is equal to η :

$$F(\eta) \equiv \int_{\frac{c}{2}-\eta}^{+\infty} [x + \eta] \sqrt{\frac{h_\mu}{2\pi}} e^{-h_\mu \frac{(x-\mu)^2}{2}} dx \quad (\text{B.1})$$

Transparency is preferable to opacity if and only if

$$D(p) \equiv pF(\Delta_\eta) + (1-p)F(-\Delta_\eta) - F[(2p-1)\Delta_\eta] > 0. \quad (\text{B.2})$$

Differentiating twice,

$$D''(p) = -4\Delta_\eta^2 \sqrt{\frac{h_\mu}{2\pi}} e^{-h_\mu \frac{[\frac{c}{2} - (2p-1)\Delta_\eta - \mu]^2}{2}} \left[1 + \frac{ch_\mu}{2} \left(\frac{c}{2} - (2p-1)\Delta_\eta - \mu \right) \right]. \quad (\text{B.3})$$

Therefore, $D(\cdot)$ changes convexity at most once on $(0, 1)$. This, together with the observation that $D(0) = D(1) = 0$, implies that $D(p) = 0$ has at most one solution in $(0, 1)$. Finally, $\frac{c}{2} + \Delta_\eta - \mu > 0$ implies $D''(0) < 0$, which in turn, implies that if there exists a $\bar{p} \in (0, 1)$ such that $D(\bar{p}) = 0$, then $D(p) > 0$ if $p \in (0, \bar{p})$ and $D(p) < 0$ if $p \in (\bar{p}, 1)$. Hence, the optimal strategy would be such that the system is transparent iff $p < p^*(h_\mu) \equiv \bar{p}$.

Alternatively, if there does not exist a $\bar{p} \in (0, 1)$ such that $D(\bar{p}) = 0$, then there is a corner solution in which either (i) $D(p) > 0$ for all $p \in (0, 1)$ and hence, $p^*(h_\mu) = 1$ (i.e., transparency dominates opacity) or (ii) $D(p) < 0$ for all $p \in (0, 1)$ and hence, $p^*(h_\mu) = 0$ (i.e., opacity dominates transparency). \square

Notice that a corner solution only happens if the distribution of $\tilde{\mu}$ is highly dispersed. If, on the contrary, the distribution is more concentrated around the mean, μ , then $p^* \in (0, 1)$. To see this, derive

$$\begin{aligned} D'(p) &= \int_{\frac{c}{2}-\Delta}^{\frac{c}{2}+\Delta} (x + \Delta) d\Phi[\sqrt{h_\mu}(x - \mu)] dx - 2\Delta \int_{\frac{c}{2}-(2p-1)\Delta}^{\frac{c}{2}+\Delta} d\Phi[\sqrt{h_\mu}(x - \mu)] dx - \\ &\quad - 2\Delta \frac{c}{2} \sqrt{\frac{h_\mu}{2\pi}} e^{-h_\mu \frac{[c/2 - (2p-1)\Delta - \mu]^2}{2}}. \end{aligned} \quad (\text{B.4})$$

Therefore, given $\frac{c}{2} - \Delta_\eta < \mu < \frac{c}{2} + \Delta_\eta$, we get

$$\lim_{h_\mu \rightarrow +\infty} D'(0) = \mu + \Delta_\eta \text{ and } \lim_{h_\mu \rightarrow +\infty} D'(1) = \mu - \Delta_\eta. \quad (\text{B.5})$$

Thus, for h_μ sufficiently large, $D'(0) > 0$ and $D'(1) > 0$ (since $\mu - \Delta_\eta > 0$), and hence, $p^* \in (0, 1)$. Moreover, as $h_\mu \rightarrow +\infty$ then $p^*(h_\mu) \rightarrow p^*$ as defined in Proposition 2.

Finally notice that in the main text we have also taken the limit $h_\varepsilon \rightarrow +\infty$. This also done to simplify the analysis. If h_ε is finite but large enough relative to h_μ , the equilibrium remains unique and the optimal disclosure policy is still one in which the regulator increases transparency following a negative shock to the financial system (i.e., when the realization of p falls below some threshold). \square

II. Disclosure Policy with Endogenous Risk

In the main text, we study the optimal disclosure policy while taking each bank's risk as given. Banks however do have some control over their risk exposure. For instance, banks may choose to diversify their idiosyncratic risk by investing across different industries, regions, or asset classes, or they may lower their exposure to aggregate risk by increasing the liquidity of their balance sheets. In fact, diversification and increased liquidity are measures often prescribed to address rollover risk (e.g., Allen and Gale, 2000; Dasgupta, 2004). In this appendix, we study the optimal disclosure policy when banks can choose their risk exposure.

II.A Diversification

We consider first the case where banks can diversify their idiosyncratic risk by investing across different assets. In particular, we assume that the return r_i , as defined in Section 1, now characterizes the return of a class of assets of type i , instead of the return of a bank. We also assume that banks can invest into different asset classes at $t = 0$ (hence, before knowing r_i or the realization of p). Specifically, each bank i can invest a fraction $\alpha_i \in (0, 1]$ of its resources in assets of class i , and the rest of its resources, $1 - \alpha_i$, into each other classes of assets $j \neq i$ in equal proportion. Thus, through the fraction α_i , bank i remains exposed to the specific risk of asset i while the rest of its resources is invested in a perfectly diversified portfolio. Notice that the model studied in previous sections corresponds to the particular case where $\alpha_i = 1$ for all i , that is, the case in which each bank chooses to be fully invested in one asset type. Using a natural extension of the terminology introduced in previous sections, we refer to an asset with idiosyncratic component $\eta_i = \Delta_\eta$, as a high-quality asset, and its corresponding bank as a high-quality bank.

Since there is a continuum of assets, the payoff of bank i from the share $1 - \alpha_i$ invested in assets $j \neq i$ is equal to $(1 - \alpha_i)[\mu + (2p - 1)\Delta_\eta]$. In this payoff, the only source of uncertainty comes from the aggregate component p . Hence the long-term return of bank i is now $\mu + (1 - \alpha_i)(2p - 1)\Delta_\eta + \alpha_i\eta_i$ where $\alpha_i\eta_i$ determines bank i exposure to asset-idiosyncratic risk.

In order to make more apparent the impact of the optimal disclosure policy on banks' diversification choices, we start with a benchmark case in which the banking system is always transparent. The following result obtains.

Proposition B.2. *If the banking system is transparent, banks optimally choose to diversify, i.e., $\alpha_i < 1$ for all i , provided μ is sufficiently high.*

Proof. Depending on the choice of α_i and the realization of p , there are three possible cases.

1. If $\mu - \alpha_i \Delta_\eta + (1 - \alpha_i)(2p - 1)\Delta_\eta > \frac{c}{2} \Leftrightarrow p > \frac{1}{2} + \frac{\frac{c}{2} - \mu + \alpha_i \Delta_\eta}{2(1 - \alpha_i)\Delta_\eta} \equiv \bar{p}(\alpha_i)$, there is no run on bank i , whatever the realization of η_i . This happens with a strictly positive probability if $\alpha_i < \frac{1}{2} + \frac{1}{2\Delta_\eta} \left(\mu - \frac{c}{2} \right) \equiv \bar{\alpha}$.
2. If $\mu + \alpha_i \Delta_\eta + (1 - \alpha_i)(2p - 1)\Delta_\eta < \frac{c}{2} \Leftrightarrow p < \frac{1}{2} + \frac{\frac{c}{2} - \mu - \alpha_i \Delta_\eta}{2(1 - \alpha_i)\Delta_\eta} \equiv \underline{p}(\alpha_i)$, there is a run on bank i , whatever the realization of η_i . This happens with a strictly positive probability if $\alpha_i < \frac{1}{2} + \frac{1}{2\Delta_\eta} \left(\frac{c}{2} - \mu \right) \equiv \underline{\alpha}$.
3. If $\underline{p}(\alpha_i) < p < \bar{p}(\alpha_i)$, there is a run on bank i , only if $\eta_i = -\Delta$.

Notice first that if $\alpha_i \geq \max(\bar{\alpha}, \underline{\alpha})$, diversification does not affect the probability of a bank run, that is, the bank is liquidated if and only if $\eta_i = -\Delta$. Thus, the expected return of a bank i is

$$\int_0^1 p[\mu + \alpha_i \Delta_\eta + (1 - \alpha_i)(2p - 1)\Delta_\eta] dp. \quad (\text{B.6})$$

(B.6) is increasing in α_i , therefore $\alpha_i = 1$ strictly dominates any $\alpha_i \in [\max(\bar{\alpha}, \underline{\alpha}), 1)$. Intuitively, when $\alpha_i = 1$, bank i only holds high-quality assets when it survives and only all low-quality assets when it is liquidated. On the contrary, when a bank diversifies but α_i stays above $\max(\bar{\alpha}, \underline{\alpha})$, bank i only holds a fraction $\alpha_i + (1 - \alpha_i)p$ of high-quality assets when it survives (i.e., when $\eta_i = \Delta$). Conversely, a quantity $(1 - \alpha_i)p$ of high-quality assets is liquidated in lieu of low-quality assets when the bank is liquidated (i.e., when $\eta_i = -\Delta$). Therefore, diversification destroys value in the range $[\max(\bar{\alpha}, \underline{\alpha}), 1)$. However, for smaller values of α_i , diversification brings one benefit: it prevents runs on bank i when $\eta_i = -\Delta$ for high realizations of p . Specifically, consider the case where $\mu \geq \frac{c}{2}$, so that $\underline{\alpha} < \bar{\alpha}$. A banks can then choose α_i in $(\underline{\alpha}, \bar{\alpha})$, that is, such that diversification prevents runs when $\eta_i = -\Delta$ and p is high, but never causes a run when $\eta_i = \Delta$, even if p is low. Such an α_i dominates $\alpha_i = 1$ if the following condition holds

$$\int_0^1 p(\mu + \Delta_\eta) dp < \int_0^{\bar{p}(\alpha_i)} p[\mu + \alpha_i \Delta_\eta + (1 - \alpha_i)(2p - 1)\Delta_\eta] dp + \int_{\bar{p}(\alpha_i)}^1 \mu + (2p - 1)\Delta_\eta dp. \quad (\text{B.7})$$

Rearranging,

$$\int_0^{\bar{p}(\alpha_i)} 2\Delta_\eta(1 - p)(1 - \alpha_i)p dp < \int_{\bar{p}(\alpha_i)}^1 (1 - p)(\mu - \Delta_\eta) dp. \quad (\text{B.8})$$

The LHS of (B.8) is the cost of diversification: when p is low, with probability $1 - p$, a quantity $(1 - \alpha_i)p$ of high-quality assets is liquidated in lieu of low-quality assets, which has a net cost of $2\Delta_\eta$ per asset. The RHS is the benefit of diversification: when p is high, even low-quality assets can be brought to maturity. Notice that $\bar{p}(\alpha_i)$ is decreasing in μ and tends to 0 when $\mu \rightarrow \frac{c}{2} + \Delta_\eta$. Therefore, there exists a threshold for μ above which both the initial assumption $\mu - \Delta_\eta < \frac{c}{2}$ and (B.8) hold. Thus, in good economic times, that is, if μ is sufficiently high, banks will choose to diversify. \square

Intuitively, when the system is always transparent, diversification allows banks to survive a bad realization of their idiosyncratic component ($\eta_i = -\Delta_\eta$), provided p is sufficiently high (that is, provided the banking system does not experience a negative aggregate shock). Diversification, however, also entails costs. First, it may cause runs on high-quality banks for low realizations of p . Second, when only low-quality banks suffer runs, that is, for intermediate realizations of p , diversification decreases the asset value of banks that turn out to be of high quality, and hence, that are not liquidated, while it increases the asset value of low-quality banks, which are liquidated. In other words, while diversification may reduce the frequency of bank runs, it makes them costlier as those diversified banks that are liquidated hold some high-quality assets. As proposition B.2 indicates, when the expected return of the financial system, μ , is high, it becomes more likely that p falls into the upper region where some diversification allows to withstand a negative idiosyncratic shock. In that case, the benefits of diversification are sufficiently large to outweigh the costs.

Turn now to the case where the regulator can adjust transparency. The following proposition characterizes the optimal disclosure policy and level of diversification.

Proposition B.3. *For any $\{\alpha_i\}_{i \in [0,1]}$, the regulator follows a policy of transparency if and only if $p < p^*$ where p^* is defined as in proposition 2. Under this disclosure policy, each bank concentrates its investments in one asset class at $t = 0$, i.e., $\alpha_i^* = 1$ for all i .*

Proof. Notice first that the optimal disclosure policy is independent of $\{\alpha_i\}_{i \in [0,1]}$. To see this, notice that, in the absence of liquidation, the expected return of a bank under opacity is

$$\mu + (1 - \alpha_i)(2p - 1)\Delta_\eta + \alpha_i[p\Delta + (1 - p)(-\Delta)] = \mu + (2p - 1)\Delta_\eta. \quad (\text{B.9})$$

This expression, and thus, the occurrence of a run, is independent from α_i . Hence, there is a run on the entire system under opacity, if and only if $\mu + (2p - 1)\Delta_\eta < \frac{c}{2}$, that is, if $p < p^*$, in which case disclosure is optimal. On the contrary, if $p \geq p^*$, opacity saves the entire system.

Notice next that for all $p \geq p^*$, the expected return of a bank is simply $\mu + (2p - 1)\Delta_\eta$ which is independent from α_i . Finally, for any $p < p^*$, the expected return of a bank is $p[\mu + \alpha_i\Delta_\eta + (1 - \alpha_i)(2p - 1)\Delta_\eta]$ which is strictly increasing in α_i . It is therefore strictly optimal to choose $\alpha_i = 1$. \square

As Proposition B.3 states, the optimal disclosure policy is independent of the bank diversification choices, $\{\alpha_i\}_{i \in [0,1]}$. Indeed, the decision to disclose depends only on the aggregate expected return of the banking

system, which is unaffected by the degree of diversification of individual banks. (The expected return of any bank under opacity is $\mu + (2p - 1)\Delta_\eta$ which is independent from α_i .) In particular, the regulator will disclose information if and only if $p < p^*$ (or equivalently if and only if $\mu + (2p - 1)\Delta_\eta < \frac{c}{2}$) where p^* is defined as in the case in which each bank's risk exposure is considered exogenous. (See Proposition 2.) Moreover, since the disclosure policy is unaffected by the degree of diversification, banks' risk choices are socially optimal. Intuitively, in the model, the only possible externality would operate via the optimal disclosure policy, which Proposition B.3 shows to be independent of $\{\alpha_i\}_{i \in [0,1]}$. Hence banks do not exert any externalities on other banks when choosing their risk exposure.

Proposition B.3 also states that under the optimal disclosure policy, each bank chooses to be fully invested in one asset class, that is, diversification is suboptimal. On the one hand, when $p \geq p^*$, the regulator does not disclose information and the expected return of a bank is independent of α_i , i.e., $\mu + (2p - 1)\Delta_\eta$.^{B1} On the other hand, when $p < p^*$, the regulator does disclose information and the expected return of bank i is $p[\mu + \alpha_i\Delta_\eta + (1 - \alpha_i)(2p - 1)\Delta_\eta]$, which is strictly increasing in α_i . It is therefore strictly optimal to choose $\alpha_i^* = 1$. Intuitively, diversification has benefits in our model only if the system is transparent and if p is high. However, when p is high, opacity allows to reach the same outcome as diversification –saving all banks– and makes individual risk choices by banks irrelevant. For lower realizations of p , however, diversification only has costs.^{B2} As discussed earlier, when the regulator switches to a transparent regime, diversification prevents assets that turn out to be of high quality from being concentrated in certain banks, which increases the value destroyed in liquidations.^{B3}

Finally, Proposition B.3 shows that the optimal transparency policy in Proposition 2 is robust to a specification where the risk profile of each bank is endogenously determined. Indeed, anticipating an optimal response of the regulator to economic conditions, banks would choose to concentrate their investments in one type of assets ($\alpha_i = 1$ for all i).

Overall, Propositions B.2 and B.3 indicate that, in our model, the optimal contingent disclosure policy can achieve the benefits of diversification while avoiding some of its costs. The results also emphasize the importance of distinguishing between measures of risk at the individual bank level (for instance, based on the volatility of a bank's assets) and measures of risk at the level of the entire banking system. Indeed, this

^{B1}We have implicitly assumed that α_i was observable. However, since the expected return of the banking system under opacity and the disclosure policy are independent of α_i s, assuming that α_i is observable under transparency but not under opacity would not change the results.

^{B2}Specifically, diversification is beneficial (allows to save low-quality banks) if and only if p is higher than a threshold $\bar{p}(\alpha_i)$, which is itself higher than p^* for any $\alpha_i \in [0, 1]$.

^{B3}This contamination is similar to the one that can occur between divisions of a conglomerate in Banal-Estañol et al. (2013).

distinction between individual risk and systemic risk is at the core of recent proposals for the reform of the financial system (Kashyap et al., 2008; Morris and Shin, 2008).

II.B Liquidity

This section studies the optimal disclosure policy when banks can address rollover risk by managing the liquidity of their balance sheets. Consider the following change to the long-term investment technology of the basic model. At $t = 0$ each bank chooses the liquidity of its investment technology, L_i . Specifically, an investor who rolls over his investment at $t = 1$ obtains a random payoff of $1 + r_i - \tau \frac{L_i^2}{2} - c \times \max\{l_i - L_i, 0\}$ at $t = 2$, where $L_i \geq 0$. Thus, L_i affects the return at $t = 2$ through two different channels. On the one hand, if no liquidations take place at $t = 1$, that is, if $l_i = 0$, then a more liquid technology is associated with a lower expected return, which is captured by $-\tau \frac{L_i^2}{2}$. One interpretation of this convex cost is that banks sacrifice first their less profitable long-term investments in order to retain liquid assets on their balance sheets. On the other hand, a more liquid technology makes liquidations less costly, which is captured by $-c \max\{l_i - L_i, 0\}$. Note that the model studied in previous sections corresponds to the particular case where $\tau \rightarrow +\infty$, that is, the case in which holding liquidity is prohibitively expensive.

We restrict attention to the case where the marginal cost of a liquid balance sheet, τ , is sufficiently large, which ensures an interior solution when solving for the optimal level of liquidity:

$$\frac{c}{\tau} \leq \min \left\{ 1 - \frac{2(\mu + \Delta)}{c}; \frac{2(\mu - \Delta)}{c} \right\}. \quad (\text{B.10})$$

As will become clear below, this condition also implies that rollover risk cannot be completely eliminated.

The following proposition, which corresponds to Proposition 2 of the basic model, characterizes the optimal disclosure policy at $t = 1$.

Proposition B.4. *If all banks choose the same level of liquidity $L \leq \frac{c}{\tau}$, the regulator follows a policy of transparency if and only if $p < p^*(L)$ where*

$$p^*(L) = \frac{1}{2\Delta} \left[\frac{c}{2} - \mu + \tau \frac{L^2}{2} - cL \right] + \frac{1}{2}. \quad (\text{B.11})$$

Proof. The proof follows the lines of Proposition 2. The regulator chooses to disclose p if it is such that there is a run on the average bank, that is, if

$$\mu + (2p - 1)\Delta_\eta - \tau \frac{L^2}{2} < c \left(\frac{1}{2} - L \right) \Leftrightarrow p < \frac{1}{2} + \frac{1}{2\Delta} \left[\frac{c}{2} - \mu + \tau \frac{L^2}{2} - cL \right]. \quad (\text{B.12})$$

□

As in Proposition 2, a policy of opacity is optimal as long as p is above some threshold $p^*(L)$. That is, the regulator chooses to disclose only if p is such that there would be a run on the average bank:

$$\mu + (2p - 1)\Delta_\eta - \tau \frac{L^2}{2} < c \left(\frac{1}{2} - L \right). \quad (\text{B.13})$$

As long as $L \leq \frac{c}{\tau}$, $p^*(L)$ decreases in the liquidity of banks' balance sheets, L , and hence opacity is more valuable in a more liquid system. Intuitively, increasing L lowers long-term expected returns but makes investors who rollover their investment less sensitive to early withdrawals by other investors. The first effect increases investors' incentives to run while the second one diminishes them. If $L \leq \frac{c}{\tau}$, the second effect dominates, and a higher L allows to pool high-quality banks with more low-quality banks without causing a run on the whole banking system. That is, a higher L allows to lower the disclosure threshold $p^*(L)$.^{B4} Finally note that independently of the disclosure policy, increasing L beyond $\frac{c}{\tau}$ is suboptimal for any bank, since it would both decrease long-term expected returns in the absence of early liquidation and increase the probability of a run in the interim period.^{B5}

Let us now turn to banks' choice of liquidity at $t = 0$. Notice first that since Proposition B.4 characterizes the optimal disclosure policy, $p^*(L)$, for any admissible liquidity choice L , it is in turn possible to characterize the socially optimal level of liquidity L^* . Indeed, L^* maximizes the expected return of the financial system given that the system is transparent below $p^*(L)$ and opaque above $p^*(L)$. Formally, L^* solves

$$\max_L \int_0^{p^*(L)} p \left(\mu + \Delta - \tau \frac{L^2}{2} \right) dp + \int_{p^*(L)}^1 \left[\mu + (2p - 1)\Delta - \tau \frac{L^2}{2} \right] dp. \quad (\text{B.14})$$

Note that (B.14) implicitly assumes that it is optimal that every bank chooses the same level of liquidity $L_i = L$, a result that is formally shown below. One can also show that this maximization problem has a unique solution L^* that is characterized by the first-order condition of the program in B.14 (see Proof of Proposition B.5 below). L^* will serve as our benchmark for the remainder of this section.

Turn now to the equilibrium choice of liquidity by banks. Since this optimal disclosure policy does not depend on the liquidity of a single bank but on the liquidity of all banks in the system, and since banks are infinitesimally small, each bank will choose its optimal liquidity taking as given the liquidity choice of all other banks, that is, taking the regulator's disclosure policy as fixed. This can lead to multiple self-fulfilling equilibria in which banks may collectively end up with a balance sheet that is either more or less liquid

^{B4}Notice that $p^*(L)$ reaches a minimum for $L = \frac{c}{\tau}$ and that assumption in (B.10) guarantees that $p^*(\frac{c}{\tau})$ is strictly positive. Hence, there are realizations of p which are sufficiently low to trigger information disclosure by the regulator and a run on low-quality banks.

^{B5}Specifically, increasing L beyond $\frac{c}{\tau}$ reduces the payoff at $t = 2$, $1 + r_i - \tau \frac{L_i^2}{2} - c \times \max \{l_i - L_i, 0\}$, for any level of liquidation l_i at the interim date. Indeed, even for $l_i > L_i$, the payoff at $t = 2$ is decreasing in L_i if $L_i > \frac{\tau}{c}$.

than is socially optimal. For instance, consider the case in which a bank expects all other banks to choose a very liquid technology, and hence the regulator's disclosure policy to be fairly opaque (i.e., $p^*(L)$ to be low). In that case, unless this bank chooses a technology that is as liquid as the one of the other banks, it will suffer a run when p is low enough (yet larger than $p^*(L)$). Hence, if a bank expects other banks to choose a very liquid technology, then it may have incentives to choose a very liquid technology as well. The following proposition states the possibility of multiple symmetric equilibria in which banks hold more or less liquidity than is socially optimal.

Proposition B.5. *If each bank's liquidity choice, L_i , is public information, there are multiple self-fulfilling equilibria in which banks may choose a balance sheet that is either more or less liquid than is socially optimal.*

Proof. Notice first $p^*(L) > 0$ reaches a minimum for $L = \frac{c}{\tau}$, and that given (B.10), $p^*\left(\frac{c}{\tau}\right) > 0$. This implies (a) that there are always runs on banks that are revealed to be of low quality, whatever their choice of L_i ; (b) that increasing L_i beyond $\frac{c}{\tau}$ is strictly dominated regardless of the disclosure policy since it does not prevent a run if the bank is revealed to be of poor quality, and it increases the probability of a run if the regulator chooses opacity. We can therefore restrict attention to liquidity choices L_i in the interval $[0, \frac{c}{\tau}]$. On that interval, $p^*(\cdot)$ is strictly decreasing.

We derive first the socially optimal liquidity of banks. We start by computing the optimal level, L^* , restricting attention to a subset of choices where all banks have the same level of liquidity, that is, $L_i = L$ for all i . We will later check that this property must be true at optimum.

Let $g(L)$ denote the aggregate return of the banking sector, given the optimal disclosure policy $p^*(L)$,

$$g(L) \equiv \int_0^{p^*(L)} p \left(\mu + \Delta - \tau \frac{L^2}{2} \right) dp + \int_{p^*(L)}^1 \left[\mu + (2p - 1)\Delta - \tau \frac{L^2}{2} \right] dp. \quad (\text{B.15})$$

Differentiating,

$$\begin{aligned} g'(L) &= p^{*\prime}(L) \left\{ p^*(L) \left(\mu + \Delta - \tau \frac{L^2}{2} \right) - \mu - [2p^*(L) - 1]\Delta + \tau \frac{L^2}{2} \right\} - \tau L \left\{ \frac{[p^*(L)]^2}{2} + 1 - p^*(L) \right\} \\ &= p^{*\prime}(L) [p^*(L) - 1] \left(\mu - \Delta - \tau \frac{L^2}{2} \right) - \tau L \left\{ \frac{[p^*(L)]^2}{2} + 1 - p^*(L) \right\} \end{aligned} \quad (\text{B.16})$$

Notice that

$$g'(0) > 0 \text{ and } g'\left(\frac{c}{\tau}\right) < 0. \quad (\text{B.17})$$

Therefore $g(\cdot)$ admits at least one maximum L^* in $(0, \frac{c}{\tau})$, and L^* is such that $g'(L^*) = 0$.

The next step consists in showing that $g'(L) = 0$ implies $g''(L) < 0$, which, together with (B.17), implies

that $g'(L) = 0$ has a unique solution. Suppose $g'(L) = 0$.

$$\begin{aligned}
g''(L) &= p^{*''}(L)[p^*(L) - 1] \left(\mu - \Delta - \tau \frac{L^2}{2} \right) + [p^{*'}(L)]^2 \left(\mu - \Delta - \tau \frac{L^2}{2} \right) \\
&\quad - 2\tau L p^{*'}(L)[p^*(L) - 1] - \tau \left\{ \frac{[p^*(L)]^2}{2} + 1 - p^*(L) \right\} \\
&< [p^{*'}(L)]^2 \left(\mu - \Delta - \tau \frac{L^2}{2} \right) - \tau \left\{ \frac{[p^*(L)]^2}{2} + 1 - p^*(L) \right\}, \tag{B.18}
\end{aligned}$$

where the last inequality stems from $p^{*''}(L) > 0$, $p^{*'}(L) < 0$ for $L \in [0, \frac{c}{\tau}]$, and, from (B.10), $\mu - \Delta - \tau \frac{L^2}{2} > 0$ for $L \in [0, \frac{c}{\tau}]$. Using $g'(L) = 0$ to substitute,

$$\begin{aligned}
g''(L) &< [p^{*'}(L)]^2 \left(\mu - \Delta - \tau \frac{L^2}{2} \right) - p^{*'}(L) \frac{p^*(L) - 1}{L} \left(\mu - \Delta - \tau \frac{L^2}{2} \right) \\
&< p^{*'}(L) \left(\mu - \Delta - \tau \frac{L^2}{2} \right) \left[p^{*'}(L) - \frac{p^*(L) - 1}{L} \right] \tag{B.19}
\end{aligned}$$

Consider the function $f(L) = Lp^{*'}(L) - p^*(L) + 1$. $f'(L) = Lp^{*''}(L) > 0$. Therefore $f(L) > f(0) = 1 - p(0) > 0$. Using again $\mu - \Delta - \tau \frac{L^2}{2} > 0$ and $p'(L) < 0$, this, in turn, implies that $g''(L) < 0$.

Therefore, L^* is uniquely defined by $g'(L^*) = 0$, and $L^* \in (0, \frac{c}{\tau})$.

In the derivation of L^* , we imposed that all banks choose the same L_i . We show now banks must hold the same liquidity level at optimum.

Consider the disclosure threshold \hat{p} as given. Notice first that for any set of liquidity choices, $\hat{p} > p^*(0)$ is strictly dominated by $\hat{p} = p^*(0)$. In words, it cannot be optimal to increase transparency above the level that is optimal when $L = 0$. Notice also that for any set of liquidity choices, $\hat{p} < p^*(\frac{c}{\tau})$ is dominated by $\hat{p} = p^*(\frac{c}{\tau})$. In words, it cannot be optimal to decrease the level of transparency below the level where a bank perceived as average fails, whatever its level of liquidity. We therefore restrict attention to the case where $p^*(\frac{c}{\tau}) \leq \hat{p} \leq p^*(0)$. The individual return of a bank is then

$$h(L_i, \hat{p}) = \int_0^{\hat{p}} p \left[\mu + \Delta - \tau \frac{L_i^2}{2} \right] dp + \int_{\max[\hat{p}, p^*(L_i)]}^1 \left[\mu + (2p - 1)\Delta - \tau \frac{L_i^2}{2} \right] dp. \tag{B.20}$$

For a given \hat{p} , optimal liquidity levels solve

$$\max_{\{L_i\}_{i \in [0,1]}} \int_0^1 h(L_i, \hat{p}) di. \tag{B.21}$$

Notice that this optimization problem boils down to maximizing $h(L_i)$ for each bank i . Notice also that $L_i > p^{*-1}(\hat{p})$ is dominated by $L_i = p^{*-1}(\hat{p}) < \frac{c}{\tau}$. Finally, for any $L_i \in [0, p^{*-1}(\hat{p})]$,

$$h'(L_i) = -\tau L_i \left[\frac{\hat{p}^2}{2} + 1 - p^*(L_i) \right] - c \left(\frac{1}{2} - L_i \right) \frac{\tau L_i - c}{2\Delta}. \tag{B.22}$$

$h'(0) > 0$, $h'(\frac{c}{\tau}) < 0$, $\lim_{L \rightarrow -\infty} h'(L) = -\infty$ and $\lim_{L \rightarrow +\infty} h'(L) = +\infty$. Therefore, since $h'(\cdot)$ is a polynomial of order three, it has exactly one root, $L_i^*(\hat{p})$, in $[0, \frac{c}{\tau}]$. Thus, either $h'[p^{*-1}(\hat{p})] \geq 0$, and it is then optimal for each bank i to choose $L_i = p^{*-1}(\hat{p})$, or $h'[p^{*-1}(\hat{p})] < 0$ and it is then optimal for each bank i to choose $L_i = L_i^*(\hat{p})$. In either case, the optimization problem has a unique solution, such that every bank chooses the same level of liquidity. Since this property holds for any p that can be part of an optimum, it must be true at the optimum of the full optimization program (jointly over p and $\{L_i\}_{i \in [0,1]}$).

We turn now to the equilibrium level of liquidity and focus on symmetric equilibria. Let L^E be a candidate equilibrium.

Notice first that, given L^E , there is no incentive for a single bank to deviate by choosing $L_i > L^E$. Indeed, the regulator chooses opacity if and only if it prevents runs on the entire system, that is, if $p \geq p^*(L^E)$. In this case, $L_i > L^E$ is dominated by $L_i = L^E$ (since liquidity is costly). On the other hand, if the regulator chooses transparency, L_i does not affect the outcome, that is, a low-quality bank suffers a run, while a high-quality bank is safe. Therefore, for any candidate equilibrium L^E we only need to check individual incentives to deviate from below, that is, by choosing $L_i < L^E$.

Given a candidate equilibrium $L^E \leq \frac{c}{\tau}$ a bank chooses the level of liquidity $L_i \in [0, L^E]$ to maximize

$$\int_0^{p^*(L^E)} p \left[\mu + \Delta - \tau \frac{L_i^2}{2} \right] dp + \int_{p^*(L_i)}^1 \left[\mu + (2p-1)\Delta - \tau \frac{L_i^2}{2} \right] dp. \quad (\text{B.23})$$

Using (B.15), this best-response function can be rewritten as

$$g(L_i) - \int_0^{p^*(L_i)} p \left[\mu + \Delta - \tau \frac{L_i^2}{2} \right] dp + \int_0^{p^*(L^E)} p \left[\mu + \Delta - \tau \frac{L_i^2}{2} \right] dp. \quad (\text{B.24})$$

Taking the first derivative of (B.24) with respect to L_i yields

$$g'(L_i) + \frac{c - \tau L_i}{2\Delta} p^*(L_i) \left(\mu + \Delta - \tau \frac{L_i^2}{2} \right) + \int_{p^*(L^E)}^{p^*(L_i)} p \tau L_i dp. \quad (\text{B.25})$$

Notice first that $g'(L_i) \geq 0$ on $[0, L^*]$, since g is single-peaked in L^* . Notice then that the second term in (B.25) is strictly positive for $L_i < L^E$, since $L^E \leq \frac{c}{\tau}$ and (B.10) holds. Notice finally that the third term is also strictly positive for $L_i < L^E$, since p^* is strictly decreasing in L_i on $[0, \frac{c}{\tau}]$.

Consider first the case where $L^E \in [0, L^*]$. It follows from the previous paragraph that (B.25) is then strictly positive for any $L_i < L^E$. Since $L_i > L^E$ is dominated by $L_i = L^E$, the best response of a bank to any $L^E \in [0, L^*]$ is to choose $L_i = L^E$. Therefore, any non-negative level of liquidity $L^E \leq L^*$ is an equilibrium.

Next, consider the case where $L^E > L^*$. For $L_i \in [0, L^*]$,

$$g'(L_i) + \frac{c - \tau L_i}{2\Delta} p^*(L_i) \left(\mu + \Delta - \tau \frac{L_i^2}{2} \right) > 0. \quad (\text{B.26})$$

By continuity, there exists $L^E > L^*$ such that (B.26) is strictly positive for $L_i \in [0, L^E)$. Therefore, there exists $L^E > L^*$ such that (B.25) is strictly positive for $L \in [0, L^E)$. Since $L_i > L^E$ is dominated by $L_i = L^E$, there exists a continuum of equilibrium levels of liquidity L^E , such that $L^E > L^*$. □

The above proposition suggests that even if each bank's liquidity choice, L_i , is public information, the equilibrium liquidity choices need not be socially optimal. Intuitively, there is a coordination problem among banks that can trap the financial system into investments that are either too liquid or too illiquid. In such cases, it is valuable for the regulator to commit to a disclosure policy as a function of p only. Indeed, under the assumption that investors observe the liquidity choice of each individual bank, this commitment would induce each bank to choose the first-best optimal level of liquidity.

Notice that Proposition B.5 relies on each bank's liquidity choice, L_i , being public information. In an opaque regime, however, investors may have difficulties assessing not only the idiosyncratic component of a bank's long-term return, η_i , but also the liquidity of its balance sheet, L_i . The corresponding assumption in the model is that both η_i and L_i are privately known to the regulator under opacity, and become public information only if the system is transparent. In this case, banks' balance sheets are too illiquid regardless of the regulator's ability to commit to an optimal p -contingent disclosure policy.

Proposition B.6. *If each bank's liquidity choice, L_i , is private information of the regulator under an opaque regime, and public information under a transparent regime, there is a unique equilibrium, in which banks choose a balance-sheet that is less liquid than is socially optimal. This proposition holds whether the regulator can commit ex-ante to an optimal p -contingent disclosure policy or not.*

Proof. Notice first that even if the regulator does not commit ex ante to a transparency policy as a function of p , his ex-post incentives to choose opacity or transparency depend on aggregate liquidity only. Since each bank is atomistic, bank i 's liquidity decision, L_i , does not affect transparency. Notice then that if the system is opaque, bank i 's expected return is either 0 or $\mu + (2p - 1)\Delta - \tau \frac{L_i^2}{2}$. If the system is transparent, bank i 's expected return is $p \left(\mu + \Delta - \tau \frac{L_i^2}{2} \right)$. Therefore, whatever the transparency policy, for any bank i , $L_i = 0$ is a strictly dominant strategy. □

Intuitively, when liquidity choices are not observed by investors under an opaque regime, banks face a commitment problem. They would like to convince investors that their balance sheets are liquid in order to sustain an opaque regime that prevent runs.^{B6} However, under an opaque regime, if investors believe that aggregate liquidity is high and thus, are willing to rollover their investment, (i.e., if p is above what investors

^{B6}Note that $p^*(L)$ as defined in Proposition B.4 is decreasing in L , that is, increasing liquidity allows to sustain an opaque regime without runs for lower values of p .

believe to be $p^*(L)$) banks have incentives to boost their long-term returns by choosing an illiquid balance sheet. Hence, there is a fundamental tension between the optimal disclosure policy (in which an increase in liquidity is associated with an increase in opacity) and private incentives to hold liquidity.

Overall, the analysis suggests the need to impose liquidity requirements on financial institutions. If liquidity is public information, Proposition B.5 shows that the equilibrium level of liquidity is, in general, different from the optimum, as the optimal disclosure policy generates a coordination problem among financial institutions. Moreover, in the more plausible situation where banks' liquidity is public information under a transparent regime, but unobservable to investors under a opaque regime, Proposition B.6 shows that banks' balance sheets are too illiquid. Imposing liquidity requirements would solve the coordination (Proposition B.5) and commitment (Proposition B.6) problems that the optimal disclosure policy generates, and is in line with Kashyap et al. (2008), who suggest the introduction of mandatory holdings of Treasury bills for banks.

III. Efficient Runs

In the paper we assumed that early liquidation is inefficient, that is, even for low-quality banks the net expected return of the long-term technology was greater than zero, i.e., $-\Delta_\eta + \mu > 0$. In doing so we emphasized the effect of information disclosure on rollover risk, which is linked to the maturity transformation role of financial institutions. However, transparency has a notable advantage that we have not considered so far: it allows investors to monitor financial institutions, which enhances market discipline and improves allocation efficiency. In this section we examine how the possibility of efficient liquidation affects the optimal disclosure policy.

Consider the following change to the bank-specific component η_i of the long-term investment technology of the basic model. We now assume that the bank-specific component η_i can take values $\Delta_\eta > 0$ (for high-quality banks), 0 for (medium-quality banks), and $-\Delta_\eta$ (for low-quality banks) with respective probabilities $\pi_h(p)$, $\pi_m(p)$ and $\pi_l(p) = 1 - \pi_m(p) - \pi_h(p)$, where, as before, $p \in (0, 1)$ parameterizes the aggregate profitability of the banking system. Specifically, we assume that the family of distributions $\{\pi_h(p), \pi_m(p), \pi_l(p)\}_p$ satisfies the monotone likelihood ratio property (MLRP): if $p_1 < p_2$,

$$\frac{\pi_m(p_1)}{\pi_l(p_1)} < \frac{\pi_m(p_2)}{\pi_l(p_2)} \quad \text{and} \quad \frac{\pi_h(p_1)}{\pi_m(p_1)} < \frac{\pi_h(p_2)}{\pi_m(p_2)}. \quad (\text{B.27})$$

Intuitively, an aggregate shock –a change in p – shifts the distribution in such a way that the ratios of high- to medium-quality banks and of medium- to low-quality banks are higher in good than in bad economic times, i.e., the ratios are increasing in p .

We also assume that early liquidation is inefficient for medium quality banks –the net expected return of the long-term technology is greater than zero– but efficient for low quality banks. Moreover, when banks' types are disclosed, we assume that both medium and low-quality banks face the risk of early liquidation while

high-quality banks do not. That is, medium-quality banks are solvent but illiquid while low-quality banks are insolvent. This boils down to the following modified version of assumption in (1) on the parameters of the model:

$$-\Delta_\eta + \mu < 0 < \mu < \frac{c}{2} < \Delta_\eta + \mu. \quad (\text{B.28})$$

The following proposition, which corresponds to Proposition 2 of the basic model, characterizes the optimal disclosure policy at $t = 1$.

Proposition B.7. *There exists a threshold p^{**} such that the regulator chooses opacity if and only if $p > p^{**}$.*

Proof. From the monotone likelihood ratio property (MLRP) –assumption in equation (B.27) – the average long-term return of the banking system, $\mu + \pi_u(p)\Delta_\eta - \pi_d(p)\Delta_\eta$ is strictly increasing in p . Thus there exists a unique $p_1 \in (0, 1)$ such that $\mu + \pi_u(p)\Delta_\eta - \pi_d(p)\Delta_\eta > \frac{c}{2}$ if and only if $p > p_1$. That is, p_1 is the threshold above which there are no runs on any bank in the financial system under opacity.

For any $p > p_1$, opacity is preferable to transparency iff

$$\mu + \pi_u(p)\Delta_\eta - \pi_d(p)\Delta_\eta > \pi_u(p)(\mu + \Delta_\eta) \Leftrightarrow \frac{\pi_m(p)}{\pi_d(p)} > \frac{\Delta_\eta - \mu}{\mu} \quad (\text{B.29})$$

From the MLRP, $\frac{\pi_m(p)}{\pi_d(p)}$ is strictly increasing in p , hence, there exists a unique p_2 such that $\frac{\pi_m(p_2)}{\pi_d(p_2)} > \frac{\Delta_\eta - \mu}{\mu}$ if and only if $p > p_2$.

Opacity is then an optimal strategy if and only if p is greater than both p_1 and p_2 . That is, $p^{**} = \max\{p_1, p_2\}$.

Notice that p^{**} may be a corner solution, that is, it can be equal to 0 or 1. Two assumptions are sufficient to rule out these trivial transparency policies. First, that $p_1 < 1$, that is, there are high enough interior realizations of p such that it is feasible to sustain an opaque regime without runs. Second, that $0 < p_2 < 1$, that is, that there are high enough interior realizations of $p > p_2$, such that a policy of opacity can be optimal and vice versa, low enough interior realizations of $p < p_2$, such that a policy of transparency can be optimal. □

As in Proposition 2 of the main model, the optimal disclosure policy is contingent on p , that is, on shocks to the average quality of banks in the financial system. If the financial system suffers a negative shock and p falls below some threshold p^{**} , then it is optimal to disclose information about the quality of each individual bank. Otherwise, it is optimal for the regulator to be opaque and not disclose information. In determining this optimal disclosure policy there are two forces at play. On the one hand, unlike in the main model, a policy of transparency has the benefit of inducing the *efficient* liquidation of low-quality firms. On the other hand, like in the main model, a policy of opacity can prevent inefficient runs on medium-quality firms (if p is high enough to sustain a pooling equilibrium without runs) but can induce inefficient runs on high-quality

banks (if p is too low to sustain a pooling equilibrium without runs). Hence, for low enough realizations of p , transparency is optimal because it prevents runs on high-quality banks and now also because it induces the efficient liquidation of low-quality banks. The situation is different for high realizations of p as the regulator faces a trade-off between preventing inefficient runs in medium-quality banks and inducing efficient runs in low-quality banks. In such case, if the proportion of medium- to low-quality banks is sufficiently large (*low*), then the first (*second*) effect dominates and a policy of opacity (*transparency*) is optimal. Notice, however, that in distributions satisfying the MLRP, a positive shock increases the ratio of medium- to low-quality banks (the ratio is increasing in p), which makes a policy of opacity more likely to be optimal. This explains the optimality of threshold strategy described in Proposition B.7. Hence, overall, allowing for the possibility of efficient runs increases the benefits of transparency, but under reasonable assumptions, namely that in bad economic times there is a larger proportion of low-quality banks, a policy that encourages opacity in good times and transparency in bad times remains optimal.

IV. Optimal Disclosure with Cross-Exposures: An Alternative Specification.

Consider the following variation of the set up in Section 3.1. Banks are randomly matched into pairs at $t = 0$, and within a pair, each investor's payoff at $t = 2$ from rolling over at $t = 1$ depends not only on rollover decisions by investors in his own bank, but also on rollover decisions by investors in the other bank. Formally, let $z(i)$ denote a one-to-one mapping of $[0, 1]$ onto itself such that $z(i) \neq i$ almost everywhere, and for every i , $z[z(i)] = i$. Bank i is exposed to bank $z(i)$ (and vice versa) in the following way: for an investor in bank i , the return at $t = 2$ from rolling over at $t = 1$ is

$$\mu + \eta_i - (1 - \alpha)l_i - \alpha l_{z(i)}, \tag{B.30}$$

where l_i is the mass of investors who withdraw from bank i and $l_{z(i)}$ is the mass of investors who withdraw from bank $z(i)$ to which bank i is exposed (i.e., paired).

As in main text, the regulator has private information about both idiosyncratic shocks $\{\eta_i\}_{i \in [0,1]}$ and cross-exposures $z(\cdot)$. Hence, letting σ denote the investors' bank-specific information at $t = 1$, the regulator can keep the system opaque, $\sigma = \{\emptyset\}$, disclose idiosyncratic shocks, $\sigma = \{\eta_i\}_{i \in [0,1]}$, or disclose both idiosyncratic shocks and cross-exposures, $\sigma = \{\{\eta_i\}_{i \in [0,1]}, z(\cdot)\}$.^{B7} Note that disclosing $z(\cdot)$ consists of providing the identity of each bank's counterpart (i.e., the matched pairs).

The analysis is similar to the specification in the main text (see Proof of Proposition 7), and we only sketch it

^{B7}For the same reason in the main text, disclosing only $z(\cdot)$ would generate the same result as full opacity (see Section 3.1).

here. Setting the optimal transparency policy requires characterizing rollover decisions in every bank under each possible transparency policy.

Two subcases are immediate: as $h_\mu \rightarrow +\infty$ and $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$,

- (i) if $\sigma = \{\emptyset\}$ (full opacity), investors withdraw from every bank if and only if $p < p^*$;
- (ii) if $\sigma = \{\{\eta_i\}_{i \in [0,1]}, z(\cdot)\}$ (full disclosure), investors rollover in bank i if $\eta_i = \eta_{z(i)} = \Delta_\eta$ (i.e., if the two paired banks are of high quality), and withdraw if $\eta_i = \eta_{z(i)} = -\Delta_\eta$ (i.e., if the two paired banks are of low quality).

Hence, only two subcases remain:

- (iii) if $\sigma = \{\{\eta_i\}_{i \in [0,1]}, z(\cdot)\}$ (full disclosure), characterizing rollover decisions in banks where $\eta_i \neq \eta_{z(i)}$ (i.e., where one of the paired banks is of high quality and the other is of low quality);
- (iv) if $\sigma = \{\eta_i\}_{i \in [0,1]}$ (partial disclosure), characterizing rollover decisions in every bank.

The analyses of cases (iii) and (iv) follow the same steps, which are summarized below.

To derive the equilibrium thresholds in (iii) and (iv), we first consider the “dispersed information” game of Section 2.1, in which investors receive a signal s_j about the common component of returns $\tilde{\mu}$. In (iii) and (iv), η_i fully characterizes public information about bank i . Suppose investor j withdraws from a bank with idiosyncratic shock η if and only if his belief ρ_j about $\tilde{\mu}$ falls below a threshold ρ_η^* . The indifference conditions of marginal investors with beliefs ρ_Δ^* and $\rho_{-\Delta}^*$, respectively in banks with $\eta = \Delta_\eta$ and $\eta = -\Delta_\eta$ are

$$\frac{\rho_\Delta^* + \Delta_\eta}{c} = [(1 - \alpha) + \alpha \bar{p}] \Phi[\sqrt{\gamma}(\rho_\Delta^* - \mu)] + \alpha(1 - \bar{p}) \Phi\left[\sqrt{\nu}\left(\rho_{-\Delta}^* - \frac{h_\mu \mu + h_\varepsilon \rho_\Delta^*}{h_\mu + h_\varepsilon}\right)\right], \quad (\text{B.31})$$

$$\frac{\rho_{-\Delta}^* - \Delta_\eta}{c} = [1 - \alpha + \alpha(1 - \underline{p})] \Phi[\sqrt{\gamma}(\rho_{-\Delta}^* - \mu)] + \alpha \underline{p} \Phi\left[\sqrt{\nu}\left(\rho_\Delta^* - \frac{h_\mu \mu + h_\varepsilon \rho_{-\Delta}^*}{h_\mu + h_\varepsilon}\right)\right], \quad (\text{B.32})$$

where $\bar{p} = 1 - \underline{p} = 0$ if $\sigma = \{\{\eta_i\}_{i \in [0,1]}, z(\cdot)\}$ (in case (iii)), and $\bar{p} = \underline{p} = p$ if $\sigma = \{\eta_i\}_{i \in [0,1]}$ (in case (iv)).

For each case (iii) and (iv), the equilibrium thresholds of investors solve the system $\{(B.31), (B.32)\}$, which has a unique solution under the same condition as in Proposition 7 (i.e., provided investors’ private signal is precise enough, relative to the precision of the prior distribution of $\tilde{\mu}$). We turn next to the the limit case in which $h_\mu \rightarrow +\infty$ and $\frac{h_\mu^2}{h_\varepsilon} \rightarrow 0$.

To build intuition, consider first case (iii) where $\sigma = \{\{\eta_i\}_{i \in [0,1]}, z(\cdot)\}$ (full disclosure). There are two possibilities:

1. $\alpha < \frac{2\Delta}{c}$. Then, investors rollover in bank i with $\eta_i = \Delta_\eta$ (and $\eta_{z(i)} = -\Delta_\eta$) if and only if

$$\frac{\mu + \Delta_\eta}{c} \geq \frac{1 + \alpha}{2}, \quad (\text{B.33})$$

and rollover in bank i with $\eta_i = -\Delta_\eta$ (and $\eta_{z(i)} = \Delta_\eta$) if and only if

$$\frac{\mu - \Delta_\eta}{c} \geq \frac{1 - \alpha}{2}, \quad (\text{B.34})$$

2. $\alpha \geq \frac{2\Delta}{c}$. Then, investors rollover if and only if

$$\frac{\mu}{c} \geq \frac{1}{2}. \quad (\text{B.35})$$

That is, if $\alpha \geq \frac{2\Delta}{c}$, withdrawal decisions do not depend on η_i . Intuitively, when α is high, liquidity externalities are strong enough to overcome differences in long-term returns (as in Corollary 4).

Notice first the similarities between the expressions in (B.33), (B.34) and (B.35), and the rollover condition in the baseline model without cross-exposures (Corollary 1), namely,

$$\frac{\mu + \eta_i}{c} \geq \frac{1}{2}. \quad (\text{B.36})$$

Notice then that from (B.33) and (B.35), a high-quality bank that is exposed to a low-quality bank could suffer a run if α is high enough (i.e., cross-exposures create contamination). Finally, if, under full disclosure, a high-quality bank that is exposed to a low-quality bank suffers a run, then under partial disclosure, $\sigma = \{\eta_i\}_{i \in [0,1]}$, a high-quality bank can also suffer a run if p is sufficiently low. Indeed, as $p \rightarrow 0$, it becomes almost certain that a high-quality bank ($\eta_i = \Delta_\eta$) is exposed to a low-quality bank ($\eta_{z(i)} = -\Delta_\eta$). Symmetrically, from (B.34) and (B.35), if α is high enough, then a low-quality bank could have its debt rolled over if the system is fully transparent and it is exposed to a high-quality bank, or even if the system is only partially transparent and p is high enough.

Formally, we obtain the following result, which is the counterpart of Lemma 2, and summarizes the discussion above

Let

$$p'_\Delta(\alpha) \equiv \min \left\{ \frac{1 + \alpha}{\alpha} - \frac{2(\mu + \Delta_\eta)}{c\alpha}, p^* \right\} \text{ and } p'_{-\Delta}(\alpha) \equiv \max \left\{ \frac{1}{\alpha} - \frac{2(\mu - \Delta_\eta)}{c\alpha}, p^* \right\}.$$

Let also α_Δ and $\alpha_{-\Delta}$ be the solutions to, respectively,

$$p'_\Delta(\alpha_\Delta) = 0, \text{ and } p'_{-\Delta}(\alpha_{-\Delta}) = 1.$$

Lemma B.1. *In equilibrium, rollover decisions are as follows,*

1. If $\sigma = \{\emptyset\}$ (opacity), investors rollover if and only if $p \geq p^*$, where p^* is as in Proposition 2;
2. If $\sigma = \{\eta_i\}_{i \in [0,1]}$ (partial disclosure), investors rollover if and only if $p \geq p'_\Delta(\alpha)$ in banks where $\eta_i = \Delta_\eta$, and if and only if $p \geq p'_{-\Delta}(\alpha)$ in banks where $\eta_i = -\Delta_\eta$.
3. If $\sigma = \{\{\eta_i\}_{i \in [0,1]}, z(\cdot)\}$ (full disclosure), investors in bank i

- (a) always rollover if $\eta_i = \eta_{z(i)} = \Delta_\eta$;
- (b) never rollover if $\eta_i = \eta_{z(i)} = -\Delta_\eta$;
- (c) rollover if and only if (i) $\mu \geq \frac{c}{2}$ or (ii) $\mu < \frac{c}{2}$ and $\alpha \leq \alpha_\Delta$, in banks where $\eta_i = \Delta_\eta$ and $\eta_{z(i)} = -\Delta_\eta$ (i.e., in high-quality banks paired with low-quality banks);
- (d) and rollover if and only if $\mu \geq \frac{c}{2}$ and $\alpha \geq \alpha_{-\Delta}$ in banks where $\eta_i = -\Delta_\eta$ and $\eta_{z(i)} = \Delta_\eta$ (i.e., in low-quality banks paired with high-quality banks).

Turn to the optimal transparency policy. Consider the two following conditions

$$\mu \geq \frac{c}{2} \text{ and } \alpha \geq \alpha_\Delta \quad (\text{B.37})$$

$$\mu < \frac{c}{2} \text{ and } \alpha > \alpha_{-\Delta} \quad (\text{B.38})$$

If neither (B.37) nor (B.38) hold, then from Lemma B.1, disclosing $z(\cdot)$ does not alter investors' rollover decision. Hence, the optimal transparency policy is as in the baseline case. Intuitively, if α is small, liquidity externalities across banks are weak, and therefore, information on cross-exposures is irrelevant.

In the more interesting case where α is large (i.e., either (B.37) or (B.38) is true), the impact of cross-exposures and hence, the form of the optimal transparency policy, depends on the condition $\mu \geq \frac{c}{2}$. The intuition is as follows. As in the main text, cross-exposures can have stabilizing or destabilizing effects. Consider a pair in which a high-quality bank is matched with a low-quality one under a full-disclosure regime. Liquidation in the low-quality bank lowers long-term returns in the high-quality bank, which increases the probability of a run in the high-quality bank, which in turn heightens liquidity problems in the low-quality bank, etc. Note however that, this spiralling effect could also work in the opposite direction: the stability of the high-quality bank lowers incentives to run in the low-quality bank, which in turn makes the high-quality bank more stable, etc. If $\mu \geq \frac{c}{2}$, then high-quality banks are relatively further from the run threshold (from above), than the low-quality banks are (from below).^{B8} As a result, the reinforcing effects generated by strategic complementarities across banks improve the stability of the system: under full disclosure, high-quality banks are always safe and low-quality banks that are matched with high-quality banks are also liquid. Hence, if (B.37) holds, the optimal transparency policy is to be opaque for $p \geq p^*$ and fully transparent for $p < p^*$. Conversely, if $\mu < \frac{c}{2}$, cross-exposures make the system more unstable: under full disclosure, low-quality banks always suffer runs and high-quality banks that are matched with low-quality banks are also illiquid. Hence, if (B.38) holds, the optimal transparency policy is opacity for $p \geq p^*$, partial transparency for $p'_\Delta(\alpha) \leq p < p^*$ and full transparency for $p < p'_\Delta(\alpha)$, for the same reasons as in the main text.

^{B8}That is, $\mu + \Delta_\eta - \frac{c}{2} \geq \frac{c}{2} - (\mu - \Delta_\eta)$.