Bank Runs, Bank Competition and Opacity*

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Abstract

We model asset opacity and deposit rate choices of banks who imperfectly compete for uninsured deposits, are subject to runs, and face a threat of entry. Higher competition increases deposit rates and bank fragility, resulting in an intermediate socially optimal level of bank competition. We provide a novel theory of bank opacity. The cost of opacity is more partial runs by creditors, which induces costly liquidation of investment and lowers current profits. The benefit of opacity is to deter entry of competitors, which increases bank charter value. Banks can be excessively opaque, motivating transparency regulation.

Keywords: Competition, entry, opacity, fragility, bank run, global games, competition policy, transparency regulation.

JEL classifications: G01, G21, G28.

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1 Introduction

Bank runs are a recurrent phenomenon and pose a threat to the potential economic growth of an economy.[1] It is therefore critical to understand how developments in the financial system affect bank fragility. We study two such developments: changes in bank competition and bank opacity. The competitive landscape has significantly changed in the last decades due to both regulation and technology.[2] The transparency of bank assets has also significantly evolved due to the availability of more complex and more opaque assets, new accounting standards, and regulations mandating minimum transparency. The principal goal of this paper is to shed light on how bank runs, bank competition, and bank opacity interact and shape outcomes of the financial system. In doing so, we obtain both positive and normative implications about the funding costs, competitive structure, opacity choices, and fragility of banks.

This paper offers a parsimonious bank-run model in which banks make risky investments funded with uninsured deposits. Banks imperfectly compete for deposits by choosing their deposit rate and asset opacity. Taking into account these bank choices, we derive novel implications for the effect of technological and regulatory changes (e.g., to bank profitability or the competitive intensity of the banking sector) on bank fragility, entry, and welfare. We highlight how these effects are shaped by the intensity of bank competition. We also establish a novel role for transparency regulation driven by a wedge between the private and social incentives for bank opacity, and describe how such regulation depends on the intensity of competition.

[1] Bank runs and panics have occurred throughout history (e.g., Calomiris and Gorton, 1991). Evidence of bank runs in the recent financial crisis include Ivashina and Scharfstein (2010) and Ippolito et al. (2016). Moreover, see, among others, Shin (2009) for the run on Northern Rock, Gorton and Metrick (2012) for the run on repo, Covitz et al. (2013) for the run on asset-backed commercial paper, and Schmidt et al. (2016) for the run on money market mutual funds. See Chen et al. (2020) for runs on uninsured deposits issued by U.S. commercial banks.

[2] The arrival of FinTechs and platform-based competitors (BigTechs) has increased contestability in recent years. The rise of shadow banks over last two decades has also increased competition (e.g. for wholesale funding). Earlier structural changes to competition in the United States arose from the elimination of restrictions to intrastate and interstate banking (e.g., Jayaratne and Strahan, 1996.)

We start our analysis in Section 2 with a one-period model in which a fixed number of banks compete for uninsured depositors from investors located on a circle (Salop, 1979).[3] At an initial date banks choose deposit rates and opacity levels of their risky investment. Each investor chooses which bank to deposit its endowment and delegates the withdrawal decision at an interim date to a fund manager who receives a noisy private signal about the investment return (Rochet and Vives, 2004; Vives, 2014). These signals are noisier for banks that chose to be more opaque, making it more difficult for fund managers to learn about the realized investment return.[4] To serve interim withdrawals, banks liquidate investment at a cost. We use global-games methods to pin down a unique equilibrium in which a bank fails whenever the return on its investment is below an (endogenous) threshold.[5]

We characterize the equilibrium deposit rate, opacity level, and bank failure threshold. When choosing its deposit rate, a bank trades off a higher market share with lower profits per unit of deposits. Higher deposit rates decrease profits because of higher funding costs and a heightened strategic complementarity of withdrawal decisions due to a larger negative impact on the residual funds of the bank. When choosing its opacity, a bank takes into account that higher transparency reduces withdrawals when investment returns are high. Lower partial runs reduce the costly liquidation of investment and increase profits, so banks choose to be fully transparent in our one-period setup. This result micro-founds the common assumption of vanishing signal noise in bank-run models. By assuming uniform distributions for the investment return and signals, we mute the direct effect of bank opacity on bank

[3]Bank debt is assumed to be demandable. Demandability arises endogenously with liquidity needs (Diamond and Dybvig, 1983) or as a commitment device to overcome an agency conflict (Calomiris and Kahn, 1991; Diamond and Rajan, 2001). Accordingly, uninsured deposits refer to any short-term or demandable debt instrument, which includes uninsured retail deposits and wholesale funding.

[4]Transparency has been defined as the precision of private signals about the fundamental in a global game of regime change in Heinemann and Illing (2002) and Moreno and Takalo (2016). Other work that endogenizes the precision of private or public information in such games includes Hellwig and Veldkamp (2009), Szkup and Trevino (2015), and Ahnert and Kakhbod (2017).

[5]Global games were pioneered by Carlsson and van Damme (1993). The more recent literature and developments are reviewed in Morris and Shin (2003) and Vives (2005).

fragility and isolate its indirect effect via changes in the deposit rates of banks.

We use the one-period model to derive testable implications. First, (exogenously) higher competition increases the probability of bank failure. Higher competition increases deposit rates, which increase the withdrawal incentives and fragility.[6] This implication is in line with the competition-instability view of banking.[7] Second, a negative shock to bank profitability can improve bank stability. Lower expected bank profits (modeled via a non-pecuniary lending cost) lowers deposit rates and therefore bank fragility.[8] Third, a higher expected investment return improves bank stability but this effect is partially mitigated by higher deposit rates. Fourth, more transparent banks are more fragile. Higher transparency could arise from exogenous technological or regulatory changes that generate better information. More transparent banks face lower partial withdrawals and, thus, have higher profits. As a result, banks compete more fiercely for funding by offering higher deposit rates that increase the incentives to withdraw from the bank. Overall, these implications only arise once the response of deposit rates is taken into account. Its magnitude depends on the level of bank competition, with larger deposit rate pass-through for lower competition.[9]

We end the analysis of the one-period setup by deriving implications for the regulation of competition and transparency. To maximize utilitarian welfare, an interior number of banks is optimal, which can be implemented via competition policy. Intuitively, the regulator increases the number of banks until the marginal benefit of greater competition in terms of higher net lending equals the marginal cost of greater competition in terms of higher withdrawal incentives and costly liquidation induced

[6]Consistent with our channel, Li et al. (2019) document that lower competition increases deposit inflows into banks and improves their profitability.

[7]Empirical evidence consistent with the competition-instability-view includes Keeley (1990), Beck et al. (2006), and Beck et al. (2013). See also the review by Vives (2016) and the literature therein.

[8]The opposite result arises in models of risk-taking on the bank's asset side (e.g., Hellmann et al. (2000), Allen and Gale (2004)), where lower profitability increases risk-taking or lowers effort that increase the risk of bank failure. The effect of lower bank profitability on bank failure therefore depends on the source of risk and fragility on the bank's balance sheet (asset versus liability side).

[9]By contrast, standard monopolist pricing reacts less to external shocks than competitive pricing.

by higher deposit rates.[10] We also find that, for a high enough degree of competition, the optimal regulatory policy is maximum transparency.

In Section 3, we add a relevant aspect of bank competition—entry—and show how it alters the choices of incumbent banks, and derive novel regulatory implications. We extend our model to a two-period setting in which banks choose their deposit rates and opacity levels at the beginning of each period. Investment returns have persistence across periods, whereby the expected return in period 2 equals the realized return in period 1. The main novel ingredient is that a new bank—a potential entrant—chooses in period 1 whether to enter and operate in period 2. To enter the market, the entrant must pay an information cost in period 1 to receive signals about the market, and an investment cost to build up capacity in period 1. Upon following the market, the entrant receives a noisy private signal about the investment return (as do fund managers). While the number of incumbent banks is fixed in period 1, the competitive structure in period 2 depends on both the entry decisions and the realized investment return that determines whether incumbent banks fail and exit.

To characterize entry decisions, deposit rates, opacity levels, and bank fragility, we work backwards. For a given number of banks in period 2, the equilibrium is as in the one-period model. The equilibrium in period 1 differs as banks internalize how their choices affect (i) the chances of obtaining future profits (in line with the charter value hypothesis) and (ii) the incentives to enter that affects future competition and profitability (a novel mechanism). We show how the entry decision is influenced by incumbent bank opacity choices in period 1. For intermediate investment costs, the potential entrant only enters if incumbent banks are transparent enough. This result arises because incumbent bank opacity distorts the entrant's investment decision (incurring type I and II errors), reducing its expected profits. Incumbent banks also offer lower deposit rates in period 1 than in period 2 due to the loss of charter value

[10] Given the Salop model of imperfect competition, net lending is defined as the lending volume of all banks net of the transportation costs of all investors.

upon default arising from higher deposit rates, resulting in lower fragility in period 1.

The model with endogenous entry offers a novel theory of bank opacity. For intermediate entry costs, entry decisions can be altered by incumbent bank opacity choices. Incumbent banks choose an interior opacity level in period 1. Its benefit is to deter entry, which increase the incumbents' expected charter value via lower future competition.[11] The cost of opacity is more partial runs on a solvent bank.[12] In sum, banks prefer not to share information with competitors but such opacity reduces the precision of information received by bank creditors, resulting in greater withdrawals.

Our final step is to derive implications for transparency regulation in the two-period setup. Policies to ensure a minimum level of transparency include changes in accounting rules, pillar 3 of Basel bank regulation, and the implementation of bank stress tests. Potential entry creates a wedge between the private and social incentives for opacity. While incumbent banks have incentives to deter entry to preserve a higher market share, the regulator recognizes the lack of aggregate market-stealing incentives (when the market is covered). When competition is low, banks choose to be opaque but the regulator imposes full transparency. Intuitively, the regulator fosters the competitor's entry to increase net lending in the economy and to preserve the gains from intermediation upon the failure of incumbent banks. Moreover, when competition is high and the entry threat absent, banks are excessively transparent and the regulator imposes minimum opacity. In contrast to banks, the regulator appreciates how opacity reduces the competition for funding and lower equilibrium deposit rates reduce the fragility of all banks.

Related literature. Our paper is related to several literatures. The first covers runs on financial intermediaries (Bryant, 1980; Diamond and Dybvig, 1983). Using the global-games approach to uniquely pin down the run probability (Goldstein and

[11] Evidence for opacity deterring entry of firms includes Bernard (2016) and Li et al. (2018).

[12] Consistent with this implication, Chen et al. (2019) find that the uninsured deposit flows of US banks are more sensitive to information about bank performance when banks are more transparent.

Pauzner, 2005; Rochet and Vives, 2004), we examine the impact of competition and opacity on fragility.[13] We share with Goldstein and Pauzner (2005) that both deposit rates and the run probability are endogenous. Our contribution is twofold. First, we also study bank opacity choices. Second, we study how imperfect competition and entry in the funding market shape the fragility and opacity of banks.

A long-standing literature studies how bank failure is determined by bank competition, focusing on the asset side of banks. Keeley (1990), Hellmann et al. (2000), and Allen and Gale (2004), among others, show how bank incentives to take risk increases in competition in the presence of moral hazard, resulting in a more probable bank failure. This result reverses when the risk choice arises from a moral hazard problem of the entrepreneur, so higher competition results in lower loan rates and safer entrepreneurs (Boyd and Nicolo, 2005).[14] Focusing on the liability side of banks, we endogenize deposit rates in a global-games bank-run model. Higher competition increases deposit rates and withdrawal incentives, making banks more prone to runs. Matutes and Vives (1996) also study competition for deposits but focus on sunspots. Our approach allows us to relate the run probability to bank competition and opacity.

A third literature studies the transparency of banks subject to runs. Bank transparency can help external financiers discipline bank managers (e.g., Calomiris and Kahn, 1991). We abstract from such agency problems and focus on the role of transparency for the probability of a bank run. We share this focus with Bouvard et al. (2015) who also use global-games methods. They examine the optimal disclosure policy of a regulator who learns about the heterogeneous quality of banks at the debt rollover stage. There are two main differences. First, we abstract from disclosure issues and consider the opacity choice of banks at the funding stage when information

[13] Recent work on bank runs in a global games setup includes Vives (2014), Ma and Freixas (2015), Morris and Shin (2016), Liu (2016), Eisenbach (2017), Allen et al. (2018), and Ahnert et al. (2019).

[14] Martinez-Miera and Repullo (2010) show that a non-monotonic relation between bank competition and stability arises when loan defaults are imperfectly correlated. Carletti and Leonello (2019) study credit market competition when banks face essential runs as in Allen and Gale (2000).

between the bank and all outsiders is symmetric. Second, we also study imperfect competition and entry and how it shapes the fragility and opacity of banks.[15]

2 A model of competition, runs, and opacity

We start by developing a model in which banks choose their level of opacity and deposit rates. The model combines bank runs in the tradition of Rochet and Vives (2004) and Vives (2014) with funding market competition among a fixed number of banks in the tradition of Salop (1979).

There are three dates $t = 0, 1, 2$, no discounting and universal risk neutrality. There are three types of agents: banks, investors, and fund managers. At date 0, each of the $N \geqslant 2$ banks has access to a risky investment technology with gross return R drawn at date 1. Its uniform common prior at date 0 is

$$R \sim \mathcal{U}\left[\underline{R}, \overline{R}\right] = \mathcal{U}\left[R_0 - \frac{\alpha}{2}, R_0 + \frac{\alpha}{2}\right], \tag{1}$$

where $\alpha > 0$ measures aggregate investment risk and $R_0 > \frac{\alpha}{2}$ the expected return.

At date 0, a unit mass of atomistic investors with a unit endowment each are symmetrically located on a unit-sized circle (Figure 1). Investors have a transport cost $\mu > 0$ per unit of distance to a bank.[16] Investors are indifferent between consumption at date 1 and 2 and cannot directly invest in the risky technology.

At date 0, banks are equidistantly located on the circle and compete for debt funding from investors. Bank $j = 1, ..., N$ chooses opacity δ^j (described below) and

[15] In our model, bank opacity choices are not driven by asymmetric information about asset quality at the funding stage or the fear of asymmetric information at the rollover stage. A literature starting with Gorton and Pennacchi (1990) emphasizes the role of opacity for secondary market liquidity.

[16] Apart from the traditional cost of travelling to banks, the transport cost can capture heterogeneity in investor taste with respect to the bundles of services offered by banks or the relationships investors formed with banks in funding markets.

the face value of debt D^j, resulting in an expected return to investors ρ^j. We assume that the transport cost is low enough for the funding market to be covered. Bank choices are observable. Debt is demandable and can be withdrawn at either date 1 or 2. Its face value is independent of the withdrawal date.

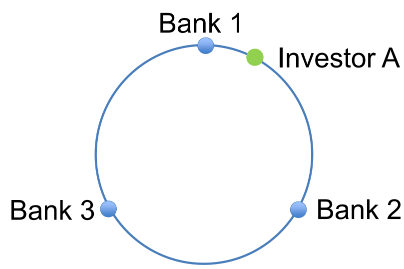

Figure 1: Location of banks on the Salop circle (for $N = 3$). Investor A has a lower transport cost to bank 1 than to bank 2.

At date 0, penniless banks are entirely funded with debt, h^j, and invest all funds in the risky technology, $I^j = h^j$. Liquidation at date 1 yields a fraction $0 < \psi < 1$ of the realized return at date 2, so the per-unit liquidation cost is $z \equiv \frac{1}{\psi} - 1 > 0$. Banks are protected by limited liability and maximize expected profits at date 2.

Investors delegate the rollover decision at date 1 to a group of atomistic fund managers $i \in [0, 1]$. If a proportion $w^j \in [0, 1]$ withdraws (or refuses to roll over), bank j liquidates some investment to serve these withdrawals. Bank j fails at date 1 and is closed early if it cannot serve interim withdrawals, $w^j D^j h^j > \psi R I^j$. Otherwise, the bank's residual investment value is $RI^j - \frac{w^j D^j h^j}{\psi}$ at date 2. Bank j fails at date 2 if it cannot serve residual withdrawals $(1 - w^j)D^j h^j$:

$$R - \frac{w^j D^j}{\psi} < (1 - w^j)D^j. \tag{2}$$

We assume zero recovery upon bank failure at either date for simplicity.

Following Rochet and Vives (2004), we assume that the simultaneous rollover decisions are governed by the compensation of fund managers. If the bank fails, a manager's relative compensation from withdrawing is a benefit $b > 0$. Otherwise, the relative compensation from withdrawing is a cost $c > 0$.[17] The conservatism ratio $\gamma \equiv \frac{b}{b+c} \in (0,1)$ summarizes these parameters, where greater conservativeness (higher γ) makes fund managers more reluctant to roll over debt.[18] This specification ensures global strategic complementarity in rollover decisions (Vives, 2005, 2014).

We assume incomplete information about the investment return at date 1 to ensure a unique equilibrium. In addition to the common prior in (1), each fund manager i receives a noisy private signal about the return (Morris and Shin, 2003):

$$x_i^j = R + \epsilon_i^j, \quad \epsilon_i^j \sim \mathcal{U}\left[-\frac{\delta^j}{2}, \frac{\delta^j}{2}\right], \tag{3}$$

where the idiosyncratic noise ϵ_i^j is independent of the aggregate investment return R and independently and identically distributed across fund managers. The idiosyncratic noise is uniformly distributed with zero mean and width $\delta^j \in [\underline{\delta}, \bar{\delta}]$. The precision of the signal depends on bank j's decisions about the opacity of its assets at date 0, where $0 \leqslant \underline{\delta} < \bar{\delta}$ measure the minimum and maximum opacity of bank assets, respectively. If a bank chooses a higher level of opacity (for example by investing in more complex assets), then fund managers receive more dispersed private signals.[19]

$t = 0$	$t = 1$	$t = 2$
1. Banks compete for funding	1. Private signals	1. Investment matures
2. Investors deposit at a bank	2. Withdrawals	2. Banks repay or default
3. Banks invest	3. Consumption	3. Consumption

Table 1: Timeline.

[17]As an example, assume the cost of withdrawal is c; the benefit from getting the money back or withdrawing when the bank fails is $b + c$; the payoff for rolling over when the bank fails is zero.

[18]Reviewing debt markets during the financial crisis, Krishnamurthy (2010) argues that investor conservatism was an important determinant of short-term lending behavior. See also Vives (2014).

[19]Other decisions that can affect the precision of signals are the choice of accounting procedures by the bank, including the adoption of voluntary accounting standards.

We now turn to solving for the equilibrium of the model. We focus on symmetric equilibrium in pure and threshold strategies. We first pin down under what conditions debt is rolled over, its face value, and expected bank profits. Then we characterize the equilibrium choices of bank opacity and returns offered to investors and then perform comparative statics with respect to the degree of competition, the opacity bound, the expected investment return, and exogenous changes in bank profitability. Finally, we derive regulatory implications for competition policy and opacity regulation.

2.1 Rollover of debt

Dropping the bank index j for expositional simplicity, we consider the debt rollover game between fund managers at date 1. In particular, we analyze how the opacity level δ and face value of debt D of a given bank affect withdrawal decisions. We also call the face value D the gross deposit rate promised to investors.

Proposition 1. ***Bank failure***. *In the rollover stage at date* 1*, there exist unique thresholds of bank failure,* $R^* \equiv (1+\gamma z)D$*, and of the signal,* $x^* \equiv R^* + \left(\gamma - \frac{1}{2}\right)\delta$*. Fund manager* i *rolls over debt if and only if* $x_i \geqslant x^*$ *and the bank fails if and only if* $R < R^*$*. The withdrawal proportion for a realized investment return is*

$$w^*(R) = \begin{cases} 1 & R \leqslant R^* - (1-\gamma)\delta \equiv \underset{\sim}{R} \\ \gamma + \frac{R^*-R}{\delta} \quad \text{if} & R \in \left(\underset{\sim}{R}, \widetilde{R}\right) \\ 0 & R \geqslant R^* + \gamma\delta \equiv \widetilde{R} \end{cases} \tag{4}$$

Proof. See Appendix A. ■

In equilibrium, the threshold fund manager receives the signal $x_i = x^*$ and is indifferent between rolling over and withdrawing funding. Both the conditional probability of bank survival of the threshold manager and the withdrawal proportion at the failure threshold are equal to the conservatism ratio, $\Pr\{R > R^*|x_i = x^*\} = \gamma = w(R = R^*)$. When fund managers are more conservative, the threshold manager requires a higher conditional survival probability and fund managers are more inclined to withdraw, $\frac{\partial w(R)}{\partial \gamma} \geqslant 0$, resulting in a higher failure threshold, $\frac{\partial R^*}{\partial \gamma} > 0$.

Opacity δ affects both the signal threshold x^* and the withdrawal proportion $w^*(R)$. Withdrawals are less sensitive to realized investment returns for a more opaque bank (Figure 2). That is, there are more partial runs when the bank survives, $R \geqslant R^*$, that, as we shall see, reduces expected profits. When the bank fails, $R < R^*$, there are fewer partial runs but a bank expected profits is always zero by limited liability. Chen et al. (2019) provide empirical evidence consistent with opacity reducing the sensitivity of withdrawals to investment returns as implied by our model.

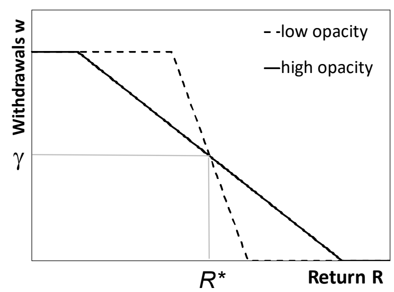

Figure 2: Opacity and withdrawals. The withdrawal proportion depends on the realized investment return for high (bold line) and low (dashed line) levels of opacity. Opacity reduces the sensitivity of withdrawals to the realized investment return.

Our choice of a uniform distribution simplifies the analysis because it implies that opacity does not directly affect bank failure, $\frac{\partial R^*}{\partial \delta} = 0$. Interestingly, the failure threshold indirectly depends on opacity via the effect of opacity on the face value.

A higher face value of debt D increases the failure threshold, $\frac{dR^*}{dD} > 0$, because withdrawals have a larger negative impact on the resources available for remaining investors. Hence, the withdrawal proportion increases, $\frac{dw^*}{dD} > 0$, for a given intermediate realized investment return. This effect arises indirectly via the failure threshold, $\frac{\partial w^*}{\partial R^*}\frac{dR^*}{dD} > 0$, as the direct effect of the face value on withdrawals is zero, $\frac{\partial w^*}{\partial D} = 0$.

2.2 Funding market outcomes

We next analyse the equilibrium in the funding market at date 0. Starting with some intermediate results, we consider a bank with opacity δ and expected return to investors ρ and derive properties of the face value of debt D consistent with the return to investors ρ and opacity δ. We also derive the expected per-unit bank profits π and the equilibrium levels of opacity, δ^*, and of expected returns to investors, ρ^*.

Lemma 1. ***Face value of debt.*** *If $\rho \leqslant \underline{\rho} \equiv \underline{R}/1+\gamma z$, then debt is always repaid, $D^* = \rho$. Moreover, there exist no face value of debt to support an expected return to investors of $\rho > \overline{\rho} \equiv \frac{\overline{R}^2}{4\alpha(1+\gamma z)}$. Otherwise, $\underline{\rho} < \rho \leqslant \overline{\rho}$, debt is risky, its face value is $D^* = \frac{R^*}{1+\gamma z} > \rho$, and the bank failure threshold is*

$$R^* = \frac{\overline{R}}{2} - \sqrt{\chi} \in \left(\underline{R}, \overline{R}\right), \quad \chi \equiv \frac{\overline{R}^2}{4} - \theta, \quad \theta \equiv \alpha(1+\gamma z)\rho. \tag{5}$$

The failure threshold increases and is convex in the expected return of investors, $\frac{dR^*}{d\rho} > 0$ and $\frac{d^2R^*}{d\rho^2} > 0$. This failure threshold also decreases and is convex in the expected investment return, $\frac{dR^*}{dR_0} < 0$ and $\frac{d^2R^*}{dR_0^2} > 0$, with the cross-partial derivative $\frac{d^2R^*}{d\rho\, dR_0} < 0$.

Proof. See Appendix B. ■

Lemma 1 states the three cases for debt pricing. For a low expected return to investors, $\rho \leqslant \underline{\rho}$, debt is always repaid, so $D^* = \rho$. For a high ρ, investors cannot receive the required ρ even with the lowest possible expected bank profits. For an intermediate expected return, debt is risky (and thus sometimes defaulted upon) and the face value of debt and the expected return of investors are linked according to $\rho \equiv D^* \Pr\{R \geqslant R^*\}$. This pricing equation has two roots and we pick the smaller one, consistent with lower bank fragility and higher expected profits. Henceforth, we focus on parameters such that debt is risky in equilibrium, $\underline{\rho} < \rho^*$.[20]

[20] Note that uninsured deposits are always risky if $\underline{\rho} = 0$, which occurs for $\underline{R} = 0$.

A main takeaway from Lemma 1 is the link between the expected return offered to investors and bank fragility. That is, the failure threshold evaluated at competitive debt pricing, R^*, increases in the expected return to investors ρ, so the range of realized investment returns for which the bank survives, $\left[R^*, \overline{R}\right]$, shrinks. Hence, a higher expected return offered to investors leads to a higher bank failure probability.

Interestingly, the uniform distribution implies $D^*(\rho, \delta) = D^*(\rho)$, so the face value of debt is independent of bank opacity (once the indirect effect via the expected returns to investors is accounted for). For ease of exposition, and without loss of generality, we henceforth state the problems of banks in terms of ρ instead of D.

We turn to the expected bank profits per unit of funding. For low investment returns, $R < R^*$, the bank fails and obtains zero profits by limited liability. Otherwise, per-unit profits are the return net of withdrawal costs. For intermediate returns, $R^* \leqslant R < \widetilde{R}$, some withdrawals occur at date 1 even if the banker is solvent due to bank opacity. Some fund managers receive a low signal and withdraw—a partial run. For high returns, $R \geqslant \widetilde{R}$, there are no withdrawals. A lower bound on investment risk, $\alpha > \underset{\sim}{\alpha}$, ensures that no withdrawals occur at the highest return, $\widetilde{R} \leqslant \overline{R}$, which we assume henceforth. Since the withdrawals $w(R)$ at date 1 cost $\frac{w(R)}{\psi}D$ due to partial liquidation, bank equity (per unit of funding) for a realized return R is:

$$E(R) \equiv \max\left\{0, R - D\big(1 + zw(R)\big)\right\}, \tag{6}$$

which is zero at the failure threshold, $E(R^*) \equiv 0$ (see also Figure 3). Integrating over all investment returns yields the expected per-unit profit, $\pi \equiv \int_{R^*}^{\overline{R}} E(R)\frac{1}{\alpha}dR$.

Lemma 2. ***Expected per-unit profit.*** *The expected per-unit bank profit is*

$$\pi \equiv -\rho + \frac{\frac{\overline{R}^2}{2} + \theta + \overline{R}\sqrt{\chi}}{2\alpha} - \frac{\gamma^2 z D^*}{2\alpha}\delta. \tag{7}$$

It decreases and is concave in the return to investors, $\frac{d\pi}{d\rho} < 0$ *and* $\frac{d^2\pi}{d\rho^2} < 0$*, and*

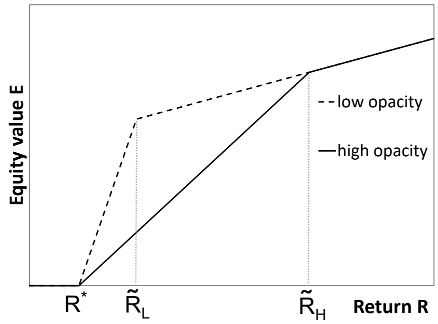

Figure 3: Bank equity value (per unit of funding) at date 2 depends on the realized investment return R and the level of opacity δ: high (bold line) and low (dashed line).

increases in the expected investment return, $\frac{d\pi}{dR_0} > 0$*. Moreover, the expected per-unit profit decreases in opacity,* $\frac{d\pi}{d\delta} < 0$*, with a negative cross-derivative,* $\frac{d^2\pi}{d\rho d\delta} < 0$*.*

Proof. See Appendix B. ■

Expected bank profits per unit of funding π comprise three terms: the cost of funding, the expected surplus generated from investment, and the cost of partial runs when the bank does not fail. A higher expected return to investors ρ reduces expected profits π by increasing the funding cost and the failure threshold R^*. Higher bank opacity δ widens the range of partial runs, $[R^*, \widetilde{R}]$, in which costly partial liquidation of investment occurs, reducing the per-unit expected profits.

Equipped with the per-unit expected profits, we solve for the equilibrium in the funding market at date 0. Bank j chooses opacity and the expected return to investors to maximize expected profits, taken as given the choices of all competing banks $(\delta^{-j},\, \rho^{-j})$:

$$\max_{\delta^j, \rho^j \leqslant \overline{\rho}} \Pi^j = h^j(\rho^j, \rho^{-j})\, \pi(\delta^j, \rho^j). \tag{8}$$

Proposition 2. ***Bank choices.*** *Banks are as transparent as possible,* $\delta^j = \delta^* = \underline{\delta}$*. The expected returns to investors* $\rho^j = \rho^* < \overline{\rho}$ *is unique and implicitly given by*

$$\left.\frac{\pi}{\mu}\right|_{(\delta^*=\underline{\delta}, \rho=\rho^*)} + \frac{1}{N} \left.\frac{d\pi}{d\rho}\right|_{(\delta^*=\underline{\delta}, \rho=\rho^*)} = 0. \tag{9}$$

Proof. See Appendix C. ■

In this setup, the only effect of opacity is in terms of partial runs on the bank and costly liquidation of investment. Hence, expected per-unit profits are lower for higher opacity levels, $\frac{d\pi}{d\delta} < 0$ (see Lemma 2) and banks choose to be as transparent as possible. Regarding the expected return offered to investors, each bank trades off its volume of funding, $\frac{dh^j}{d\rho^j} > 0$, with the expected profits per unit of funding, $\frac{d\pi^j}{d\rho^j} < 0$, which pins down the expected return to investors ρ^*. Because of the mapping between ρ^* and D^*, we also refer to ρ^* as the equilibrium deposit rate. In the symmetric equilibrium, each bank attracts an equal amount of funding, $h^j = h^* = \frac{1}{N}$.

Turning to comparative statics, we consider changes in (a) the number of banks N and the transport cost μ (measures of the degree of competition); (b) the minimum opacity level $\underline{\delta}$ that can be linked to secular changes in technology; (c) the expected investment return R_0; and (d) an exogenous change in per-unit profits. To isolate the effects of bank profitability on fragility, we also consider a version of the model with a non-pecuniary per-unit cost of lending $\lambda > 0$, such as variable operational costs.

Proposition 3. ***Comparative statics.***

(a) *Greater competition increases the deposit rate,* $\frac{d\rho^*}{dN} > 0$*, and fragility,* $\frac{dR^*}{dN} > 0$*. A bank's expected profit decreases in competition,* $\frac{d\Pi^*}{dN} < 0$*.*

(b) *Lower minimum opacity increases the deposit rate,* $\frac{d\rho^*}{d\underline{\delta}} < 0$*, and increases fragility,* $\frac{dR^*}{d\underline{\delta}} < 0$*, but raises expected profits,* $\frac{d\Pi^*}{d\underline{\delta}} < 0$*. For* $N \to \infty$*, we have* $\frac{d\rho^*}{d\underline{\delta}} \to 0$ *and* $\frac{dR^*}{d\underline{\delta}} \to 0$*.*

(c) *A higher expected investment return increases the deposit rate,* $\frac{d\rho^*}{dR_0} > 0$*, and expected bank profits,* $\frac{d\Pi^*}{dR_0} > 0$*. The deposit rate response dampens the (direct) stabilizing effect of higher investment returns on bank stability,* $\Pr\{R \geqslant R^*\}$*.*

(d) *With a non-pecuniary per-unit cost of lending* λ*, bank profits and the deposit* *rate are lower, $\rho^*_\lambda < \rho^*$, which reduces bank fragility, $R^*_\lambda < R^*$.*

Proof. See Appendix C. ■

First, a larger number of banks induces banks to compete more fiercely for funding and, in equilibrium, results in higher deposit rates and lower expected per-unit profits. Higher deposit rates result in a higher face value of debt (Lemma 1) that, in turn, lead to higher bank fragility (Proposition 1), as shown in Figure 4.[21] These results are consistent with the competition-instability view of banking and highlight that greater competition can introduce fragility from a bank's liability side.

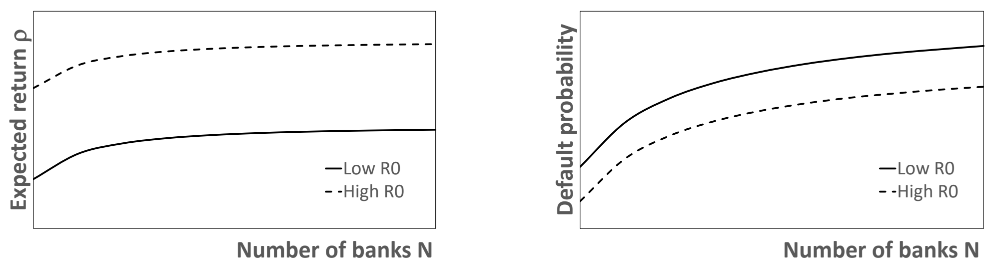

Figure 4: Competition-instability channel: the expected return of investors ρ^* and the probability of bank failure $\Pr\{R < R^*\}$ increase in the degree of competition N.

We argue that our result on the competition-instability view of banking extend to other imperfect competition setups, such as the Cournot model. To illustrate this point, consider an increasing and weakly convex inverse demand function for bank deposits $\rho(H)$, where h_j is bank j's deposits and $H = \sum_{j=1}^N h_j$ are total deposits. Following the same argument as in Proposition 2, banks also choose minimum opacity, $\delta^*_j = \underline{\delta}$. Thus, bank j's expected profit maximization problem reduces to

$$\max_{h_j} h_j \, \pi(\rho(H)). \tag{10}$$

The first-order condition, $\pi + h_j \frac{d\pi}{d\rho} \frac{d\rho}{dH} = 0$, specifies a profit maximum. In the sym-

[21] If instead lower transport costs are used as a measure of greater competition, $\mathrm{d}\mu < 0$, we similarly get higher expected returns, $\frac{d\rho^*}{d\mu} < 0$, and thus higher fragility, $\frac{dR^*}{d\mu} < 0$.

metric equilibrium, $h_j^* = h^*$, higher bank competition increases total deposits raised by banks, $\frac{dH^*}{dN} > 0$. Given the increasing inverse demand, higher bank competition increases the deposit rate, $\frac{d\rho^*}{dN} > 0$, that also increases bank fragility, $\frac{dR^*}{dN} > 0$.

For the second comparative static, a reduction in minimum opacity increases both expected per-unit profits, $\pi_{\delta} < 0$, and its marginal change with respect to deposit rates, $\pi_{\rho\delta} < 0$ (Lemma 2). As a result, banks compete more fiercely for funding and deposit rates are higher, which raises both the face value of debt and fragility:

$$\frac{dR^*}{d\underline{\delta}} = \frac{\partial R^*}{\partial \underline{\delta}} + \frac{\partial R^*}{\partial \rho^*}\frac{d\rho^*}{d\underline{\delta}} > 0, \tag{11}$$

where our choice of a uniform distribution highlights the role of bank competition. This distribution implies no direct effect of opacity on fragility, $\frac{\partial R^*}{\partial \underline{\delta}} = 0$, and thus allows us to cleanly identify its indirect effect via changes in the deposit rate. The magnitude of the indirect effect depends on the intensity of bank competition, as shown in Figure 5. The effects are smaller for a larger number of banks and tend to zero as the intensity of bank competition increases, as shown in Proposition 3.

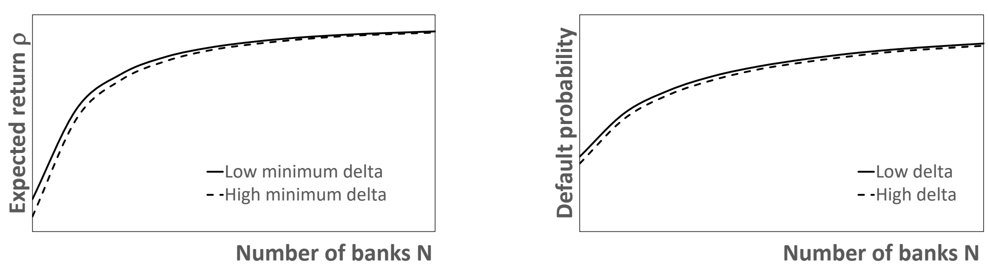

Figure 5: The effect of changes in maximum bank transparency $\underline{\delta}$ on the deposit rate ρ^* and failure probability $\Pr\{R < R^*\}$ depend on the intensity of competition N.

Third, a higher expected investment return R_0 directly reduces withdrawal incentives (note that $\frac{\partial \Pr\{R<R^*\}}{\partial R_0} < 0$ is implied by $\frac{\partial R^*}{\partial R_0} < 0$ from Lemma 1). Moreover, it indirectly increases withdrawal incentives by increasing the incentives for banks to raise funding, resulting in a higher equilibrium deposit rate ρ^* (Figure 4), given by $\frac{\partial R^*}{\partial \rho} > 0$ in Lemma 1. Hence, the endogenous deposit rate response dampens the reduction in the failure probability, $\Pr\{R < R^*\}$, as the expected investment return R_0 improves. The magnitude of this effect again depends on bank competition. In line with our previous results, there are higher effects for lower bank competition.

Finally, we consider the effects of a non-pecuniary cost of lending for bank fragility. Such a lending cost reduces bank profitability and, therefore, the incentives of banks to compete for funding. Hence, higher non-pecuniary lending costs reduce the deposit rate, which in turn reduces bank fragility. This result sharply contrasts with models of risk-taking on the asset side via a moral hazard problem (for example, Hellmann et al. (2000); Allen and Gale (2004)). The opposite result arises in those environments because lower expected profits increase the incentives for lower effort or higher risk-taking and, thus, reduce bank stability. Our result therefore highlights the importance of whether the source of bank instability arises from its asset side (e.g., via risk-taking) or its liability side (via a fragile funding structure and runs).

2.3 Regulatory implications

We next turn to regulatory implications of our one-period setup. We first consider competition policy, i.e. a regulator who sets the number of banks in the economy, N. Next, we consider transparency regulation that enforces bounds on the opacity level, $\underset{\sim}{\delta} \leqslant \delta^j \leqslant \tilde{\delta}$. Policies and regulations mandating transparency includes the pillar 3 of Basel bank regulation, the IFRS accounting standard, and bank stress tests.

A regulator takes as given the incomplete information and the privately-optimal choices of opacity and deposit rates given regulation. That is, banks choose $\delta^* = \underset{\sim}{\delta}$ and $\rho^*(\underset{\sim}{\delta}, N)$. The regulator maximizes utilitarian welfare that comprises expected bank profits and the deposit rates received by investors net of transport costs.[22] We

[22]For the welfare analysis of the Rochet-Vives model, we follow the approach in Ahnert et al. (2019) and mute the impact of fund managers' payoffs on welfare. That is, we set $b \to 0$ and $c \to 0$ at a rate that preserves the positive implications of this approach, where $\frac{b}{b+c} \to \gamma$ remains constant.

interpret the per-unit liquidation cost z as a social cost (e.g., redeployment of resources to a worse user; Shleifer and Vishny, 1992). Total transport costs are $TC = \frac{\mu}{4N}$ and decrease in the number of banks at a diminishing rate, $\frac{dTC}{dN} < 0$ and $\frac{d^2TC}{dN^2} > 0$.[23]

Banks raise a unit mass of deposits, $\sum_{j=1}^{N} h_j = 1$. The regulator takes into account that, from a social perspective, there are no market-stealing incentives as the market for funding is covered. Since $N\Pi^* = \pi^*$, welfare can be expressed as

$$W \equiv \pi^* + \rho^* - TC. \tag{12}$$

We have the following implications for regulation.

Proposition 4. ***Regulation.***

(a) ***Competition policy.*** *If the consequences of rollover risk are severe enough (γz is high) and the transport cost μ is low enough, then the optimal number of banks is interior. $N^* \in (0, \infty)$. It is implicitly given by $\frac{dW}{dN} = 0$ that yields*

$$6 + 4 \left.\frac{d\pi}{d\rho}\right|_{N=N^*} + \frac{\mu}{N^*} \left.\frac{\frac{d^2\pi}{d\rho^2}}{\frac{d\pi}{d\rho}}\right|_{N=N^*} = 0. \tag{13}$$

(b) ***Opacity regulation.*** *If the transport cost μ is low enough or the number of banks N high enough, the regulator imposes maximum transparency, $\underset{\sim}{\delta}^* = \underline{\delta}$.*

Proof. See Appendix D. ■

A larger number of banks is associated with a trade-off. Its benefits is a reduction in transport costs, $\frac{dTC}{dN} < 0$, i.e. higher lending net of transport costs. The costs of a larger number of banks arise from fiercer competition for funding that results in a higher deposit rate, $\frac{d\rho^*}{dN} > 0$. While the funding cost itself is merely a transfer

[23] Investors with a distance $d_k \in \left[0, \frac{1}{2N}\right]$ on either side of a given bank's position deposit with this bank because it is the closest. Hence, total transport costs are $TC = \mu \cdot 2N \int_0^{\frac{1}{2N}} d_k \, dd_k = \frac{\mu}{4N}$.

between banks and investors and hence does not affect welfare, a higher deposit rate increases bank fragility, $\frac{dR^*}{dN} > 0$, and the costs associated with a partial run and the liquidation of investment, reducing welfare.[24]

When regulating opacity, the planner considers two effects as shown by the first-order condition:

$$\frac{dW}{d\delta} = \frac{\partial \pi}{\partial \delta} + \left(1 + \frac{\partial \pi}{\partial \rho^*}\right) \frac{d\rho^*}{d\delta}. \tag{14}$$

First, higher minimum opacity results in more partial runs, higher liquidation costs, and hence lower per-unit profits, reducing welfare. This effect is internalized by banks when choosing opacity. Second, and as a result of the lower per-unit profits, banks compete less fiercely for funding and the deposit rate and fragility are lower, $\frac{d\rho^*}{d\delta} < 0$. The second effect is not internalized by banks, resulting in an additional social cost of transparency. For a low transport cost or a large number of banks, however, the degree of competition and the deposit rate are high, resulting in a low sensitivity of fragility to increases in deposit rates due to greater transparency Thus, the second effect is dominated by the first one and the regulator chooses minimum opacity.

3 Entry and deterrence: a theory of bank opacity

In this section, we modify our basic setup to study a key element of bank competition: the entry of competitors. We consider the entry decisions of a potential entrant who can learn about underlying economic conditions from incumbent banks. Hence, we study the incentives of an entrant to enter and the circumstances under which incumbent banks have incentives to modify their opacity choices to deter the entrant.

There are two periods $T = 1, 2$, each of which resembles the model presented in section 2. The investment return follows $R_T = R_{T-1} + \eta_T$, where $R_0 > \alpha$, η_T is

[24] A similar trade-off would occur if we used a Cournot model of imperfect competition, where the trade-off would be between bank fragility and loan quantity (instead of transport costs).

independently and identically uniformly distributed, $\eta_T \sim U[-\frac{\alpha}{2}, \frac{\alpha}{2}]$, and independent of R_T. Since R_{T-1} is publicly observed at date 0 of period T, the common prior of R_T at date 0 is

$$R_T \big| R_{T-1} \sim U\left[R_{T-1} - \frac{\alpha}{2}, R_{T-1} + \frac{\alpha}{2}\right]. \tag{15}$$

At date 0 in each period, bank j chooses its opacity δ_T^j and the face value of debt D_T^j that results in an expected return to investors ρ_T^j and the balance sheet is $I_T^j = h_T^j$. Investors have an outside option normalized to zero in each period.

At date 0 of period 1, there are N incumbent banks that maximize the sum of expected profits in each period. Banks who fail in period 1 exit and are not active in period 2. A potential entrant E can operate in period 2 only. We assume that (a) investors live for one period and are replaced with new investors with the same endowments; and (b) banks consume their equity value at the end of each period. If at least 2 banks are active at date 0, all banks are equidistantly located on the circle.

After incumbent banks have chosen their levels of opacity and deposit rates at date 0 of period 1, the potential entrant E decides whether to follow the market. Doing so entails a cost $C > 0$ that captures resources and time devoted (e.g., of bank executives) to study the market. Without following the market, E receives an outside option normalized to zero. If E follows the market, it receives two pieces of information. First, at date 1 of period 1 (simultaneous to the rollover decisions of fund managers), E is randomly located on the circle and receives a private signal about the investment return of the nearest bank, indexed by J. Paralleling the signals received by fund managers, the entrant's signal also depends on bank opacity choices:

$$x_E = R_1 + \epsilon_E^J, \quad \epsilon_E^J \sim \mathcal{U}\left[-\frac{\delta_1^J}{2}, \frac{\delta_1^J}{2}\right], \tag{16}$$

where ϵ_E^J is independent of R_1.[25] In sum, an incumbent bank's opacity choice affects

[25]We consider a symmetric information structure for private signals. Our results qualitatively generalize to an entrant's signal of the form $x_E = R_1 + \chi\epsilon_E^J$ for $0 < \chi < \infty$. For example, $\chi < 1$

the precision of private information of both fund managers and the potential entrant.

Second, at date 2 of period 1 the entrant observes whether incumbent banks fail, $R_1 < R_1^*$. Based on these pieces of information, E decides whether to pay a fixed cost $F > 0$ of entry that allows it to operate in period 2. Our assumption that the fixed cost is paid before the realized investment return R_1 is publicly observed captures various costly decisions banks have to make before they can effectively operate in a given market (e.g., the creation of relevant capacities by hiring specialized human capital, building offices, etc.).

In sum, the entry choice has two stages: an information stage in which E chooses whether to receive information about the market at cost C and an investment stage in which E decides whether to build capacity at cost F based on the information received. The number of active banks in period 2 depends on entry and exit:

$$N_2 = \begin{cases} N + \mathbf{1}\Big\{\text{E enters}\Big\} & R_1 \geqslant R_1^* \\ & \text{if} \\ \mathbf{1}\Big\{\text{E enters}\Big\} & R_1 < R_1^*, \end{cases} \tag{17}$$

where $\mathbf{1}\{\cdot\}$ is the indicator function that takes value of 1 whenever E enters.

As in our previous analysis, we study perfect Bayesian equilibrium and focus on symmetric equilibrium in pure strategies and threshold strategies. Generalizing previous results, the failure threshold of the investment return is $R_T^* \equiv (1 + \gamma z)D_T$ and the signal threshold is $x_T^* \equiv R_T^* + \left(\gamma - \frac{1}{2}\right)\delta_T$. The withdrawal proportion is $w_T^* = w^*(R_T)$ and the highest investment return is $\overline{R}_T \equiv R_T + \frac{\alpha}{2}$. We assume $\underline{\delta} \equiv 0$. Table 2 summarizes the timeline of events in period 1.

would capture that the entrant is better informed than the wholesale creditors of incumbent banks.

$t = 0$	$t = 1$	$t = 2$
1. Banks compete for funding	1. Private signals	1. Investment matures
2. Investors deposit at a bank	2. Withdrawals	2. Banks repay or default
3. Entrant may follow the market	3. Consumption	3. Entrant may build capacity
4. Banks invest		4. Consumption

Table 2: Timeline (Period 1).

3.1 Entry

We proceed backwards and start our analysis with E's decision to enter upon having followed the market. The potential entrant forms a posterior $g(R_1|x_E, \delta_1^J)$ that depends on its two pieces of information and the opacity choice of the nearest incumbent bank. Knowledge about the current investment return R_1 helps the potential entrant form expectations about investment returns and thus expected profits in period 2.

Consider first the failure of incumbent banks, $R_1 < R_1^*$. If E enters, it captures the entire market, $h_E^* = 1$ (given our maintained assumption of a low transport cost μ in order to ensure a covered market). We label this case as monopolist (M). The equilibrium expected return is $\rho_E^* = \frac{\mu}{2}$ and $\pi_2^*(R_1, \rho_E^*) \equiv \pi_{2M}^*(R_1)$. E's expected profits are

$$V(x_E, \delta_1^J) = \int_{\underline{R}_1}^{R_1^*} \pi_{2M}^*(R_1)\, g(R_1|x_E, \delta_1^J)\, dR_1. \tag{18}$$

Consider next the case of survival (S) of incumbent banks, $R_1 \geqslant R_1^*$. The entrant assigns expected profits $\Pi_2^*(R_1, N+1) = \frac{\pi_2^*(R_1, \rho_2^*(R_1))}{N+1} \equiv \frac{\pi_{2S}^*(R_1)}{N+1}$ to each of the possible returns R_1, where ρ_2^* solves a generalized equation (9), where the prior is R_1, $N_2 = N + 1$, and $\delta_2^* = \underline{\delta}$. Thus, the entrant's expected profits are

$$V(x_E, \delta_1^J) \equiv \int_{R_1^*}^{\overline{R}_1} \frac{\pi_{2S}^*(R_1)}{N+1}\, g(R_1|x_E, \delta_1^J)\, dR_1. \tag{19}$$

We have the following result on entry choice at $t = 2$ upon following the market.

Proposition 5. ***Entry.*** *Upon the survival of incumbent banks, $R_1 \geqslant R_1^*$, there exist bounds on the fixed cost of entry, $\left(\underline{F}, \overline{F}\right)$ with $\underline{F} < \overline{F}$:*

- *E always enters if $F \leqslant \underline{F}$, while E never enters if $F \geqslant \overline{F}$.*
- *If $F \in \left(\underline{F}, \overline{F}\right)$, then there exists a threshold signal x_E^* defined by $V(x_E^*, \delta_1^J) \equiv F$ such that E enters if and only if the signal is high enough, $x_E \geqslant x_E^*$.*

Similarly upon the failure of incumbent banks, $R_1 < R_1^*$, there exist bounds $\left(\underset{\sim}{F}, \widetilde{F}\right)$:

- *E always enters if $F \leqslant \underset{\sim}{F}$, while E never enters if $F \geqslant \widetilde{F}$.*
- *If $F \in \left(\underset{\sim}{F}, \widetilde{F}\right)$, then there exists a x_E^{**} such that E enters if and only if $x_E \geqslant x_E^{**}$.*

Proof. See Appendix E. ∎

At the lower bounds on the entry cost, $\underset{\sim}{F}$ and $\underline{F}$, the potential entrant is indifferent about entry after inferring the lowest possible investment return ($R_1 = \underline{R}_1$ and $R_1 = R_1^*$, respectively). Similarly, at the upper bounds on the entry cost, $\widetilde{F}$ and $\overline{F}$, the potential entrant is indifferent about entry after inferring the highest possible investment return ($R_1 = R_1^*$ or $R_1 = \overline{R}_1$). For intermediate fix costs, we define threshold levels of the investment return, $\breve{R}_1$ and $\widehat{R}_1$, such that the potential entrant is indifferent about entry if it observes R_1 without any noise (that is, if $\delta^J = 0$):

$$\pi_{2M}^*(\breve{R}_1) \equiv F \equiv \frac{\pi_{2S}^*(\widehat{R_1})}{N+1}. \tag{20}$$

That is, under perfect information E enters at date 2 of period 1 if and only if $R_1 \geqslant \widehat{R}_1$ when incumbent banks survive and if and only if $R_1 \geqslant \breve{R}_1$ when these banks fail.

We turn to E's incentives to follow the market. It does so whenever its expected profits from following exceed the cost, $\Pi_E \equiv \Pi_E^M + \Pi_E^S \geqslant C$, where the expected profits arise after both the failure of incumbent banks and their survival:

$$\begin{aligned}\Pi_E^M &\equiv \int_{\underline{R}_1}^{R_1^*} \Big[\pi_{2M}^*(R_1) - F\Big]\, \mathbf{1}\Big\{\text{E enters}\Big\}\, \frac{1}{\alpha} dR_1, \\ \Pi_E^S &\equiv \int_{R_1^*}^{\overline{R}_1} \Big[\frac{\pi_{2S}^*(R_1)}{N+1} - F\Big]\, \mathbf{1}\Big\{\text{E enters}\Big\}\, \frac{1}{\alpha} dR_1.\end{aligned}$$

For intermediate fix costs, the threshold strategy implies a probability of entry:

$$q(R_1) = \Pr\{x_E \geqslant x_E^* | R_1\} = \begin{cases} 1 & R_1 \geqslant x_E^* + \frac{\delta_1^J}{2} \\ \frac{1}{2} - \frac{x_E^* - R_1}{\delta_1^J} & \text{if} \quad R_1 \in \Big[x_E^* - \frac{\delta_1^J}{2}, x_E^* + \frac{\delta_1^J}{2}\Big]. \\ 0 & R_1 \leqslant x_E^* - \frac{\delta_1^J}{2} \end{cases} \tag{21}$$

For expositional simplicity, we focus on intermediate fix costs, $\underline{F} < F < \overline{F}$ and $\underset{\sim}{F} < F < \widetilde{F}$ in the remainder of this subsection. This allows us to decompose E's expected profit into a perfect-information benchmark and the costs of making mistakes due to an imprecise signal x_E. These are a type-I error of entering when doing so is unprofitable and a type-II error of not entering when doing so is profitable:

$$\begin{aligned}\Pi_E^M &\equiv \underbrace{\int_{\breve{R}_1}^{R_1^*} \Big[\pi_{2M}^*(R_1) - F\Big] \frac{dR_1}{\alpha}}_{\text{perfect information}} - \underbrace{\int_{x_E^* - \frac{\delta^J}{2}}^{\breve{R}_1} q\Big[F - \pi_{2M}^*(R_1)\Big] \frac{dR_1}{\alpha}}_{\text{type-I error}} - \underbrace{\int_{\breve{R}_1}^{x_E^* + \frac{\delta^J}{2}} (1-q)\Big[\pi_{2M}^*(R_1) - F\Big] \frac{dR_1}{\alpha}}_{\text{type-II error}}, \\ \Pi_E^S &\equiv \underbrace{\int_{\hat{R}_1}^{\overline{R}_1} \Big[\frac{\pi_{2S}^*(R_1)}{N+1} - F\Big] \frac{dR_1}{\alpha}}_{\text{perfect information}} - \underbrace{\int_{x_E^* - \frac{\delta^J}{2}}^{\hat{R}_1} q\Big[F - \frac{\pi_{2S}^*(R_1)}{N+1}\Big] \frac{dR_1}{\alpha}}_{\text{type-I error}} - \underbrace{\int_{\hat{R}_1}^{x_E^* + \frac{\delta^J}{2}} (1-q)\Big[\frac{\pi_{2S}^*(R_1)}{N+1} - F\Big] \frac{dR_1}{\alpha}}_{\text{type-II error}}.\end{aligned}$$

This decomposition clarifies the dependence of expected profits on the opacity choice of incumbent banks, $\Pi_E = \Pi_E(\delta_1^J)$. Let $\underset{\sim}{C} \equiv \min_\delta \Pi_E(\delta)$ and $\widetilde{C} \equiv \max_\delta \Pi_E(\delta)$ denote the bounds on the expected profits of the potential entrant, where $\widetilde{C} = \Pi_E(0)$. In words, the expected profits of E is maximized when incumbent banks are fully transparent, as E makes no mistakes in its entry choice. Since these mistakes are costly, we have $\widetilde{C} \geqslant \underset{\sim}{C}$. We have the following result on the entry choice at $t = 0$.

Proposition 6. ***Following the market.*** *If $C \geqslant \widetilde{C}$, E does not follow the market. If $C < \underset{\sim}{C}$, then E always follows the market. If an intermediate cost range exists, then E follows the market for $C \in \left(\underset{\sim}{C}, \widetilde{C}\right)$ if and only if $\Pi_E(\delta_1^J) \geqslant C$.*

Proof. The proof derives from the discussion in the main text. ■

The fix cost of entry F determines whether an intermediate range of costs of following the market exist. When $F \notin (\underline{F}, \overline{F})$ and $F \notin \left(\underset{\sim}{F}, \widetilde{F}\right)$, then the choice to enter at $t = 2$ is independent of the private signal x_E and, therefore, of incumbent banks choices of opacity, resulting in $\underset{\sim}{C} = \widetilde{C}$. However, as long as the fixed cost F lies in at least one of the intermediate ranges above, the choice to enter at $t = 2$ depends on the private signal of the entrant and thus incumbent bank opacity choices, resulting in $\underset{\sim}{C} < \widetilde{C}$. In this case, there is scope for incumbent banks to deter the potential entrant, as we see next.

3.2 Incumbent bank choices of opacity and deposit rates

Having characterized the entrant's behaviour, we next characterize the decisions of incumbent banks. When maximizing the sum of expected profits in both periods, Π_I, incumbent banks take into account how their choices of opacity and the deposit rate in period 1 affect their charter value (the expected profits in period 2). An incumbent bank j receives the charter value only if solvent, $R_1 \geqslant R_1^*$, so its problem in period 1 is

$$\max_{\delta_1^j, \rho_1^j} \Pi_I^j = h_1^j(\rho_1^j)\, \pi_1(\rho_1^j, \delta_1^j) + \int_{R_1^*(\rho_1^j)}^{\overline{R}_1} \Pi_2^*(R_1, N_2(\delta_1^J)) \frac{1}{\alpha} dR_1, \tag{22}$$

where $N_2 = N + 1$ if E chooses to follow the market and then chooses to enter. An incumbent bank's choice of opacity can affect the potential entrant when E randomly appears closest to this bank, which occurs with probability $\Pr\{\delta_1^j = \delta_1^J\} = \frac{1}{N}$.[26]

[26]Our results are unchanged if E learns from all banks and forms the average $\delta^J \equiv \frac{1}{N}\sum_{j=1}^N \delta^j$ because of risk-neutrality. In the main text, $\frac{d\delta^J}{d\delta_1^j} = 1$ w.p. $\frac{1}{N}$ and else 0, while $\frac{d\delta^J}{d\delta_1^j} = \frac{1}{N}$ w.p. 1 in

Let δ_D denote the deterrence level of opacity. It is the smallest level of opacity for which the potential entrant chooses not to follow the market, $\Pi_E(\delta) \leqslant C$, for an intermediate cost of following the market, $C \in \left(\underset{\sim}{C}, \widetilde{C}\right)$. The following proposition states incumbent bank opacity choices in period 1.

Proposition 7. ***Bank opacity choice (with entry).*** *If the entrant's choice to follow the market depends on incumbent bank opacity choices, $C \in \left(\underset{\sim}{C}, \widetilde{C}\right)$, then there exists an upper bound on the number of incumbent banks $\overline{N}$ such that incumbent banks prefer deterrence via opacity over full transparency, $\Pi_I^*(\delta_D) > \Pi_I^*(0)$, for all $N < \overline{N}$.*

If the entrant's choice to follow the market does not depend on incumbent bank opacity choices, (i) $C \geqslant \widetilde{C}$ or (ii) $C < \underset{\sim}{C}$, $F \notin (\underline{F}, \overline{F})$, and $F \notin \left(\underset{\sim}{F}, \widetilde{F}\right)$, then incumbent banks choose minimum opacity, $\delta_1^* = 0$.

Proof. See Appendix F. ■

The main result is that there are circumstances, which are more prone to happen for lower bank competition, in which incumbent banks choose to be opaque in order to deter entry. The benefit of opacity is to deter entry, so incumbent banks enjoy a higher charter value for two reasons. Without entry, the future market share is higher and competition for funding is less fierce, so future deposit rates are lower. A lower bound on this benefit per unit of funding decreases in the number of incumbent banks. The difference in market share moving from N competing banks to $N + 1$ decreases as the number of incumbent banks increases, giving banks in less competitive setups higher incentives to deter. The cost of opacity arises from partial runs and costly liquidation in period 1, as in the model without entry. As a result, incumbent banks choose a higher level of opacity than in the model without entry.

Proposition 8. ***Bank deposit rates (with entry).*** *The expected return offered*

the alternative model. The incentives for deterrence are the same in both approaches.

to investors, ρ_1^*, implicitly given by

$$\left.\frac{\pi_1}{\mu}\right|_{\rho_1^*,\delta_1^*} + \frac{1}{N}\left.\frac{d\pi_1}{d\rho_1}\right|_{\rho_1^*,\delta_1^*} - \frac{\Pi_2^*(R_1^*)}{\alpha}\frac{dR_1^*}{d\rho_1} = 0. \tag{23}$$

Proof. The proof is immediate from the discussion in the main text. ■

Compared to the model without entry, incumbent banks offer a lower deposit rate ρ_1^* for two reasons. First, the charter value offers incentives to be solvent more often—the third term in equation (23). By competing less fiercely for funding in period 1, incumbent banks internalize that a lower deposit rate reduces their fragility, $\frac{dR_1^*}{d\rho_1} > 0$, and thus increases the probability of survival and keeping the charter value.[27] Second, greater opacity, $\delta_1^* \geqslant 0$, leads to a partial run and costly liquidation, which reduces an incumbent's incentive to compete for funding (see also Proposition 3, b).

3.3 Regulatory implications

We turn to implications for transparency regulation in the model with endogenous entry. Since the regulator can set both upper and lower bounds on the level of opacity chosen by banks, it effectively picks δ_1 and δ_2 for them, where δ_1^R and δ_2^R denote the regulator's choice of opacity. The regulator maximizes utilitarian welfare that comprises the sum of expected bank profits net of entry costs and the expected payoffs to investors net of transport costs in both periods, $W = W_1 + W_2$. Thus, we interpret the (opportunity) costs of following the market and of investment, C and F, as social costs.

Proposition 9. *We have the following implications for transparency regulation:*

[27]The incumbent bank only looses the charter value *at the margin*, $\Pi_2^*(R_1^*)$, but keeps it for high returns. This result arises since the realized return in period 1 jointly determines (i) the failure of banks in period 1, and (ii) the expected investment return (and thus the charter value) in period 2.

(a) ***Excessive transparency.*** *Consider the case of no entry, $C > \widetilde{C}$. If the number of incumbent banks N is high enough (or the transport cost μ is low enough) and the expected investment return R_0 is high enough, then the regulator chooses more opacity than incumbent banks, $\delta_1^R > \delta_1^* = 0$.*

(b) ***Excessive opacity.*** *Consider the case of potential entry and deterrence, $C \in \left(\underset{\sim}{C}, \widetilde{C}\right)$. For a small enough cost of liquidation in period 1, z_1, and a small enough number of incumbent banks, $N < \underline{N}$, then the regulator chooses more transparency than incumbent banks, $\delta_1^R = 0 < \delta_1^*$.*

Proof. See Appendix G. ■

The first case of no entry corresponds to a two-period version of the model in section 2. Both banks and the regulator take into account the cost of opacity in terms of partial runs and costly liquidation in period 1, $\frac{d\pi_1}{d\delta_1} < 0$. However, only the regulator takes into account how opacity reduces the equilibrium deposit rate (via its effect on competitor deposit rates) and thus bank fragility, $\frac{d\rho_1^*}{d\delta_1} < 0$. Proposition 4 shows that, for a low transport cost or a large number of banks, the net effect is maximum transparency in the one-period model and we obtain the same result in the final period, $\delta_2^R = 0 = \delta_2^*$. In period 1, however, there is an additional social benefit of opacity. Lower fragility preserves the marginal surplus from intermediation in period 2, Δ, over the outside option of no intermediation (that we normalize to zero):

$$\Delta(R_1^*) \equiv \pi_2^*(R_1^*, \rho_2^*(R_1^*, N, \delta_2 = 0), \delta_2 = 0) + \rho_2^*(R_1^*, N, \delta_2 = 0) - \frac{\mu}{4N} > 0. \tag{24}$$

When $\frac{\mu}{N}$ is low enough, a sufficient condition for the overall social benefit of opacity (evaluated at full transparency, $\delta_1 = 0$) to exceed the social cost of opacity arises when the expected investment return R_0 is high enough. Intuitively, the marginal surplus matters a lot in this case, inducing the regulator to impose some opacity.

The second case allows for entry and deterrence via opacity. When the liquidation cost in period 1 vanishes, $z_1 \to 0$, the social cost of opacity in terms of fragility in period 1 (discussed in previous paragraph) are muted, $\frac{d\pi_1}{d\delta_1} \to 0$ and $\frac{d\rho_1^*}{d\delta_1} \to 0$. Moreover, some social benefits of transparency are not internalized by banks. Transparency supports entry and reduces transport cost of investors in period 2 (when incumbent banks survive, $R_1 \geqslant R_1^*$) and a positive surplus from intermediation (otherwise). Next, the private benefit of a higher future market share because of deterrence is not a social benefit because a fixed amount of deposits is raised when the market is covered. While entry also increases deposit rates and fragility in period 2, this social cost of transparency is also a private cost taken into account by banks. Since the net social benefit of transparency exceeds the net private benefit, the regulator prefers full transparency over deterrence, $W(\delta_1 = 0) > W(\delta_1 = \delta_D)$, when the opposite ranking arises for incumbent banks, $\Pi_I^*(0) < \Pi_I^*(\delta_D)$. For a low enough number of incumbent banks, the social benefit of transparency and induced entry are high, while the social cost in terms of fragility are low, so the regulator prefers full transparency, $\delta_1^R = 0$.

There are three main take-aways from section 3.3. First, allowing for bank charter value can overturn the policy implications, which shifts from full transparency (Proposition 4) to some opacity (Proposition 9, a)). Second, taking bank entry into account can result in excessive opacity of the banking system (Proposition 9, b)). Third, two key elements of these results are the response of the banking sector (via deposit rates and opacity) that, in turn, depends on the level of bank competition.

4 Conclusion

This paper presents a tractable model in which imperfectly competitive banks choose their deposit rates and opacity levels that in turn determine the probability of a bank run and the entry choice of competitors. Using this model, we evaluate how different recent developments in the banking industry, such as changes in the competitive intensity or in asset opacity, affect bank fragility and welfare. We also derive novel regulatory insights about competition policy and the regulation of bank transparency.

We offer a parsimonious micro-founded setup in which higher bank competition results in higher deposit rates that increase strategic complementarities in withdrawal decisions, resulting in a higher probability of a bank run. We also propose a theory of bank opacity. On the one hand, bank opacity increases partial runs on a solvent bank, lowering expected bank profits. Hence, banks have an incentive to be transparent. On the other hand, opacity reduces the incentives of a potential entrant to enter which raises incumbent bank profits and lowers future competitive intensity and thus reduces future bank fragility. These private incentives for opacity deviate from the social incentives. We characterize circumstances under which welfare-maximizing regulation imposes higher or lower levels of bank transparency.

We conclude with two general take-aways from our analysis. The first is the relevance of bank competition for understanding how different (technological or regulatory) shocks affect the economy. We have shown how the overall effects of these shocks depend on the level of bank competition, and how less competitive environments can react more to shocks than more competitive environments do. The second general take-away is how the endogenous choice of opacity by banks affects bank fragility and can lead to excessively or insufficiently transparent banking systems, motivating regulation. We show how this decision in turn affects the equilibrium competitive structure of the banking system (via entry choices). Interestingly, we find that less competitive banking systems are more prone to be excessively opaque.

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A Proof of Proposition 1

Figure 6 shows the dominance regions if the investment return R were common knowledge. When no funding is withdrawn, $w = 0$, the bank fails when the return is below $\breve{R} \equiv D$, the face value of debt. When all funding is withdrawn, $w = 1$, the bank does not fail when the return exceeds $\widehat{R} \equiv \frac{D}{\psi} > \breve{R}$.

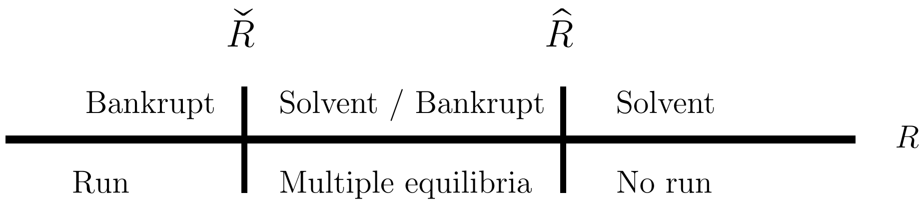

Figure 6: Tripartite classification of investment return (complete information)

Turning to the equilibrium when information about the investment return is incomplete, we solve for the signal and return thresholds (x^*, R^*). Since the insolvency condition is less restrictive than the illiquidity condition, the former is used (Rochet and Vives, 2004). Thus, a **critical mass condition** states that the bank fails at R^*:

$$R^* = [1 + zw(R^*)]\, D, \tag{25}$$

where the face value is chosen at date 0 and the withdrawal proportion at date 1 is

$$w(R) = \Pr\{x_i < x^* | R\} = \begin{cases} 1 & R \leqslant \underset{\sim}{R} = x^* - \frac{\delta}{2} \\ \frac{x^* - R + \delta/2}{\delta} \quad \text{if} & R \in \left(\underset{\sim}{R}, \widetilde{R}\right) \\ 0 & R \geqslant \widetilde{R} = x^* + \frac{\delta}{2} \end{cases}$$

due to the distribution of ϵ_i. The posterior distribution is $R|x_i \sim \mathcal{U}\left[x_i - \frac{\delta}{2}, x_i + \frac{\delta}{2}\right]$ for signals $\underline{R} + \frac{\delta}{2} \equiv \underline{x_i} \leqslant x_i \leqslant \overline{x_i} \equiv \overline{R} - \frac{\delta}{2}$ by Bayesian updating. We study these signals first and 'extreme signals' at the end of this proof. A manager who receives $x_i = x^*$ is indifferent between rolling over and withdrawing (**indifference condition**):

$$c \Pr\{R > R^* | x_i = x^*\} = b \Pr\{R < R^* | x_i = x^*\}. \tag{26}$$

Using the posterior distribution of $R|x^*$, the indifference condition can be expressed as $\gamma = \frac{x^* - R^* + \frac{\delta}{2}}{\delta}$. This result implies the stated failure threshold R^* and signal threshold x^*. Inserting x^* into $\widetilde{R}$ and $\underset{\sim}{R}$ yields the bounds of $w^*(R)$ stated in the main text.

Finally, we consider extremely low and high signals, $x_i \leqslant \underline{x_i}$ and $x_i \geqslant \overline{x_i}$. These imply that the posterior distribution becomes non-uniform since the boundary of the signal is close to the boundary of the investment return. We impose sufficient conditions for our focus on the uniform part of the posterior to be appropriate. In particular, we proceed by imposing a lower bound on α to ensure that a fund manager who receives $x_i = \underline{x_i}$ strictly prefers to withdraw, and a fund manager who receives $x_i = \overline{x_i}$ strictly prefers to roll over. These conditions have to hold for any level of opacity and are most stringent for $\delta = \bar{\delta}$. Using the posterior $R|\underline{x_i} \sim \mathcal{U}\left[\underline{R}, \underline{R} + \delta\right]$, a manager with signal $x_i = \underline{x_i}$ strictly prefers to withdraw if the conditional probability of failure strictly exceeds $1 - \gamma$, which can be expressed as $\frac{\alpha}{2} > (1-\gamma)\bar{\delta} - R^* + R_0$. Similarly, using the posterior $R|\overline{x_i} \sim \mathcal{U}\left[\overline{R} - \delta, \overline{R}\right]$, a manager with $x_i = \overline{x_i}$ strictly prefers to roll over if the conditional probability of failure is strictly below $1-\gamma$, which is expressed as $\frac{\alpha}{2} > \gamma\bar{\delta} + R^* - R_0$. Deriving upper and lower bounds on $R^* - R_0$ and using the bounds on the return to investors derived below, a sufficient lower bound is $\alpha \geqslant \underline{\alpha} \equiv \max\left\{4\gamma\bar{\delta}, \frac{4}{3}(1-\gamma)\bar{\delta} + 2\frac{1+\sqrt{2}}{3}R_0\right\}$, which we impose henceforth.

B Proof of Lemmas 1 and 2

We first derive the bounds on ρ for debt to be risky and partially defaulted upon. If debt is safe, $D^* = \rho$ and $R^* = (1 + \gamma z)\rho$. Thus, for debt to be indeed safe, we require $R^* \leqslant \underline{R}$, which yields the lower bound $\underline{\rho}$. If debt is risky instead, its pricing is $\rho = \frac{\overline{R} - R^*}{\alpha} D^*$, where we used the prior in (1). Substituting in from the failure threshold stated in Proposition 1, we obtain the quadratic equation $(\overline{R} - R^*)R^* = \theta > 0$. The maximum of the left-hand side is reached at $R^{max} = \frac{\overline{R}}{2}$ and yields the value $\frac{\overline{R}^2}{4}$, so a necessary condition is $\overline{R} \geqslant 2\sqrt{\theta}$, which yields $\rho \leqslant \frac{\overline{R}^2}{4\alpha(1+z\gamma)}$. The smaller root of the quadratic equation, which is consistent with higher bank profits lower bank fragility, is given in Lemma 1. Verifying the supposed partial default requires $\underline{R} < R^*$, which yields $\rho > \underline{\rho}$. Note that $R^* < \overline{R}$.

Next, the failure threshold depends on the expected investment return R_0 and the return of investors ρ as follows:

$$\begin{aligned}\frac{dR^*}{dR_0} &= \frac{1}{2} - \frac{\overline{R}}{4\sqrt{\chi}} < 0, \frac{d^2R^*}{dR_0^2} = \frac{\theta}{4\sqrt{\chi}^3} > 0, \frac{d^2R^*}{d\rho\, dR_0} = -\frac{\alpha(1+\gamma z)\overline{R}}{8\sqrt{\chi}^3} < 0, \\ \frac{dR^*}{d\rho} &= \frac{\alpha(1+\gamma z)}{2\sqrt{\chi}} > 0, \frac{d^2R^*}{d\rho^2} = \frac{\alpha(1+\gamma z)}{2\chi}\frac{dR^*}{d\rho} > 0, \frac{d^3R^*}{d\rho^3} = \frac{3\alpha(1+\gamma z)}{2\chi}\frac{d^2R^*}{d\rho^2} > 0.\end{aligned} \tag{27}$$

Expected per-unit profits are $\pi = \frac{1}{\alpha}\int_{R^*}^{\overline{R}} \big[R - D^*(1 + zw(R))\big]dR$. We assume that there are no partial runs for a sufficiently high investment return, $\widetilde{R} < \overline{R}$. Rewriting this yields the sufficient condition $\alpha > \underset{\sim}{\alpha} \equiv \max_\delta \frac{\gamma\delta(R_0-\gamma\delta)}{(1+\gamma z)\rho - \frac{\gamma\delta}{2}}$ assumed henceforth. The expected per-unit profit stated in Lemma 2 follows and changes according to:

$$\frac{d\pi}{d\rho} = -1 + \frac{1+z\gamma}{2}\left[1 - \frac{\overline{R}}{2\sqrt{\chi}}\right] - \frac{\gamma^2 z\delta}{2\alpha(1+z\gamma)}\frac{dR^*}{d\rho} < 0 \tag{28}$$

$$\frac{d^2\pi}{d\rho^2} = -\frac{\alpha(1+z\gamma)^2\overline{R}}{8\sqrt{\chi}^3} - \frac{\gamma^2 z\delta}{2\alpha(1+z\gamma)}\frac{d^2R^*}{d\rho^2} = \frac{\alpha(1+z\gamma)}{2\chi}\frac{d\pi}{d\rho} + \frac{\alpha(1-z^2\gamma^2)}{4\chi} < 0$$

$$\frac{d^3\pi}{d\rho^3} = \frac{3\alpha(1+z\gamma)}{2\chi}\frac{d^2\pi}{d\rho^2} < 0, \quad \frac{d^2\pi}{dR_0\, d\rho} = \frac{1}{4\sqrt{\chi}^3}\left[(1+z\,\gamma)\theta + \frac{\gamma^2 z\delta}{4}\overline{R}\right] > 0$$

$$\frac{d\pi}{dR_0} = \frac{1}{2\alpha}\left(\overline{R} + \sqrt{\chi} + \frac{1}{4\sqrt{\chi}}\overline{R}^2\right) - \frac{\gamma^2 z\delta}{2\alpha(1+z\gamma)}\frac{dR^*}{dR_0} > 0 \tag{29}$$

$$\frac{d^2\pi}{dR_0^2} = \frac{1}{2\alpha}\left(1 + \frac{3\overline{R}}{4\sqrt{\chi}} - \frac{\overline{R}^3}{16\sqrt{\chi}^3}\right) - \frac{\gamma^2 z\delta}{2\alpha(1+z\gamma)}\frac{d^2R^*}{dR_0^2} \tag{30}$$

$$\frac{d\pi}{d\delta} = -\frac{\gamma^2 zR^*}{2\alpha(1+z\gamma)} < 0, \quad \frac{d^2\pi}{d\delta^2} = 0, \quad \frac{d^2\pi}{d\delta d\rho} = -\frac{\gamma^2 z}{2\alpha(1+z\gamma)}\frac{dR^*}{d\rho} < 0 \tag{31}$$

$$\frac{d^3\pi}{d\delta d\rho^2} = -\frac{\gamma^2 z}{2\alpha(1+z\gamma)}\frac{d^2R^*}{d\rho^2} = \frac{\alpha(1+z\gamma)}{2\chi}\frac{d^2\pi}{d\delta d\rho} = -\frac{\gamma^2 z(1+z\gamma)\alpha}{8\sqrt{\chi}^3} < 0. \tag{32}$$

C Proof of Propositions 2 – 3

We solve the Salop model of competition at date 0. The return of some investor k from depositing with bank j is $\rho^j - \mu d_k^j$, where d_k is distance. For a fully covered market, $\mu \leqslant \bar{\mu}$, we can focus on the two banks nearest to investor k, whose distance is d_k and $\frac{1}{N} - d_k$ as banks are equidistant on the unit circle (Figure 1). Hence, the location at which investor k is indifferent between going to either bank is $d_k^* = \frac{\rho^1 - \rho^2}{2\mu} + \frac{1}{2N}$. Total funding supply comes from both sides relative to a bank's location on the circle, so the amount of funding is $h^j = 2d_k^* = \frac{\rho^j - \rho^{-j}}{\mu} + \frac{1}{N}$, which is independent of the opacity choice, $\frac{dh^j}{d\delta^j} = 0$, but increases in the return to investors offered by bank j, $\frac{dh^j}{d\rho^j} = \frac{1}{\mu} > 0$.

Using a Lagrangian approach, one can show that the first derivative of the Lagrangian with respect to ρ_j evaluated at $\rho_j = \overline{\rho}$ is negative, so the bank always chooses $\rho_j^* < \overline{\rho}$. Hence, the interior solution is given by the first-order condition of the unconstrained problem. Recall that total expected profits are Π^j and per-unit expected profits are π^j. We have:

$$\frac{d\Pi^j}{d\delta^j} = \frac{dh^j}{d\delta^j}\pi^j + h^j \frac{d\pi^j}{d\delta^j} < 0, \qquad \frac{d\Pi^j}{d\rho^j} = \frac{dh^j}{d\rho^j}\pi^j + h^j \frac{d\pi^j}{d\rho^j}. \tag{33}$$

Thus, $\delta^j = \delta^* = \underline{\delta}$ for all j. The first-order condition (FOC) for the expected return evaluated at the symmetric equilibrium, $h^j = h^* = \frac{1}{N}$, is given in (9). The SOC is $\frac{d^2\Pi}{d\rho^2} = \frac{2}{\mu}\frac{d\pi}{d\rho} + h\frac{d^2\pi}{d\rho^2} < 0$, so we have a unique solution and a global maximum.

We turn to comparative statics. For the first part of the proposition, note that $\frac{d^2\Pi^j}{d\rho^j dN} = -\frac{d\pi^j}{d\rho^j}\frac{1}{N^2} > 0$, so we obtain $\frac{d\rho^*}{dN} > 0$ from the implicit function theorem (IFT). Thus, $\frac{dR^*}{dN} > 0$ follows from $\frac{dR^*}{d\rho} > 0$ (Lemma 1). Similarly, $\left.\frac{d^2\Pi^j}{d\rho^j d\mu}\right|_{\rho=\rho^*} = -\frac{1}{\mu^2}\pi^j < 0$, so we obtain $\frac{d\rho^*}{d\mu} < 0$ from the IFT and $\frac{dR^*}{d\mu} < 0$ follows. Next, using the envelope theorem (ET), we have $\frac{d\Pi^*}{dN} = -\frac{\pi^*}{N^2} < 0$. The second part considers changes in $\underline{\delta}$. The IFT implies $\frac{d\rho^*}{d\underline{\delta}} < 0$ because $\frac{d^2\Pi}{d\rho d\delta} = \frac{1}{\mu}\frac{d\pi}{d\delta} + h\frac{d^2\pi}{d\rho d\delta} < 0$. Thus, $\frac{dR^*}{d\underline{\delta}} < 0$ again follows from Lemma 1. Using the ET again, we have $\frac{d\Pi^*}{d\underline{\delta}} = \frac{1}{N}\frac{d\pi}{d\delta} < 0$. For $N \to \infty$, we have

$\rho^* \to \overline{\rho}$. Evaluating the comparative static $\frac{d\rho^*}{d\underline{\delta}} = -\frac{\pi_\delta + \frac{\mu}{N}\pi_{\rho\delta}}{2\pi_\rho + \frac{\mu}{N}\pi_{\rho\rho}} < 0$ in this limit, we obtain zero as the numerator converge to a constant, while the denominator converges to infinity. The third part considers changes in R_0. The IFT implies $\frac{d\rho^*}{dR_0} > 0$ because $\frac{d^2\Pi}{d\rho dR_0} = \frac{1}{\mu}\frac{d\pi}{dR_0} + h\frac{d^2\pi}{d\rho dR_0} > 0$. Using the ET again, we have $\frac{d\Pi^*}{dR_0} = \frac{1}{N}\frac{d\pi}{dR_0} > 0$. For the fourth part of the proposition, we modify our basic setup by introducing a non-pecuniary cost of lending λ. The expected profits change to $\Pi_\lambda = h\left[\pi - \lambda\right]$, where we drop the bank index again. Thus, $\frac{d\Pi_\lambda}{d\delta} = \frac{d\Pi}{d\delta} < 0$ and $\delta^* = \underline{\delta}$. Moreover, $\frac{d\Pi_\lambda}{d\rho} = \frac{d\Pi}{d\rho} - \frac{\lambda}{\mu}$, so $\frac{d^2\Pi_\lambda}{d\rho^2} = \frac{d^2\Pi}{d\rho^2} < 0$ and $\frac{d^2\Pi_\lambda}{d\rho d\lambda} = -\frac{1}{\mu} < 0$. By the IFT, $\frac{d\rho^*}{d\lambda} < 0$ and $\rho^*_\lambda < \rho^*$. The result on fragility follows from Lemma 1 and Proposition 1.

D Proof of Proposition 4

We use the following expressions for partial derivatives, e.g. $\pi_\rho \equiv \frac{d\pi}{d\rho}$, $\pi_{\rho\rho} \equiv \frac{d^2\pi}{d\rho^2}$, as given in Appendix B, and the derivatives $\frac{d\rho^*}{dN} = \frac{\mu\pi_\rho}{2N^2\pi_\rho + \mu N\pi_{\rho\rho}} > 0$ and $\frac{d\rho^*}{d\underline{\delta}} < 0$ (see Appendix C). Starting with competition policy, the first- and second-order conditions are:

$$\frac{dW}{dN} = (1+\pi_\rho)\frac{d\rho^*}{dN} - \frac{dTC}{dN} = \frac{1}{4}\frac{d\rho^*}{dN}\left[6 + 4\pi_\rho + \frac{\mu}{N}\frac{\pi_{\rho\rho}}{\pi_\rho}\right], \tag{34}$$

$$\left.\frac{d^2W}{dN^2}\right|_{N=N^*} = \frac{1}{4\pi_\rho}\frac{d\rho^*}{dN}\left[-\frac{\mu}{N^2}\pi_{\rho\rho} + \frac{d\rho^*}{dN}\left(6 + 8\pi_\rho + \frac{\mu}{N}\pi_{\rho\rho\rho}\right)\right]. \tag{35}$$

Therefore, a sufficient condition for a local welfare maximum is $\frac{d\rho^*}{dN}\left(6 + 8\pi_\rho + \frac{\mu}{N}\pi_{\rho\rho\rho}\right) \geqslant \frac{\mu}{N^2}\pi_{\rho\rho}$. Using the first-order condition for N^*, $6 + 4\pi_\rho + \frac{\mu}{N}\frac{\pi_{\rho\rho}}{\pi_\rho} = 0$, this sufficient condition can be expressed as $\frac{3}{2} + 2\pi_\rho + \frac{\mu}{4N}\pi_{\rho\rho\rho} > \frac{N}{2\mu}\pi_\rho(1+\pi_\rho)(3+2\pi_\rho)$. This condition holds for small enough μ if $3 + 2\pi_\rho < 0$. Since $\delta \geqslant 0$, a sufficient condition for the latter condition is $\frac{\overline{R}^2}{4\alpha(1+z\gamma)}\frac{3+2z\gamma}{(2+z\gamma)^2} < \rho^*$. Note that $\frac{\overline{R}^2}{4\alpha(1+z\gamma)}\frac{3+2z\gamma}{(2+z\gamma)^2} < \overline{\rho}$. Given our focus on $\rho^* > \underline{\rho}$ (Lemma 1), the additional bound on ρ^* is slack if $\frac{\overline{R}^2}{4\alpha\underline{R}} \leqslant \frac{(2+\gamma z)^2}{3+2\gamma z}$, which holds for high enough γz. The solution is interior because $\left.\frac{dW}{dN}\right|_{N=0} = \infty > 0$

and $\frac{dW}{dN}\big|_{N\to\infty} < 0$ (when evaluated at a N high enough such that $\rho^* \to \overline{\rho}$).

Turning to opacity regulation, the first-order condition is:

$$\frac{dW}{d\underset{\sim}{\delta}} = \frac{N(\pi_\rho - 1)\pi_\delta + \mu\pi_\delta\pi_{\rho\rho} - \mu(1+\pi_\rho)\pi_{\rho\delta}}{2N\pi_\rho + \mu\pi_{\rho\rho}}. \tag{36}$$

Thus, $\underset{\sim}{\delta}^* = \underline{\delta}$ if $\frac{dW}{d\underset{\sim}{\delta}} < 0$, which can be written as $\pi_\rho - 1 + \frac{\mu}{N}\pi_{\rho\rho} < \frac{\mu}{N}(1+\pi_\rho)\frac{\pi_{\rho\delta}}{\pi_\delta}$. A low enough μ or high enough N suffice for this inequality to hold because $\pi_\rho < -1$.

E Proof of Proposition 5

To shed some light on the posterior g, consider for illustration the case of failure of incumbent banks, so $\underline{R}_1 \leqslant R_1 \leqslant R_1^*$. In this case, the potential entrant infers that $R_1 = \underline{R_1}$ after the worst possible signal, $x_E = \underline{R}_1 - \frac{\delta_J}{2}$ and that $R_1 = R_1^*$ after the best possible signal, $x_E = R_1^* + \frac{\delta_J}{2}$. For intermediate signals, $\underline{R}_1 + \frac{\delta_J}{2} \leqslant x_E \leqslant R_1^* - \frac{\delta_J}{2}$, the posterior distribution is uniform, $R_1|x_E \sim \mathcal{U}[x_E - \frac{\delta_J}{2}, x_E + \frac{\delta_J}{2}]$.

The bounds on the fix cost imply entry after the best-possible or worst-possible profits in period 2 for the entrant. These profits arise when the entrant infers that the investment return is certainly $\underline{R}_1$, R_1^*, or $\overline{R}_1$. That is, after the failure (F) of incumbent banks, we have

$$\underset{\sim}{F} \equiv \pi_{2M}^*(\underline{R}_1) < \pi_{2M}^*(R_1^*) \equiv \widetilde{F}, \tag{37}$$

and after the survival of incumbent banks we have

$$\underline{F} \equiv \frac{\pi_{2S}^*(R_1^*)}{N+1} < \frac{\pi_{2S}^*(\overline{R}_1)}{N+1} \equiv \overline{F}, \tag{38}$$

because of the strict monotonicity of Π_2^* in R_1 (see Proposition 3).

The equilibrium is characterized by a threshold strategy. E enters whenever $F \leqslant V$, where the value of entering, V, increases in the signal x_E for two reasons. First, a higher signal x_E leads to a more favorable posterior, $R_1|x_E$, in the first-order stochastic dominance sense. Second, the potential entrant assigns a higher expected profit to these higher realizations of the investment return (because $\frac{d\Pi_2^*}{dR_1} > 0$). Taken together, we have $\frac{dV}{x_E} > 0$, so a unique threshold x_E^* exists for intermediate fix costs. (Note that this argument applies irrespective of the survival of incumbent banks.)

F Proof of Propositions 7

For $C \geqslant \widetilde{C}$, then E does not follow the market and thus does not enter irrespective of incumbent banks opacity choices. Then there is no benefit for incumbent banks to be opaque and $\delta_1^* = 0$, as the cost of opacity is strictly positive. For $F \notin \left(\underline{F}, \overline{F}\right)$ and $F \notin \left(\underset{\sim}{F}, \widetilde{F}\right)$, we have $\underset{\sim}{C} = \widetilde{C}$. For $C < \underset{\sim}{C}$, then E always follows the market but its choice to enter is again independent of incumbent banks opacity choices, so $\delta_1^* = 0$.

For $F \in \left(\underline{F}, \overline{F}\right)$ or $F \in \left(\underset{\sim}{F}, \widetilde{F}\right)$ or both, we have $\underset{\sim}{C} < \widetilde{C}$ and for $\underset{\sim}{C} < C < \widetilde{C}$, the incumbent bank's choices of opacity affect the choices of the entrant to follow the market and to enter. We wish to establish conditions sufficient for incumbent banks choosing some opacity, $\delta_1^* > 0$. Comparing the case of deterrence (δ_D) to the case of full transparency ($\delta = 0$), the benefit of deterrence is the lower future competition and higher charter value because E does not follow the market. When $\delta = 0$ and $\underset{\sim}{C} < C < \widetilde{C}$, E enters whenever $R_1 \geqslant \widehat{R}_1$. An incumbent bank only considers $E's$ entry choice and its effect on the charter value upon survival of incumbent banks.

Thus, the benefit of opacity and its lower bound are:

$$\frac{1}{N}\int_{\widehat{R}_1}^{\overline{R}_1}\left[\frac{\pi_2^*(R_1,\rho_2^*(R_1,N))}{N} - \frac{\pi_2^*(R_1,\rho_2^*(R_1,N+1))}{N+1}\right]\frac{dR_1}{\alpha} \geqslant \frac{1}{N^2(N+1)}\int_{\widehat{R}_1}^{\overline{R}_1}\pi_2^*(R_1,\rho_2^*(R_1,N))\frac{dR_1}{\alpha}, \tag{39}$$

because $\Pr\{\delta_1^j = \delta_1^J\} = \frac{1}{N}$ and $\rho_2^*(R_1, N+1) > \rho_2^*(R_1, N)$. Note that $\frac{1}{N+1}\int_{\hat{R}_1}^{\overline{R}_1} \pi_2^*(R_1, \rho_2^*(R_1, N))\frac{dR_1}{\alpha}$ decreases int the number of incumbent banks, both because of a lower market share and a higher deposit rate. The cost of deterrence is:

$$h_1^j \left[\pi_1^*(\delta_1 = 0, \rho_1^j) - \pi_1^*(\delta_D, \rho_1^j)\right] = h_1^j \frac{\gamma^2 z R_1^j(\rho_1^j)}{2\alpha(1 + z\gamma)}\delta_D. \tag{40}$$

Taken together, there exist an upper bound $\overline{N}$ at which the benefit of deterrence (opacity) exceeds its cost.

G Proof of Proposition 9

Consider case (a) without entry: a situation in which the potential entrant does not follow the market in the unregulated equilibrium. Welfare in period 1 is $W_1 = \pi_1^* + \rho_1^* - TC_1$ and welfare in period 2 is

$$W_2 = \int_{\underline{R}_1}^{R_1^*} 0\frac{dR_1}{\alpha} + \int_{R_1^*}^{\overline{R}_1} \left(\pi_2^*(R_1, \rho_2^*(R_1, N, \delta_2), \delta_2) + \rho_2^* - \frac{\mu}{4N}\right)\frac{dR_1}{\alpha}. \tag{41}$$

The first-order condition with respect to δ_1 is

$$\frac{dW}{d\delta_1} = \frac{d\pi_1}{d\delta_1} + \frac{d\rho_1^*}{d\delta_1}\left[1 + \frac{d\pi_1}{d\rho_1} - \frac{\Delta(R_1^*)}{\alpha}\frac{dR_1^*}{d\rho_1^*}\right]. \tag{42}$$

To establish that $\delta_1^R > 0$, it suffices to show that $\left.\frac{dW}{d\delta_1}\right|_{\delta_1=0} > 0$. A sufficient condition for this when using $\mu \to 0$ is $\frac{d\pi_1}{d\rho_1} - 1 + \frac{\Delta(1+z\gamma)}{2\sqrt{\chi_1}} > 0$. Since $\chi_1 \leqslant \frac{\overline{R}_1^2}{4}$, a simpler and tighter sufficient condition is

$$R_0 \geqslant \alpha\frac{5 - 3z\gamma}{1 + z\gamma}, \tag{43}$$

which holds for R_0 high enough. Case (b) can be derived from the argument and expressions in the main text.