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Dividend Payouts and Rollover Crises*

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Abstract

We study dividend payouts when banks face coordination-based rollover crises. Banks in the model can use dividends to both risk shift and signal their available liquidity to short-term lenders, thus, influencing the lenders' actions. In the unique equilibrium both channels induce banks to pay higher dividends than in the absence of a rollover crisis. In our model banks exert an informational externality on other banks via the inferences and actions of lenders. Optimal dividend regulation that corrects this externality and promote financial stability includes a binding cap on dividends. We also discuss testable implications of our theory. (*JEL* G01, G21, G35)

The dividend policies of banks received much attention in the wake of the 2007–2008 financial crisis. The U.S. banking sector maintained large dividend payouts throughout 2007 and 2008, even as losses were increasing rapidly (Acharya et al., 2009), so that aggregate dividends paid by U.S. banks in 2008 exceeded their aggregate earnings by about 30% (Floyd et al., 2015). One explanation for banks' dividend policies during the early stages of the financial crisis is that they reflected a form of moral hazard. Scharfstein and Stein (2008) argue that banks engaged in "risk shifting" and

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that their dividend policies were "... an attempt by shareholders to beat creditors out the door." Another explanation focuses on a signaling role of dividends in response to rollover risk. Acharya et al. (2011) suggest that U.S. banks were worried that cutting dividends could induce a run by their short-term creditors.

At first glance these two views seem incompatible. After all, if high dividend payouts are associated with bank insiders "beating creditors out the door," then they are also bad news about the bank's ability to survive a run. Consequently, paying dividends in the middle of a rollover crisis should exacerbate rather than soften a run by short-term creditors. Second, and related to the first point, while the role of dividends as a (positive) signal of future profitability has been well established (e.g., Bhattacharya 1979), the question of the role of dividends as a signal of *available liquidity* in the midst of a rollover crisis has received far less attention. This is worrying, because a proper understanding of that role is central for the design of dividend regulation policies that can improve financial stability.

In this paper, we examine theoretically the role of dividends when banks are subject to coordination-based rollover crises or runs. We show that higher dividends can (in equilibrium) be interpreted as good news about available liquidity even if banks can (and in some cases do) use them to engage in risk shifting. Moreover, the interaction between signaling and coordination *reverses* the signaling incentives relative to the established view of dividend signaling: the *lower*-quality types overpay dividends in an attempt to mimic higher-quality types, rather than higher-quality types overpaying dividends in order to separate from lower types. Finally, when dividends signal available liquidity, banks' dividend choices fail to internalize an informational externality that operates through the inferences and actions of lenders. In that case a cap on dividends that forces surviving banks to pool on a common dividend level improves financial stability.

We consider a bank that is financed by a continuum of short-term lenders that face a coordination problem when rolling over maturing debt.[1] If a sufficient share of lenders refuse to roll over (run, for short), then the bank does not have enough liquidity to repay all lenders and is forced to fail. In that case, an individual lender is better off running than rolling over. At an initial stage, prior to the rollover episode, the bank (owner) chooses a dividend payout. It derives a

[1] Even though we motivate and frame our analysis in the context of banking and dividend payouts, the implications are applicable more generally to any firm subject to rollover risk and that can take an action that has a direct negative effect on its liquidity position but also conveys information to lenders. See Section 6 for a further discussion.

positive payoff from consuming the dividends but also incurs a reduction in the liquidity available to meet the demands of running lenders and in the value of bank assets, given successful rollover. Therefore, a bank that expects an unsuccessful rollover has an incentive to pay out all available liquidity in dividends. Additionally, and consistent with the existing dividend signaling literature, we assume that (conditional on surviving the rollover episode) the marginal cost of liquidity is lower for higher-quality banks.

We introduce dividend signaling to this environment by assuming that the lenders observe the bank's dividends and make their rollover decisions based on the inferences they draw about the bank's type and its available liquidity. Therefore, the dividend choice of the bank acts as an endogenous signal about the bank's probability of surviving the run. To ensure equilibrium uniqueness, we also assume that lenders observe the dividend with small idiosyncratic noise.[2] With rollover risk, the ability to pay dividends means that some banks that can survive the rollover instead choose to "beat creditors out the door" by paying out all available liquidity as dividends. We call this direct negative effect on survival the *resilience effect* of dividends. However, dividends also convey information, so they indirectly affect the incentives of short-term lenders to roll over their debt. We call this second indirect effect on survival the *signaling effect*.

Whether the signaling effect reinforces or counters the resilience effect depends on whether higher dividends are good or bad news about the bank's type and its available liquidity. Nevertheless, how lenders interpret a higher dividend signal may be endogenous to the behavior of banks, thus, giving rise to multiple equilibria (Angeletos et al., 2006). We show conditions under which higher dividends are interpreted as good news and, moreover, no equilibria exist in which higher dividends are interpreted as bad news. Our conditions are a simple strengthening of the assumptions on the existence of dominance regions familiar from global games. Specifically, if a sufficiently large share of low-quality banks always fail and pay no dividends, then it is possible for dividends to signal good news about survival in equilibrium. Intuitively, even if some failing banks are paying higher dividends than some surviving banks, if lenders' priors are such that, "on average," failing banks are associated with limited liquidity and a low dividend payout, then higher dividends can be interpreted as good news in equilibrium.

[2] If dividends are common knowledge, the economy trivially admits multiple equilibria. Introducing a small amount of private noise in the observation of dividends removes the common knowledge aspect from the dividend signal. Such private noise can be interpreted as the result of limited attention (Sims (2003); Myatt and Wallace (2012)).

Under these conditions, if lenders observe dividend signals with sufficiently small noise, then the signaling effect dominates the resilience effect and paying dividends can actually *decrease* the total liquidity outflow that the bank experiences. Intuitively, the high signal precision means that the dividend choice of the bank affects the inference and actions of many lenders, so that a reduction in the liquidity outflow due to a lower dividend payout is dominated by the increase in the run size. One implication of facing such a trade-off is that banks would never choose a dividend that leaves them on the downward sloping part of the liquidity outflow schedule. Therefore, banks choose to distort their dividends up to a level where the total liquidity outflow is again increasing in dividends. At that level any additional benefits associated with dividend signaling are small and so a large set of (surviving) banks choose similar dividend payouts. Therefore, the equilibrium outcome of a strong signaling effect is a dividend policy that features both *higher* dividend payouts and a *lower* sensitivity of dividends to the bank type compared to the dividend policy absent rollover.

Unlike dividend signaling about future profitability, in the case with dividend signaling about available liquidity and rollover risk the banks that distort their dividends the most in equilibrium are low type (surviving) banks rather than high types. The intuition for this reversal in signaling incentives is simple: In the presence of a coordination-based rollover episode, the lower-quality (surviving) banks, which are more exposed to the rollover, have stronger incentives to signal that they have sufficient available liquidity. In contrast when signaling about future profitability, it is higher types that have stronger incentives to distort their dividends up and separate from lower types.

As lenders observe bank dividends with smaller and smaller noise, the strengthening of the signaling effect relative to the resilience effect *lowers* the bank failure cutoff – the value of fundamentals at which a bank is indifferent between failing and surviving. We show this interesting feature of the signaling effect in the limiting case in which the noise vanishes and lenders are almost perfectly coordinated. In that case for a bank that is subject to a run, even a marginal increase in dividends ends up inducing all lenders to choose to roll over.[3]

Despite this intriguing effect of dividend signaling on the failure cutoff, we show that from the point of view of a regulator with preferences for minimizing the bank failure cutoff, the banks'

[3] Also, in the limit, incentives to compress dividend payouts are so strong for surviving banks around the failure threshold so that, locally, banks pool their dividend payouts.

equilibrium dividend payouts can be inefficiently high during a rollover episode. There are two sources of inefficiencies: the risk shifting that banks may engage in, which mechanically raises the failure cutoff, and an informational externality that banks fail to take into account when choosing their dividends. We show that the optimal dividend policy in a rollover episode consists of a common dividend payout for all surviving banks. This effective dividend cap pools all surviving banks together, which decreases the dividend signal cutoff at which a lender is indifferent between running and rolling over. At the same time more failing banks are forced to pay zero dividends under the optimal dividend policy. Intuitively, the regulator wants failing and surviving banks to pay sufficiently distinct dividends, so that, given the noise in lender observations, the lenders can identify failing from surviving banks more easily. Therefore, with dividend signaling, a binding cap on dividends is a more effective macroprudential tool compared to a complete dividend restriction (Goodhart et al., 2010).

Finally, we discuss the empirical relevance of our theory. We test two salient implications of the signaling effect, namely that it leads to a dividend policy that features both *higher* dividend payouts and a *lower* sensitivity of dividends to fundamentals compared to the dividend policy absent rollover. We also provide a test to identify the signaling effect from the resilience effect, leveraging on the observation that for banks with relatively high fundamentals, higher exposure to rollover risk moves dividends in opposite directions under the two effects. We document two novel facts consistent with our model. Consistent with the first implication, we show that surviving banks which were more reliant on short-term funding prior to the 2007-2008 financial crisis paid higher dividends during the crisis. Also, consistent with the second implication, we show that, across industries, dividend payouts are less variable in industries that are more reliant on short-term funding.

1 Related Literature

Our paper is related to the growing literature on bank dividend payouts, particularly during a financial crisis, and the optimal policy response to those (Acharya et al. (2016), Floyd et al. (2015), Hirtle (2014), Cziraki et al. (2016)).Acharya et al. (2016) study a model of bank dividend payouts, in which risk shifting by the bank equity holders due to a possible low future franchise value influences bank dividend payouts. When banks are linked through an inter-bank market, this risk shifting interacts with an additional dividend externality that may trigger a systemic crisis. Our modeling approach complements this important framework by studying the informational role of dividends when banks are exposed to a coordination-based run. We argue that with dividend signaling there is an additional informational externality that banks fail to internalize in addition to the risk-shifting inefficiencies. However, rather than arising from direct spillovers via bank linkages, in our model, the informational externality arises through the inference of lenders and their rollover decisions.

The informational role of dividends relates our model to the seminal paper on dividend signaling about future profitability of Bhattacharya (1979) and a large subsequent literature (Miller and Rock (1985), John and Williams (1985), Hausch and Seward (1993), Guttman et al. (2010), Baker et al. (2016)). Bhattacharya (1979) argues that with asymmetric information about future profitability, if the marginal cost of paying dividends is decreasing in the firm's type (so there is single crossing), then dividends can serve as a signal to outside investors that separates higher from lower profitability firms. In contrast, we show that with coordination-based runs the signaling incentives are completely reversed. Specifically, it is the lower-quality (surviving) banks that have the stronger signaling incentives. Therefore, despite single crossing, the interaction of the coordination-based run and signaling in our framework pushes the banks that signal through dividends toward *pooling* rather than toward separation in equilibrium.

The reduced sensitivity of dividends to fundamentals that results from these dividend signaling incentives relates the paper to the partial pooling result of Guttman et al. (2010). However, there are several important differences. Conceptually, the reduced sensitivity of dividends in our framework is the unique outcome of the signaling incentives imposed by the underlying coordination game and is not driven by out-of-equilibrium beliefs. Consequently, our model makes new testable predictions about when dividends should be expected to be less sensitive to fundamentals. Finally, the informational externality that we uncover in our framework is a unique feature of the interaction between dividend signaling and coordination.

Our paper is related to the large literature on global games of regime change (e.g., Carlsson and van Damme (1993); Morris and Shin (1998)) and, particularly, to global game models of bank runs (Goldstein and Pauzner (2005); Rochet and Vives (2004)) and rollover crises (Morris and

Shin, 2004).[4] We contribute to this important literature by analyzing how banks use their dividend payouts to manage the rollover crisis. In addition, while most of these models assume an exogenous information structure for lenders or an exogenous resilience level for banks, both the information structure of lenders and the resilience level of banks are endogenous in our model. This endogenous information structure relates our paper to a growing literature on information acquisition in global games (He and Manela (2016); Szkup and Trevino (2015); Yang (2015); Ahnert and Kakhbod (2017)) and also to papers studying the effects of information quality and transparency on stability (Iachan and Nenov (2015); Moreno and Takalo (2016); Ahnert and Martinez-Miera (2019)).

Our paper is particularly related to models of signaling in global games. Angeletos et al. (2006) and Angeletos and Pavan (2013) consider a regime-change game in which a policy maker can take a costly policy action to influence the cost of attacking. They show that there exist multiple equilibria, depending on how the policy action is interpreted. For example, there always exists an "inactive-policy" equilibrium in which agents ignore the policy action when choosing to attack and the policy maker anticipates this and does not intervene. There also exists an "active-policy" equilibrium in which only intermediate types choose to intervene. In contrast, there is a unique equilibrium interpretation of dividend signals in our framework. One reason for this is that the bank enjoys a direct utility from paying dividends, which rules out any "inactive-policy" type equilibria. In addition, the dividend action has no direct effect on the cost of attacking and, rather, affects the lenders' actions only through their inferences. Finally, because dividends have a large impact on lenders' inferences for all bank types, all surviving banks signal through dividends in equilibrium.

Edmond (2013) studies a model of regime-change in which the regime can engage in costly manipulation of the private information of agents considering staging a revolution. In equilibrium, agents try to infer the true type of the regime given the signals they observe. His framework features a unique equilibrium. As in Edmond (2013), our economy also admits a unique equilibrium despite the signaling effect of the bank's actions and the endogenous information structure that arises. However, while he studies how a regime engages in costly manipulation of agents' private signals about its type (i.e., propaganda), we study how a bank optimally chooses its dividend policy when faced with a coordination-based run. Also, in our framework, the direct effect of paying out dividends is to weaken the ability of the bank to survive the rollover episode. In contrast, in

[4] Vives (2014) uses a global games model of bank runs to analyze liquidity regulation.

Edmond (2013) the regime's action cannot be destabilizing.

Goldstein and Huang (2016a) study how a regime can increase the probability of survival by committing to abandoning the status quo for some fundamentals. However, the information transmission that takes place in their model, and which ends up stabilizing the regime, is more in the spirit of the Bayesian persuasion literature (Kamenica and Gentzkow, 2011) rather than through sending a costly signal.[5]

Finally, our focus on the link between dividend signaling and financial stability relates our paper to the recent literature on the effects of information disclosure on financial stability (for instance, from stress-testing as in Bouvard et al. (2015), Faria-e Castro et al. (2016), and Goldstein and Leitner (2018) or credit ratings as in Goldstein and Huang (2016b) and Holden et al. (2018)). In contrast to many of these papers, we focus on information generated by one of the parties in the rollover game, which maximizes its own payoff, rather than a third party (i.e., a regulator) who has an explicit objective to improve financial stability.

2 Model

Consider an economy with three periods, $t \in \{0, 1, 2\}$. There is a bank with an exogenously given balance sheet. At $t = 0$ the bank (owner) chooses how much to pay in dividends from the bank's total available liquidity. The bank has a continuum of short-term creditors who make rollover decisions on their debt at $t = 1$. The bank uses its total remaining available liquidity (net of the $t = 0$ dividend payout) to repay creditors who refuse to roll over. The bank fails if it cannot pay all creditors that refuse to roll over. At $t = 2$ creditors obtain payoffs based on their actions and the outcome of the rollover episode, and the bank owner obtains any remaining equity value. Figure 1 illustrates a summary of the timing of events. We now provide the details for this environment.

[Figure 1 here.]

[5]Shapiro and Skeie (2015) also study a model of signaling and banking crises. However, in their paper the sender of the costly signal is a policy maker rather than the bank itself. Also, runs on banks are not due to a coordination failure like in our framework.

2.1 The bank

2.1.1 Assets. At the beginning of $t = 0$, the bank holds a portfolio of assets that deliver payoffs at $t = 2$. At $t = 0$ and $t = 1$ the bank can convert part of these assets into liquidity by selling or borrowing against them as collateral. We call the maximum liquidity the bank can obtain in this way, its total available liquidity and denote it by $\bar{\ell}$. The bank uses liquidity to make a dividend payment d at $t = 0$ and to meet redemptions by short-term creditors at $t = 1$. We let l equal the sum of the dividend payment and the redemptions by short-term lenders that the bank chooses to meet. Therefore, $l \leq \bar{\ell}$ is the total liquidity outflow from the bank at the end of $t = 1$.

We denote the $t = 2$ value of the remaining bank assets, given successful rollover at $t = 1$, by $v(\theta, l)$. Here, $\theta \in \mathbb{R}$ parametrizes the portfolio quality of the bank (its "fundamentals"), and l is the liquidity outflow. We assume that $v(\theta, l)$ is twice continuously differentiable, with $v_\theta > 0$, and $v_l < 0$. Therefore, the value of the bank's assets is increasing in θ (so higher θ means stronger fundamentals). It is also decreasing in l, because obtaining liquidity shrinks the asset portfolio at $t = 2$. We assume that the total available liquidity $\bar{\ell}(\theta)$ satisfies

$$v\left(\theta, \bar{\ell}(\theta)\right) = \kappa \tag{1}$$

for some $\kappa \geq 0$. By the properties of v, $\bar{\ell}(\theta)$ is strictly increasing in θ (i.e., $\bar{\ell}' = -v_\theta / v_l > 0$). Therefore, banks with better fundamentals also have more available liquidity to pay dividends and meet redemptions by short-term lenders. In addition to these assumptions, we let $v_{ll} < 0$, so that the marginal cost of liquidity is strictly increasing. Also, we assume that $v_{l\theta} > 0$, so that the marginal cost of liquidity is lower for higher θ banks. Finally, we assume

Assumption B1. $\frac{v_\theta(\theta,l)}{-v_l(\theta,l)}$ is strictly decreasing in l.

We briefly discuss some of our assumptions on v and their implications for the analysis and for the empirical relevance of the model. The assumption $v_{l\theta} > 0$ is a single crossing condition that is often made in signaling models (e.g., Bhattacharya (1979)). In standard signaling environments this assumption implies a positive link between dividends and future profitability, consistent with empirical evidence (see, e.g., Nissim and Ziv (2001); Cziraki et al. (2016)). While this condition is only sufficient for our results, as we discuss in Section 3.2.5, we maintain it in most of the analysis to facilitate comparison with the existing dividend signaling literature. To provide additional intuition for the single crossing condition and the portfolio restrictions that it implies, in the Online Appendix we present one possible microfoundation for v that gives rise to this condition (and the other conditions on v). Our example is a continuous and "smoothed" version of the asset portfolios commonly assumed in banking models, where assets are grouped into discrete asset classes based on their liquidity. Finally, Assumption B1 ensures that a bank's incentives to fully liquidate its portfolio and pay it out as dividends at $t = 0$ are *decreasing* in θ.[6]

2.1.2 Liabilities and bank payoff. The $t = 0$ liabilities of the bank consist of dispersed short-term debt that matures at $t = 1$ with a total face of $b > 0$.[7] The short-term debt is held by a unit-measure continuum of lenders, who at $t = 1$ choose whether to redeem it or roll it over into $t = 2$. The bank may fail at $t = 1$, if it does not have enough liquidity to meet redemptions by short-term lenders. Specifically, if A denotes the fraction of short-term lenders that refuse to roll over, then the bank can survive iff

$$\bar{\ell} - d \geq bA. \tag{2}$$

We assume that the expected $t = 2$ payoff of the bank owner conditional on survival is $v(\theta, l)$. Hence, conditional on successful rollover, there is no conflict of interest between the (remaining) lenders and the bank owner, because the bank owner cares about the full residual value of the bank's assets. Therefore, we can write the bank owner's $t = 0$ payoff as

$$W(\theta, d, A) = \lambda d + \mathbf{1}_{\left\{\bar{\ell} - d \geq bA\right\}} v(\theta, d + bA), \tag{3}$$

where $\mathbf{1}_{\left\{\bar{\ell} - d \geq bA\right\}}$ is an indicator for whether the bank survives the rollover episode at $t = 1$, and $\lambda > 0$ parametrizes the degree to which the bank owner cares about paying out a dividend at $t = 0$

[6] To see how this assumption relates to our other assumptions about v, we differentiate the logarithm of $v_\theta / (-v_l)$ with respect to l and rearrange to obtain the following condition that is equivalent to Assumption B1: $v_{l\theta} < v_\theta \frac{v_{ll}}{v_l}$. Therefore, one way to interpret Assumption B1 is that it puts an upper bound on $v_{l\theta}$, so that even though the marginal cost of liquidity is lower for higher θ banks, it remains increasing in the amount of liquidity that the bank extracts.

[7] For simplicity, we disregard long-term debt. Long-term liabilities will decrease the equity payout to the bank owner conditional on bank survival and will strengthen the owner's incentives to liquidate early. See also footnote 8.

versus waiting for assets to mature. Therefore, there is a conflict of interest at $t = 0$, because the dividend payoff carries a direct private benefit to the bank owner and no benefit to lenders.[8]

2.2 The lenders

At $t = 1$, after dividends are paid out, the lenders decide whether to roll over their debt to $t = 2$ or refuse to roll over (or run, for short). We assume that the lenders have a uniform prior about θ over $[-K, K]$ for $K > 0$. Lenders observe additional information, which we detail in Section 3. Because the information will be heterogeneous across agents, we will denote the probability with respect to lender i's information set by $\Pr_i\{.\}$.

We assume that a lender i chooses to run if the probability she assigns to the bank surviving is sufficiently low. Formally, the lender runs iff

$$\Pr_i\left\{\bar{\ell} \geq d + bA\right\} \leq p, \tag{4}$$

where as is standard in regime-change global games, p determines the aggressiveness of lenders and the severity of the rollover crisis, while b determines the short-term liabilities of the bank.[9] Defining

$$\hat{\pi}_i \equiv p - \Pr_i\left\{\bar{\ell} \geq d + bA\right\}, \tag{5}$$

we have that a lender i runs iff $\hat{\pi}_i \geq 0$. In our analysis below, we will work with this object when characterizing the lenders' actions.[10]To simplify notation, for most of the analysis below we will analyze the model for the case when $b = 1$. However, we return to the more general case in Section 5 and show that the equilibrium effects from changes in p versus b tend to be qualitatively similar.

[8] Assuming instead that the bank owner only cares about his expected $t = 2$ equity payoff net of promised payments to maturing short-term lenders would lead to a $t = 2$ continuation payoff for the bank owner of

$$W_2 = \max\{0, v(\theta, d + bA) - B(1 - A)\},$$

where $B > b$ is the promised payoff to lenders that roll over. Noting that, given $t = 1$ survival, $W_2 \leq v(\theta, d + bA)$, it follows that if the $t = 2$ payoff is W_2 rather than v, then the bank owner's incentives to liquidate early by paying out a large dividend and inducing the bank's failure, even when the bank has the resources to survive, are only strengthened. Because such incentives are already present even with the payoffs assumed in (3), allowing for the more general continuation payoff for the bank owner will not change the qualitative predictions of our model but will come at a substantial reduction in tractability.

[9] In general, p and b are related, as we show in the Online Appendix.

[10] In the Online Appendix we further discuss lender payoffs that will give rise to the reduced-form payoff in (5).

2.3 Dominance regions

We assume that there exist lower and upper dominance regions.

- *Lower dominance region:* There exists a $\underline{\theta} > -K$, such that for $\theta < \underline{\theta}$, $\overline{\ell}(\theta) = 0$.
- *Upper dominance region:* There exists a $\overline{\theta} < K$, such that for $\theta > \overline{\theta}$, $\overline{\ell}(\theta) > 1$, and $\lambda\overline{\ell}(\theta) < v(\theta, 1)$.
- *Multiplicity region:* For $\theta \in (\underline{\theta}, \overline{\theta})$, $\overline{\ell}(\theta) \in (0, 1)$.

Therefore, banks with very weak fundamentals are insolvent and fail with probability one for any $A \in [0, 1]$. Conversely, banks with very strong fundamentals can meet all demands for withdrawals. Furthermore, it is never optimal for such banks to liquidate all their assets at $t = 0$.[11] In between, whether or not a bank can survive depends on whether lenders coordinate on running or rolling over. If all lenders run, then the bank cannot survive, and if all lenders roll over, the bank can survive. The equilibrium concepts that we work with are standard and are included in the Online Appendix.

2.4 No-run benchmark

To highlight the interaction between dividends and rollover risk, we first characterize the dividend payout of a bank that does not face a run. We assume that

Assumption B2. $\lambda \geq -v_l(\underline{\theta}, 0)$,

so that even banks with low values of θ find it optimal to pay dividends. We view this particular case as the empirically relevant one in light of our discussion of the risk-shifting incentives by banks in the Introduction.

Proposition 1. *(No run benchmark) Consider a bank that does not face a run, that is, $A = 0$. There is a unique cutoff $\theta^{nr} \in [\underline{\theta}, \overline{\theta})$ that solves*

$$\lambda = -v_l\left(\theta^{nr}, \overline{\ell}(\theta^{nr})\right), \tag{6}$$

[11] To see this, observe that $\overline{\ell}(\theta) > 1$ and the properties of v (i.e., $v_{ll} \leq 0$), imply that $\lambda + v_l\left(\theta, \overline{\ell}(\theta)\right) \leq \lambda + v_l(\theta, 1)$. Furthermore, $\lambda\overline{\ell}(\theta) < v(\theta, 1) < \lambda + v(\theta, 1)$, and because $W_d = \lambda + v_l(\theta, d)$ is monotone decreasing in d (because $v_{ll} < 0$), it follows that $\lambda + v_l\left(\theta, \overline{\ell}(\theta)\right) < 0$.

such that banks with $\theta \leq \theta^{nr}$ choose $d_{nr}(\theta) = \bar{\ell}(\theta)$, and banks with $\theta > \theta^{nr}$ choose $d_{nr}(\theta) = d^*$, where d^* solves the first-order condition

$$\lambda = -v_l(\theta, d^*). \tag{7}$$

Moreover, $d_{nr}(\theta)$ is increasing in θ.

Proof. See the appendix. ■

Proposition 1 shows that, in the absence of runs, banks with higher portfolio quality pay higher dividends. This outcome is a direct implication of the single crossing condition, $v_{l\theta} > 0$.

3 Equilibrium Analysis

We characterize equilibrium outcomes under two different information structures. First, we consider the case when lenders do not observe the dividend choice of the bank and instead observe an exogenous private signal about the bank's type. Then, we introduce dividend signaling by assuming that lenders observe the bank's dividend and make inferences about the bank's type based on that information and their prior beliefs.

3.1 Exogenous information and the resilience effect

Suppose that lenders do not observe the bank's dividend choice but only observe a private signal about θ, $\theta_i = \theta + \eta_i^\theta$, with $\eta_i^\theta \sim_{i.i.d.} N\left(0, \alpha_\theta^{-1}\right)$, where α_θ denotes the signal precision.[12] We consider equilibria in monotone strategies by lenders; that is, lenders attack iff their signal $\theta_i \leq \hat{\theta}$ for some $\hat{\theta}$. In addition, the bank's problem is characterized by a failure cutoff θ_f, such that a bank with type $\theta < \theta_f$ fails the rollover episode, and a bank with type $\theta > \theta_f$ survive. Given the distribution of signals and a monotone strategy summarized by the cutoff $\hat{\theta}$, the share of lenders that run on a bank of type θ is

$$A\left(\theta, \hat{\theta}\right) = \Phi\left(\sqrt{\alpha_\theta}(\hat{\theta} - \theta)\right) \tag{8}$$

[12] For simplicity, for this section only, we assume that lenders have improper uniform priors over the entire real line, that is, $K \to \infty$.

Proposition 2 shows that there is a unique equilibrium in monotone strategies, and that this is the unique equilibrium of the rollover game.

Proposition 2. *(Exogenous information) There exists a unique equilibrium, which is in monotone strategies and is given by a failure cutoff θ_f, and a strategic cutoff $\hat{\theta}$ that satisfy*

$$\lambda\bar{\ell}\left(\theta_f\right) = \lambda d^*\left(\theta_f\right) + v\left(\theta_f, d^*\left(\theta_f\right) + p\right), \tag{9}$$

and

$$\Phi\left(\sqrt{\alpha_\theta}\left(\hat{\theta} - \theta_f\right)\right) = p, \tag{10}$$

where $d^*\left(\theta\right) \geq 0$ satisfies the Kuhn-Tucker conditions $\lambda + v_l\left(\theta, d^* + A\left(\theta, \hat{\theta}\right)\right) \leq 0$, and

$$\left(\lambda + v_l\left(\theta, d^* + A\left(\theta, \hat{\theta}\right)\right)\right) d^* = 0. \tag{11}$$

Furthermore, the optimal bank policy satisfies

$$d\left(\theta\right) = \begin{cases} \bar{\ell}\left(\theta\right) & ,\theta \leq \theta_f \\ d^*\left(\theta\right) & ,\theta > \theta_f \end{cases}.$$

Proof. See the appendix. ■

[Figure 2 here.]

Figure 2 illustrates the optimal dividend policy in this equilibrium. To gain some intuition, note first that with exogenous lender signals the size of the run does not depend on the dividend payout of the bank. Moreover, as in other global games models (Morris and Shin, 2003), the strategic uncertainty resulting from dispersed private information determines a run size of $A\left(\theta_f, \hat{\theta}\right) = p$ for a bank at the equilibrium failure threshold, θ_f. Such a bank is indifferent between paying out $\bar{\ell}\left(\theta_f\right)$ and failing or paying out $d^*\left(\theta_f\right)$, enduring a run of size p, and surviving. Therefore, the total liquidity outflow for a bank at the failure threshold is $d^* + p$. In this case, higher dividend payouts always increase the liquidity outflow of the bank. Contrast this with the case when banks do not pay dividends. In that case the failure threshold is not determined by whether the bank *chooses* to survive but by whether survival is *feasible* given the run size p.

Because the liquidity outflow for the bank at the failure threshold is only p in that case, and a higher liquidity outflow can be met only by a bank with higher type, paying dividends clearly leads to more banks failing. We call this the *resilience effect* associated with dividend payouts.

Finally, as Figure 2 illustrates, compared to the no run benchmark, in the exogenous information case a bank that chooses to survive distorts its dividend payout *below* the no-run dividend level, $d_{nr}(\theta)$ determined by Equation (7). Specifically, $d^*(\theta) = \max\left\{0, d_{nr}(\theta) - A\left(\theta, \hat{\theta}\right)\right\}$. Therefore, for a bank that chooses to survive, payouts to running lenders *crowd out* dividend payouts.

3.2 Endogenous information and the signaling effect

Next, we introduce dividend signaling by assuming that lenders observe the bank's dividend and make inferences about the bank's type based on that information and their prior beliefs. We assume that dividends are observed by lenders with idiosyncratic noise. Formally, each lender observes a private signal about dividends, $d_i = d(\theta) + \eta_i^d$, with $\eta_i^d \sim_{i.i.d.} N\left(0, \alpha^{-1}\right)$, where $d(\theta)$ is the dividend choice of a bank with type θ, and α denotes the dividend signal precision. We make this assumption to abstract away from the equilibrium multiplicity arising because of common certainty, resulting from the observation of a public signal (as in Woodford (2002), Myatt and Wallace (2014), Kolbin (2015), Gaballo (2016), or Angeletos and Lian (2018)). In addition to its technical role, we can interpret the private noise in dividend observations as a reduced form for limited attention by lenders.[13]

[Figure 3 here.]

We again consider monotone strategy equilibria, in which a lender runs if $d_i < \hat{d}$, for some cutoff $\hat{d}$.[14] With normally distributed dividend signals and monotone strategies, the share of lenders running given $\hat{d}$, is

$$A(d(\theta), \hat{d}) = \Phi(\sqrt{\alpha}(\hat{d} - d(\theta))), \tag{12}$$

and the total liquidity outflow from paying out a dividend d is

$$l(d) = d + A\left(d, \hat{d}\right). \tag{13}$$

[13] The Online Appendix provides a microfoundation for dispersed dividend signals of agents based on limited attention.

[14] Proposition 9 in the appendix shows conditions under which that restriction is without loss of generality.

3.2.1 Dividend payouts with signaling. When lenders follow a monotone strategy $\hat{d}$, a bank reduces the run it is facing by paying higher dividends. We call this the *signaling effect.* It is useful to define $d_{\min}$ as the minimizer of $l(d)$.[15] We will consider economies with $\hat{d} \in (0,1)$ and α sufficiently large, so that $d_{\min} > 0$.[16] In that case, as Figure 3 shows, the liquidity outflow that a bank experiences is decreasing for some values of d, so that the signaling effect dominates the resilience effect.

We focus on this case, because it highlights how signaling affects the equilibrium dividend policies of banks. Given the interpretation of α as a parameter that determines the degree of lender attention toward publicly available information, we also believe that it is empirically plausible in many relevant cases, for example, when banks have sophisticated institutional lenders. Proposition 3 characterizes the solution to the bank problem in that setting.

Proposition 3. *Suppose that lenders follow a monotone strategy with cutoff at $\hat{d}$. Then there is a unique critical threshold over bank fundamentals given by θ_f, such that banks with $\theta \leq \theta_f$ fail and banks with $\theta > \theta_f$ survive. Furthermore, θ_f satisfies*

$$\lambda \bar{\ell}(\theta_f) = \lambda d^*(\theta_f) + v\left(\theta_f, d^*(\theta_f) + A\left(d^*(\theta_f), \hat{d}\right)\right), \tag{14}$$

where $d^*(\theta) > d_{\min}$ satisfies the condition

$$\lambda = -v_l\left(\theta, d^*(\theta) + A\left(d^*(\theta), \hat{d}\right)\right)\left(1 + A_d\left(d^*(\theta), \hat{d}\right)\right). \tag{15}$$

The bank's optimal dividend policy is given by

$$d(\theta) = \begin{cases} \bar{\ell}(\theta) & , \theta \leq \theta_f \\ d^*(\theta) & , \theta > \theta_f \end{cases}. \tag{16}$$

[15] For sufficiently large α, d_{min} is formally the solution to $1 + A_d\left(d, \hat{d}\right) = 0$, such that $\hat{d} < d_{\min}$.

[16] Conditions B3 and B4 in the appendix ensure that in any monotone strategy equilibrium of this economy, $\hat{d} \in (0,1)$, while the observation that $d_{\min} \to \hat{d}$ and $A\left(0, \hat{d}\right) \to 1$ as $\alpha \to \infty$ ensure that $d_{\min} + A\left(d_{\min}, \hat{d}\right) \leq A\left(0, \hat{d}\right)$, for sufficiently large α. Focusing on economies in which $\hat{d} \in (0,1)$ is the most interesting given the assumption on feasible dividend payouts for banks at the lower and upper dominance thresholds. In the Online Appendix we characterize the equilibrium for all values of α.

Proof. See the appendix. ■

As in the exogenous information case, a bank chooses whether to fail or survive by comparing the payoff from paying out $\bar{\ell}(\theta)$ and failing the rollover episode, against the payoff from paying a dividend d^* and surviving a run of size $A\left(d^*(\theta_f), \hat{d}\right)$. A bank at the failure threshold is then exactly indifferent between failing (and paying out $\bar{\ell}(\theta_f)$) and surviving (and paying out $d^*(\theta_f)$).

The dividend payout of surviving banks is given by Equation (15). The left-hand side corresponds to the marginal benefit from paying out one more dollar of dividends, whereas the right-hand side corresponds to the marginal cost. Because of the signaling effect, the (effective) marginal cost of paying dividends is lower compared to both the no run case (cf. Equation (7)) or the case with exogenous information (cf. Equation (11)). Intuitively, paying out one more dollar in dividends leads to a total liquidity outflow of only $1 + A_d < 1$. The lower effective marginal cost implies that a bank has incentives to distort its dividend payout *above* the no-run dividend level, $d_{nr}(\theta)$. On the other hand, as in the exogenous information case, the resilience effect tends to push toward the bank setting a dividend payout *below* the no-run level, due to crowding out by the run. When the signaling effect is strong, the former effect dominates, and the bank increases its dividend above $d_{nr}(\theta)$.[17]

The signaling effect is particularly strong for banks with type θ, such that $d_{nr}(\theta) \leq d_{\min}$. For these banks, increasing the dividend above $d_{nr}(\theta)$ is associated with a *lower* liquidity outflow. Banks then optimally choose a dividend of at least $d_{\min}$. In addition, the marginal impact on the size of the run given by A_d, decreases strongly in d around $d_{\min}$. Intuitively, because lenders care about whether the bank fails or survives the rollover episode (rather than the specific bank type), the dividend payouts of banks with higher fundamentals are already interpreted by most lenders as strong evidence that the bank will survive the rollover episode, so any upward distortion in dividends has only a small effect on lenders' inference. Therefore, all banks that distort their dividends *above* the no-run level choose payouts above but close to $d_{\min}$. In summary, a strong signaling effect induces (surviving) banks with different types to choose similar dividend payouts.

[17] In the Online Appendix we discuss the equilibrium dividend policy when the signaling effect is weak. In that case, the resilience effect might dominate the signaling effect for some bank types despite dividends being interpreted as good news about survival by lenders.

3.2.2 Lenders' inference and actions. Unlike the exogenous information case, how lenders interpret a higher dividend signal – whether as good or bad news about bank survival – can now be endogenous to the behavior of banks. On the other hand, the banks' behavior depends on how lenders interpret higher dividends. Therefore, it can easily be the case that there are multiple equilibria as in Angeletos et al. (2006). Moreover, from Equation (16) and as illustrated in Figure 4, even when higher dividends are good news about survival and lead to fewer lenders running, the dividend policy of banks is nonmonotone and some failing bank types choose to pay *higher* dividends than some surviving banks. Therefore, a lender's posterior belief about the bank failing given dividend signal d_i, $\Pr(\theta < \theta_f | d_i)$, may not always decrease with d_i. Put differently, a higher dividend signal may not *always* be good news about bank survival.

With these subtleties in mind, we first characterize the lenders' inference and the conditions under which $\Pr(\theta < \theta_f | d_i)$ is decreasing in d_i. To do so, we define two probability densities,

$$\psi_{N,i}(x) = \frac{\phi\left(\sqrt{\alpha}\left(\overline{\ell}(x) - d_i\right)\right)}{\int_{-K}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\overline{\ell}(z) - d_i\right)\right) dz}, \text{ for } x \in [-K, \theta_f], \tag{17}$$

and

$$\psi_{D,i}(x) = \frac{\phi\left(\sqrt{\alpha}\left(d^*(x) - d_i\right)\right)}{\int_{\theta_f}^{K} \phi\left(\sqrt{\alpha}\left(d^*(z) - d_i\right)\right) dz}, \text{ for } x \in [\theta_f, K], \tag{18}$$

Analogously, we define expectations $E_{N,i}[.]$ and $E_{D,i}[.]$. The following result summarizes when higher dividends are good news about survival.

Lemma 1. *The posterior belief of a lender observing signal d_i, $\Pr_i\{\theta < \theta_f | d_i\}$, is strictly decreasing in d_i iff*

$$E_{N,i}\left[\overline{\ell}(\theta)\right] < E_{D,i}\left[d^*(\theta)\right]. \tag{19}$$

Proof. See the appendix. ∎

Intuitively, if a lender with signal d_i expects a lower dividend from a bank that fails compared to a bank that survives, then a lender with a marginally higher signal is more optimistic about the bank surviving. To apply Lemma 1, notice that by Proposition 3, $d^*(\theta) > d_{\min}$, so $E_{D,i}[d^*(\theta)] > d_{\min}$. Therefore, higher dividends are always good news about bank survival if $E_{N,i}\left[\overline{\ell}(\theta)\right] < d_{\min}$. One sufficient condition for this inequality is that K is sufficiently large, so that the lower dominance region (in which $\overline{\ell}(\theta) = 0$) is large. In that case lenders expect most failing bank to have no available liquidity, including for paying dividends. We use this observation to characterize the lenders' actions.

Proposition 4. *Suppose that banks with $\theta < \theta_f$ fail, where $\theta_f \leq \overline{\theta}$ is given in (14) and that banks follow the dividend policy given in (16). There exists a $\overline{K}_1 > 0$ such that for $K > \overline{K}_1 > 0$, there is a lender with signal $d_i = \hat{d}$, where $\hat{d}$ is uniquely determined by*

$$\frac{\int_{-K}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\overline{\ell}(\theta) - \hat{d}\right)\right) d\theta}{\int_{\theta_f}^{K} \phi\left(\sqrt{\alpha}\left(d^*(\theta) - \hat{d}\right)\right) d\theta} = \frac{1-p}{p}, \tag{20}$$

who is indifferent between running and rolling over, with $\phi(.)$ denoting the standard normal p.d.f. Furthermore, a lender that observes $d_i < \hat{d}$ is strictly better off from running, while a lender observing $d_i > \hat{d}$ is strictly worse off from running.

Proof. See the appendix. ■

3.2.3 Equilibrium characterization. Turning to equilibrium characterization, Proposition 9 in the appendix combines the results from Propositions 3 and 4, and characterizes equilibria in monotone strategies for this economy with the property that higher dividends are good news about bank survival. Furthermore, it shows conditions under which, if the monotone strategy equilibrium is unique, it is the unique equilibrium of this economy. To show equilibrium uniqueness, one has to show that in any equilibrium higher dividends can only be interpreted as good news.[18] A sufficient condition for this is that the dominance regions (parametrized by K) are large and there is single crossing, $v_{l\theta} > 0$, so that the dividend payouts of surviving banks are increasing in θ. Intuitively, because banks with very low θ always pay no dividends and fail, and banks with very high θ always pay dividends and survive, when these types are sufficiently prevalent, a higher private signal is always interpreted as good news about survival, regardless of the actions of lenders with intermediate signals or the dividend policies of banks in the multiplicity region.

[18] If higher dividends can be bad news about survival in equilibrium, then the signaling and resilience effects would reinforce each other, and the equilibrium structure will be similar to that in the exogenous information case studied in Section 3.1.

[Figure 4 here.]

Figure 4 illustrates the equilibrium dividend policies and marginal lender for one particular example. The figure plots both the dividend policy with endogenous information (solid line), and the dividend policy in the no-run case (dashed line) for banks in the multiplicity region. Banks below the failure threshold pay out all available liquidity as dividends. In contrast to the exogenous information case, surviving banks pay a dividend that is *higher* than their no-run dividend. Furthermore, the dividend payouts of surviving banks are more similar and vary less with θ relative to the no-run case. As the signal precision is increased and the signaling effect is strengthened, the dividend payouts of banks close to the failure threshold become even more similar (and even less sensitive to θ).

Hence, dividend signaling in the presence of rollover risk implies a stronger upward distortion in dividends for (surviving) banks with *low* types. This is intuitive – in the presence of rollover risk banks signal available liquidity and the ability to survive a rollover episode. The lower-quality banks which are more exposed to rollover thus signal "more." This is opposite to the established view of signaling future profitability (Bhattacharya, 1979), where the incentives to signal high future profitability induce higher types to signal more and separate from lower types. In the Online Appendix, we consider a modification of our model that illustrates this outcome. We use that modified environment to point out three notable differences with our model. First, signaling about future profitability implies no dividend distortion for the lowest bank type. In contrast, signaling about available liquidity means that the distortion is largest for the lowest (surviving) bank type. Second, signaling about future profitability implies dividend distortions for all types, including the highest types. In contrast, signaling about available liquidity (combined with single crossing) means that the distortion becomes arbitrarily small with type, because both the equilibrium run size ($A\left(d, \hat{d}\right)$) and the marginal effect of higher dividends on the run size ($A_d\left(d, \hat{d}\right)$) go to zero as d increases. Third, signaling about future profitability may imply that dividend distortions are actually *increasing* in type.

3.2.4 A limit result. Next, we show the following stark result for the limiting case when lender signals become arbitrarily precise.

Proposition 5. *In the limit, as $\alpha \to \infty$, there is a unique equilibrium with $\theta_f \to \theta^{nr}$, $\hat{d} \to \bar{\ell}(\theta^{nr})$. Furthermore, the bank's dividend policy, $d(\theta) \to d_{nr}(\theta)$, $\forall\theta$.*

Proof. See the appendix. ■

To build some intuition for this result, note that for any $d > \hat{d}$, a higher value of α ends up decreasing the liquidity outflow, $l(d) = d + A\left(d, \hat{d}\right)$. Intuitively, when α is larger, lenders are more coordinated and the same dividend choice influences the actions of more lenders. Put differently, less noise in the observation of dividends strengthens the signaling effect. As $\alpha \to \infty$, lenders become almost perfectly coordinated and so $A \to 0$, for $d > \hat{d}$. Therefore, even a marginal increase in dividends induces (almost) all lenders to choose to roll over. Consequently, any surviving bank will face no run, including a bank at the failure cutoff θ_f, and the liquidity outflow will only equal the dividend payout itself. This, however, can only be consistent with indifference between survival and failure if $\theta_f = \theta^{nr}$ – the "failure" cutoff when there is no run on the bank. Figure 4 illustrates the strengthening of the signaling effect for finite values of α. More precise dividend signals reduce the failure cutoff and bring it closer to the no-run cutoff. Additionally, $d_{\min}$ decreases, which further reduces the cost associated with signaling.[19]One interesting implication of the limiting case, (also suggested by Figure 4), is that when lenders observe arbitrarily precise signals, $d^{*\prime}(\theta_f) \to 0$. Therefore, in equilibrium, banks that are close to the failure cutoff (approximately) pool on their dividend payouts.[20]

3.2.5 Dividend signaling without single crossing.

We extend our analysis to cases in which the single crossing condition, $v_{l\theta} > 0$, does not hold. The single crossing condition holds in many realistic settings linking bank type to the underlying portfolio. Nevertheless, it is violated if, for example, a high θ bank has less cash than a low θ bank but has more (or higher-quality) illiquid assets. Similarly, if banks have to liquidate assets at a common price that is independent of the underlying asset quality, then $v_{l\theta} < 0$, as well.

[19]These direct effects ends up dominating any indirect effects arising from changes in the marginal lender. In fact, as Proposition 5 suggests, for sufficiently high signal precision, changes in the marginal lender, $\hat{d}$, should reinforce these effects on θ_f.

[20]Intuitively, when lenders observe very precise signals, having an equilibrium marginal lender who observes a signal $\hat{d}$ *lower* than the dividend payout of all surviving banks means that the set of surviving banks paying dividends close to $\hat{d}$ must be large relative to the noise in the lender's signal.

Equilibrium characterization changes little without the single crossing condition.[21] Specifically, Proposition 3 holds independently of the single crossing condition. Intuitively, even if the single crossing condition is reversed, so $v_{l\theta} < 0$, all surviving banks choose to pay a dividend above $d_{\min}$, the dividend payout that minimizes the total liquidity outflow. Given Proposition 3, the single crossing condition is not relevant for the lenders' inference, either, because it is still the case that $d^*(\theta) > d_{\min}$ and so having a sufficiently large share of very low types that fail and pay no dividends means that higher dividends are still interpreted as good news about survival in equilibrium. Therefore, Proposition 4 continues to hold, as well.

Where the single crossing condition matters is for equilibrium uniqueness. Specifically, it is no longer clear that in any equilibrium higher dividends can only be interpreted as good news. However, one can show equilibrium uniqueness under different conditions than the single crossing condition. For example, as long as there are sufficiently many banks in the upper dominance region that pay a positive dividend (that is also bounded away from zero), Proposition 9 will still hold as well.

In terms of equilibrium outcomes, without single crossing, the equilibrium dividend payouts of surviving banks need not be increasing in θ. Instead, the dividend payouts of these banks could be nonmonotone or even decreasing in θ. Moreover, it will no longer be the case that the lowest surviving types distort their dividend payout the most relative to the no-run case. Instead, it is high surviving types, which would prefer to pay a low dividend in the absence of a rollover episode, that may have to distort up their dividend payout the most.

4 Policy Implications

The possibility that banks can influence the coordination-based run they face via their dividend choices has important implications for dividend regulation aimed at improving financial stability during a rollover crisis. In particular, suppose that a regulator cares about minimizing the set of banks failing due to a coordination-based run (i.e., minimizing the failure threshold θ_f). In this section, we characterize the dividend policy, denoted by $d^P(\theta)$, that achieves this. We will call this

[21] This observation provides another point to distinguish the signaling that takes place in our coordination-based environment relative to classical dividend signaling à la Bhattacharya (1979), in which the single crossing condition is necessary for signaling to commence.

policy the optimal dividend policy for concreteness.

We assume that the regulator knows θ, so that there is no asymmetric information friction between the regulator and the bank(s). We also assume that the regulator respects the information sets of lenders and so cannot directly communicate any information to the lenders. The first assumption ensures that we derive a benchmark optimal dividend policy akin to "first-best" optimal policies in economies with asymmetric information. The second assumption is standard in the literature on optimal policy in games with dispersed information(Angeletos and Pavan, 2007). Later on, we discuss the implications of relaxing each of these assumptions.

Let θ_f^P denote the failure threshold that the regulator can achieve by imposing the optimal dividend policy $d^P(\theta)$. Two sources of inefficiency may lead to $\theta_f \geq \theta_f^P$. First, some bank types are better off failing and paying $d = \overline{\ell}(\theta)$ even when it is feasible for them to survive. This mechanically raises the failure threshold, holding the behavior of lenders fixed. Formally, θ_f is determined by Equation (14), while the smallest bank type for which surviving the run is feasible is given by θ_0, such that

$$\overline{\ell}(\theta_0) = d_{\min} + A\left(d_{\min}, \hat{d}\right). \tag{21}$$

Second, by Equation (20), the bank's dividend policy influences the marginal lender with dividend signal cutoff $\hat{d}$ and, hence, the size of the run, A, that other bank types experience. This second effect operates through the lenders' inference. We will call the first source of inefficiency a "risk shifting externality," whereas the second an "informational externality." We have the following characterization result.[22]

Proposition 6. *For sufficiently large values of α, the optimal dividend policy d^P has the following properties*

$$d^P(\theta) = \begin{cases} 0 & ,\theta < \overline{\ell}^{-1}\left(\hat{d}^P\right) \\ \left\{0, \overline{\ell}(\theta)\right\} & ,\theta \in \left[\overline{\ell}^{-1}\left(\hat{d}^P\right), \theta_f^P\right] \\ d_{\min}^P & ,\theta > \theta_f^P \end{cases}, \tag{22}$$

where $d_{\min}^P = \hat{d}^P + C_0$, and $\theta_f^P = \overline{\ell}^{-1}\left(d_{\min}^P + C_1\right)$, $\hat{d}^P$ solves (20), given $\left\{d^P(\theta)\right\}$, and C_0 and C_1

[22]For technical reasons we will restrict the optimal policy function d^P to be a step function on $[-K, K]$, where the number of steps is large but finite. Also, for technical reasons, we assume that the regulator cannot regulate the dividend choice of a bank exactly at the failure cutoff θ_f, so that $d^P(\theta_f) = \overline{\ell}(\theta_f)$. Finally, because $\overline{\ell}(\theta) = 0$, for $\theta \leq \underline{\theta}$, to have a well-defined inverse we will adopt the notation $\overline{\ell}^{-1}(0) = \underline{\theta}$.

are two constants.

Proof. See the appendix. ■

The most striking difference between the optimal dividend policy, $d^P(\theta)$, and the equilibrium dividend policy $d(\theta)$ from (16) is that the dividend payout for surviving banks is capped at $d^P_{\min}$ and, moreover, that cap is binding for all surviving banks. In contrast, $d(\theta)$ is increasing in θ (due to single crossing). Intuitively, under the equilibrium dividend policy, a lender observing the marginal dividend signal, $\hat{d}$, assigns a relatively low probability that the bank has a very high type, as higher types pay much higher dividends than $\hat{d}$. Suppose that all surviving types are mandated to pay the same dividends at some level close to $\hat{d}$. Because all of these banks survive the run, observing a dividend of $\hat{d}$ becomes stronger evidence in favor of survival, and the lender observing $\hat{d}$ becomes strictly better off rolling over – the marginal lender becomes a lender with a lower dividend signal.

Another important feature of the optimal dividend policy is that more failing banks are forced to pay zero dividends compared to the equilibrium dividend policy. Intuitively, the regulator can lower $\hat{d}$ in two ways – by mandating that all surviving banks pool on paying the same dividend or, due to the noise in lender dividend signals, by ensuring that failing and surviving banks pay as distinct dividends as possible.

Proposition 6 provides a partial characterization of the optimal dividend policy, because $d^P(\theta) \in \{0, \overline{\ell}(\theta)\}$ in the set $\theta \in \left[\overline{\ell}^{-1}\left(\hat{d}^P\right), \overline{\ell}^{-1}\left(\hat{d}^P + C_0 + C_1\right)\right)$. However, that set is small for large values of α, because both C_0 and C_1 tend to 0 as $\alpha \to \infty$. Therefore, as lender signals become perfectly precise, we can characterize the optimal dividend policy (almost) fully. In that case we can also determine the smallest failure cutoff θ^P_f and the associated dividend cutoff $\hat{d}^P$.

Proposition 7. *In the limit, as $\alpha \to \infty$,*

$$d^P(\theta) \to \lim d^P = \begin{cases} 0 & , \theta < \theta^P_f \\ d^P_{\min} & , \theta > \theta^P_f \end{cases}, \tag{23}$$

where $\theta^P_f \to \overline{\ell}^{-1}\left(\lim \hat{d}^P\right)$, $d^P_{\min} \to \lim \hat{d}^P$, and $\lim \hat{d}^P = 0$.

Proof. See the appendix. ■

This result is intuitive in light of the regulator's objective. The regulator does not put any weight on the bank's payoffs but only cares about minimizing the failure cutoff, so he chooses a dividend policy to achieve the smallest feasible failure cutoff. In the limit, as $\alpha \to \infty$ and lenders become perfectly coordinated, the smallest feasible failure cutoff is at the lower dominance threshold, so $\theta_f^P \to \underline{\theta}$. In contrast, with no dividend regulation, by Proposition 5, the failure threshold approaches $\theta^{nr} > \underline{\theta}$. Moreover, the distance between the two thresholds increases with λ.

4.1 Discussion

The two key features of the dividend policy from (22) are the full dividend restriction for low failing types and the binding dividend cap for high surviving types. This structure is somewhat different from macroprudential dividend regulation measures commonly proposed in the literature, which call for a restriction of dividend payouts of all banks (Goodhart et al., 2010). The reason for the difference is the dividend signaling effect, which a regulator can also utilize when stabilizing the financial system. Below, we will examine the robustness of these features of the optimal dividend policy to a set of alternative modeling assumptions.

4.1.1 Asymmetric information. In the presence of asymmetric information between the regulator and the bank, the dividend policy in (22) may not be incentive compatible for some bank types for the following reasons. First, the policy (22) may contain nonmonotonicities. For example, if $d^P(\theta_1) = \bar{\ell}(\theta_1) > d^P(\theta_2)$, for $\theta_1 < \theta_2$, then with asymmetric information, a bank with type θ_2 may be better off paying $d^P(\theta_1)$. Second, the policy mandates a full dividend restriction for some bank types, for which paying a higher dividend may be feasible. In the Online Appendix we argue that the region of fundamentals where these issues arise is small for high values of signal precision and show that in that case a two-dividend menu, given by $d \in \{0, \bar{d}\}$, for an appropriately chosen value of $\bar{d}$, approximates well the optimal policy $d^P(\theta)$.

4.1.2 Regulator communication. In the presence of dividend signaling, a regulator who observes θ uses the dividend policy to (indirectly) communicate information to lenders about the bank's ability to survive a run. Abstracting away from the small nonmonotonicity region, the dividend policy (22) then looks like a binary disclosure rule that pools bank types into two groups – the failing banks and the surviving banks. This is similar to the disclosure rules analyzed in Goldstein and Leitner (2018) in the context of stress testing, though in a different economic environment. In our setting, rather than directly disclosing the results of the stress test via a binary scoring rule, the regulator communicates the results of the stress test by either allowing the bank to pay a dividend or not. Therefore, interpreted through the lens of stress testing and information disclosure, the dividend policy we derive implies a link between stress test results and dividend payouts.

One can use the insight that the regulator communicates with lenders via the bank's dividend policy to also understand direct disclosures by the regulator in the context of our model. In the Online Appendix we argue that optimal dividend policy (22) is qualitatively unchanged even with direct (but noisy) regulator disclosure. In that case the regulator can use both the dividend and its own direct disclosure to improve the overall precision of the lenders' information.

4.1.3 Alternative policy objective.

The assumption that the regulator only cares about minimizing bank failure is appropriate when thinking about policies that promote financial stability but is generally quite stark, because it disregards any direct benefits from paying dividends. Therefore, in the Online Appendix we consider an alternative notion of optimality, namely, maximizing the expected bank payoff prior to the realization of the fundamental θ. A bank that can commit to this optimal dividend policy will internalize the informational externality. We show that when λ is small, this optimal dividend policy also features a binding cap on dividends for surviving banks and a zero dividend payoff for low types.

5 Testable Implications and Empirical Relevance

Our model predicts that higher rollover risk leads to higher average dividend payouts. We capture higher rollover risk by increasing the lenders' incentive to run ($p \uparrow$) or the bank's reliance on short-term debt ($b \uparrow$).[23]

Proposition 8. $\lim_{\alpha\to\infty} \frac{d\hat{d}}{dp} > 0$ *and* $\lim_{\alpha\to\infty} \frac{d\theta_f}{dp} > 0$. *Moreover,* $\lim_{\alpha\to\infty} \frac{d\hat{d}}{db} \geq 0$ *and* $\lim_{\alpha\to\infty} \frac{d\theta_f}{db} \geq 0$

[23] While we have focused on the case $b = 1$ so far, all of the results we have shown hold more generally for $b > 0$, provided that the upper dominance region assumption is modified as follows: there exists a $\overline{\theta}$, such that for $\theta > \overline{\theta}$, $\overline{\ell}(\theta) > b$, and $\lambda\overline{\ell}(\theta) < v(\theta, b)$. Also, for the comparative statics below, we will assume that p is increasing in b as in the partial microfounded example for the lenders' payoffs in the Online Appendix.

Proof. See the appendix. ■

Intuitively, as p is increased, the marginal lender needs to be more optimistic about bank survival to be indifferent between running and rolling over. As a consequence, the new marginal lender becomes an agent that observes a higher dividend signal – $\hat{d}$ goes up. Because $d_{\min}$ – the lower bound on dividend payouts for surviving banks, defined in Section 3.2.1 – is increasing in $\hat{d}$, it follows that dividends also increase. A change in the reliance on short-term debt, b, has an analogous effect. We illustrate the comparative statics for p and b from Proposition 8 in Figure 5, away from the limiting case of perfect signal precision.

[Figure 5 here.]

A second important prediction of our model, which we discussed in Section 3.2.1 in the context of Proposition 3, is that the upward distortions in dividends due to signaling lowers the sensitivity of dividends to fundamentals, because banks with different types choose similar dividend payouts in equilibrium. This prediction is illustrated in Figure 5, where we also plot the dividend policy in the no run case.

We document two novel empirical facts and relate them to our main testable implications.[24] We first investigate cross-sectional variation in the evolution of dividend payouts during the 2007 financial crisis. We test the first prediction (cf. Proposition 8) – that an increase in rollover risk increases the average dividend payout – by investigating whether banks that were more reliant on short-term funding and, therefore, all else equal, were subject to more rollover risk, had higher dividend payouts as the crisis progressed. We rank U.S. banks according to the share of liabilities in short-term debt in 2006 and examine the behavior of dividend payouts for banks in the first and fourth quartiles as the financial crisis was unfolding.

As shown in Panel (a) of Figure 6, both groups have similar trends in dividend growth before 2007. However, after 2007 their dividend payments diverge sharply. Banks that relied relatively less on short-term debt decreased their dividend payouts starting in 2007. In contrast, banks that relied relatively more on short-term debt stayed on their pre-2007 dividend growth trend during 2007 and 2008.

[24]The Online Appendix provides additional information on data and measurement.

While this pattern is consistent with our model, it does not allow us to identify whether the signaling or the resilience effect dominates during the crisis. Specifically, if the resilience effect dominates, it is possible for dividend payouts to go up with higher exposure to rollover risk, driven by an increase in dividends by failing banks that ends up outweighing any decline in dividends by surviving banks due to the crowd-out effect.[25] To distinguish between these two effects, we use the observation that among the set of surviving banks, which are banks with relatively high fundamentals, higher exposure to rollover risk implies that dividend payouts move in opposite directions under the two effects. Specifically, if the signaling effect dominates, these banks would *increase* dividends, while if the resilience effect dominates, they would *decrease* dividends.

[Figure 6 here.]

To implement this test empirically, we use a proxy for the bank fundamentals and repeat the analysis for a subset of relatively strong banks. Specifically, we consider a subsample of banks with average Return on Assets (RoA) in 2009 above the median.[26] Panel (b) of Figure 6 plots the evolution of dividends for this subsample of banks. The pattern is very similar to the one in the left panel. Overall, we conclude that Figure 6 is consistent with a strong signaling effect.

Next, we test the second prediction (cf. Proposition 3) – exposure to rollover risk decreases the sensitivity of dividends to fundamentals. In Figure 7, we plot the standard deviation of dividend growth against the average share of short-term debt relative to assets for different U.S. industries. Therefore, variation in the share of short-term debt captures variation in the exposure to rollover risk, while variation in the standard deviation of dividend growth captures variation about the sensitivity of dividends to fundamentals in a sector. These two quantities are negatively related, suggesting that dividends are less variable in industries that rely more on short-term funding. This is consistent with dividend payouts being less sensitive to fundamentals in industries where rollover risk is higher.

[Figure 7 here.]

[25] For example, for the exogenous information case in Section 3.1, one can show that in the limit as $\alpha_\theta \to \infty$, when the crowd-out effect is switched off, an increase in p (weakly) increases $d(\theta)$.

[26] The results are qualitatively similar if we use other proxies for fundamentals such as return on equity or if we use a higher cutoff on 2009 RoA.

6 Why Do Banks Signal through Dividends?

Our analysis focuses on dividend payouts as a signal of a bank's available liquidity. This is motivated by the recent financial crisis and the possible use of dividend signaling to manage coordination-based runs. However, banks also take other actions in times of financial stress to signal "balance sheet strength" that seem to worsen their liquidity positions. For example, Duffie (2010) provides a description of a hypothetical dealer bank's actions in response to financial stress. He notes that the bank "... takes actions that worsen its liquidity position in a rational gamble to signal its strength and protect its franchise value. [The bank] wishes to reduce the flight of its clients, creditors, and counterparties." Such actions include compensating clients for losses on investments arranged by the bank or continuing with over-the-counter (OTC) derivative trades that reduce available liquidity. Another related action, which is more relevant for classical bank runs, is the decision of a bank that faces a run by depositors to not suspend convertibility of deposits into cash immediately but instead to service withdrawing depositors. Although these actions are not our proximate motivation, our theoretical framework can be interpreted more broadly and used to analyze their signaling effects as well.

A bank can take other possible actions to convey information about its liquidity position and balance sheet. One alternative is information disclosure in the form of updated balance sheet data or other forms of bank health statements. A key challenge with such disclosures, however, is that such statements may not be credible. As an example, Lehman Brothers boasted a Tier 1 capital ratio of 11 % – well above the regulatory minimum – 5 days before its bankruptcy (The Economist, 2010).Another costly alternative to dividend payments is share repurchases. Without any difference in signaling, share repurchases look similar to dividends from the bank's perspective by constituting an outflow of liquidity. Empirically, however, the signaling content of share repurchases is less pronounced (Hirtle, 2014). One possible explanation is that share repurchases are most often discretionary and conducted in the open market. Given stock market volatility, it may be hard for market participants to infer from market prices whether a bank has discontinued a share repurchase program to save on liquidity.

7 Concluding Comments

U.S. banks paid large amounts in dividends during the financial crisis despite mounting losses. In our paper we study a framework that incorporates two distinct views of the underlying reasons for this behavior – risk shifting and signaling. We show that both of these increase the dividend payouts of lower-quality banks when there is a coordination-based run. First, more banks choose to liquidate early because of the rollover crisis, thus "beating creditors out the door." Second, banks that choose to survive pay higher dividends than is optimal for them in the absence of a rollover crisis, because lenders interpret higher dividends as good news about the bank's available liquidity. Therefore, through the lens of our model, both forces lead to banks with low asset quality paying high dividends during a financial crisis.

The signaling effect and related reluctance of banks to cut dividends due to an increased risk of a rollover crisis may also explain why banks were reluctant to issue new equity (essentially a negative dividend) during the financial crisis (Bigio, 2012). Examining the implications of new equity issuance in an environment with rollover crises is a potentially important extension of our framework that we leave for future research.

Appendix

A.1 Details on the Dividend Signaling Equilibrium Characterization

We first derive a condition under which in any monotone strategy equilibrium of this economy, the cutoff $\hat{d} \in (0, 1)$. To this end, we characterize the optimal dividend policy of a bank that faces a run of $A = 1$ regardless of its fundamentals θ.

Lemma 2. *Consider a bank that does face a run by all lenders, that is, $A = 1$, suppose that $\lambda \geq -v_l(\underline{\theta}, 0)$, and let $d_r(\theta)$ denote the bank's optimal dividend policy. Then banks with $\theta < \overline{\theta}$ choose $d_r(\theta) = \bar{l}(\theta)$, while banks with $\theta \geq \overline{\theta}$ choose $d_r(\theta) = d^*$, where d^* solves the first-order condition*

$$(\lambda + v_l(\theta, d^* + 1)) d^* = 0. \tag{A2}$$

Proof. See the Online Appendix. ■

Next, let us define $\hat{d}_{\max}$ as the unique solution to

$$\frac{\int_{-K}^{\overline{\theta}} \phi\left(\sqrt{\alpha}\left(\overline{\ell}\left(\theta\right) - \hat{d}_{\max}\right)\right) d\theta}{\int_{\overline{\theta}}^{K} \phi\left(\sqrt{\alpha}\left(d_r\left(\theta\right) - \hat{d}_{\max}\right)\right) d\theta} = \frac{1-p}{p}. \tag{A3}$$

By Lemma 1 and the discussion after it, it follows that for any α, there is a sufficiently large K, such that the left-hand side of (A3) is decreasing in $\hat{d}_{\max}$ and so (A32) can have at most one solution. Furthermore, the left-hand side of that expression can be made arbitrarily large (arbitrarily close to 0) for sufficiently small (large) values of $\hat{d}_{\max}$ and so there exists a solution. We can now state condition B3 which ensures that in any monotone equilibrium, $\hat{d} < 1$.

Assumption B3. $\hat{d}_{\max} < 1$.

Notice that $\hat{d}_{\max}$ is the signal of a marginal lender who is indifferent between running and rolling over if all other lenders run regardless of their signal, and hence banks suffer a run of $A = 1$ regardless of θ. Therefore, this is the lender cutoff in the most pessimistic possible case, when other lenders run regardless of their signals and only banks in the upper dominance region survive. As we show in the proof of Proposition 9 below, this condition then ensures that in any monotone strategy equilibrium, $\hat{d} < \hat{d}_{\max} < 1$.

Similarly, let $\hat{d}_{\min}$ be the unique solution to

$$\frac{\int_{-K}^{\theta^*} \phi\left(\sqrt{\alpha}\left(\overline{\ell}\left(\theta\right) - \hat{d}_{\min}\right)\right) d\theta}{\int_{\theta^*}^{K} \phi\left(\sqrt{\alpha}\left(d_{nr}\left(\theta\right) - \hat{d}_{\min}\right)\right) d\theta} = \frac{1-p}{p}, \tag{A4}$$

where θ^* and $d_{nr}(\theta)$ were defined in Proposition 1 that examines optimal bank behavior in the case of no run. As with the case of $\hat{d}_{\max}$ it is straightforward to show that for sufficiently large K, $\hat{d}_{\min}$is unique. Condition B4 then is analogous to condition B3:

Assumption B4. $\hat{d}_{\min} > 0$.

Therefore, $\hat{d}_{\min}$ is the signal of a marginal lender who is indifferent between running and rolling over if all other lenders roll over regardless of their signal and hence the bank experiences no run for any θ. Therefore, this is the lender cutoff in the most optimistic possible case, when other lenders do not run regardless of their signal and only banks with $\theta < \theta^*$ fail. As we show in the proof of Proposition 9 , this condition then ensures that in any monotone strategy equilibrium, $\hat{d} > \hat{d}_{\min} > 0$.

Finally, to show equilibrium uniqueness, we additionally have to show that there cannot exist equilibria in which higher dividends are interpreted as bad news about survival. Single crossing, $v_{l\theta} > 0$, is a sufficient condition for this together with K being sufficiently large, as we will show next.

Lemma 3. *There exists a $\overline{K}_2$ such that for $K > \overline{K}_2$, in any equilibrium of this economy* $\Pr\{\theta \in \Theta_F | d_i\}$ *is strictly decreasing in d_i, where $\Theta_F \subset \mathbb{R}$ denotes a set of fundamentals for which a bank chooses to fail.*

Proof. See the Online Appendix. ■

An equilibrium in monotone strategies consists of a lender cutoff $\hat{d}$, a bank cutoff θ_f and a bank dividend policy $d(\theta)$.

Proposition 9. *Consider equilibria of this economy, in which lenders follow a monotone strategy with cutoff at $\hat{d}$. In those equilibria banks fail according to a cutoff θ_f, and $\hat{d}$ and θ_f jointly satisfy conditions (20) and (14), where the banks follow a dividend policy $d(\theta)$ given by Equation (16). Furthermore, if θ_f and $\hat{d}$ are unique, and assumptions B3 and B4 hold, then there exist a $\overline{K}_2 > 0$ such that for $K > \overline{K}_2$ the unique monotone strategy equilibrium is also the unique equilibrium of this economy.*

Proof. See the Online Appendix. ■

A.2. Omitted Proofs

Proof of Proposition 1. The bank owner solves

$$\tilde{W}(\theta) = \max_{d \in [0, \ell(\theta)]} \{\lambda d + v(\theta, d)\}.$$

Taking the first-order condition with respect to d and given Assumption B2, the optimal d^* solves

$$\lambda = -v_l(\theta, d^*) + \kappa_{\overline{\ell}},$$

where $\kappa_{\overline{\ell}}$ is the Lagrange multiplier on the liquidity constraint $l \leq \overline{\ell}(\theta)$, so that $\kappa_{\overline{\ell}}$ and d^* satisfy the complementary slackness condition $\kappa_{\overline{\ell}}\left(\overline{\ell}(\theta) - d^*\right) = 0$. Therefore, d^* satisfies

$$[\lambda + v_l(\theta, d^*)]\left(\overline{\ell}(\theta) - d^*\right) = 0, \tag{A5}$$

Let

$$\varphi(\theta) \equiv \lambda\overline{\ell}(\theta) - \tilde{W}(\theta).$$

Given Assumption B1, $\varphi(\theta)$ is (weakly) decreasing in θ. To show this, note first that $\tilde{W}(\theta) \geq \lambda\overline{\ell}(\theta)$ with equality, whenever $d^* = \overline{\ell}(\theta)$, so $\varphi(\theta) \leq 0$. Also, note that because the problem is convex, $\tilde{W}$ is differentiable for $d^* \in \left(0, \overline{\ell}(\theta)\right)$ and an envelope theorem holds. Therefore, $\varphi(\theta)$ is also differentiable for $d^* \in \left(0, \overline{\ell}(\theta)\right)$. Also, by the theorem of the maximum, $\tilde{W}(\theta)$ is continuous in θ, so d^* and $\varphi(\theta)$ are also continuous in θ. Therefore, there are intervals of $\{\theta \geq \underline{\theta}\}$, where d^* may be in the interior or on the upper boundary of the feasible set. Denote those by Θ_I, and Θ_U, respectively. For $\theta \in \Theta_U$, $\varphi(\theta) = 0$. Similarly, for $\theta \in \Theta_I$, applying the envelope theorem, we obtain

$$\varphi'(\theta) = \lambda\overline{\ell}'(\theta) - v_\theta(\theta, d^*). \tag{A6}$$

New we show that $\varphi(\theta)$ is strictly decreasing in θ, for any $\theta_0 \in \Theta_I$. Noting that $\overline{\ell}' = -\frac{v_\theta\left(\theta_0, \overline{\ell}(\theta_0)\right)}{v_l\left(\theta_0, \overline{\ell}(\theta_0)\right)}$ and using the first-order condition for d^* at θ_0, $\lambda = -v_l(\theta_0, d^*(\theta_0))$, we obtain

$$\begin{aligned} \varphi'(\theta_0) &= v_l(\theta_0, d^*(\theta_0)) \frac{v_\theta\left(\theta_0, \overline{\ell}(\theta_0)\right)}{v_l\left(\theta_0, \overline{\ell}(\theta_0)\right)} - v_\theta(\theta_0, d^*(\theta_0)) & \text{(A7)} \\ &= v_l(\theta_0, d^*(\theta_0)) \left(\frac{v_\theta\left(\theta_0, \overline{\ell}(\theta_0)\right)}{v_l\left(\theta_0, \overline{\ell}(\theta_0)\right)} - \frac{v_\theta(\theta_0, d^*(\theta_0))}{v_l(\theta_0, d^*(\theta_0))}\right) < 0, & \text{(A8)} \end{aligned}$$

where the last inequality comes from Assumption B1 and from $v_l < 0$.

Finally, given assumption B2 a nonincreasing $\varphi(\theta)$ implies that there is a unique critical value of θ, θ^{nr}, such that for a bank with $\theta \leq \theta^{nr}$, $d^* = \overline{\ell}(\theta)$ and for a bank with $\theta > \theta^{nr}$, $d^* < \overline{\ell}(\theta)$.

Furthermore, $v_{l\theta} > 0$, and continuity of d^* imply that $d^* > 0$ for $\theta > \theta^{nr}$. To show this, note that for $\theta \in \Theta_I$, $\frac{\partial d^*}{\partial \theta} = -\frac{v_{l\theta}}{v_{ll}} > 0$, and because $d^* > 0$, for $\theta \leq \theta^{nr}$ and is continuous, there can be no value of $\theta > \theta^{nr}$, for which $d^* = 0$. Finally, d^* is increasing in θ, because $\frac{\partial d^*}{\partial \theta} = \overline{\ell}'(\theta)$, for $\theta < \theta^{nr}$. Finally, notice that continuity of d^* implies that θ^{nr} must solve

$$\lambda = -v_l\left(\theta^{nr}, \overline{\ell}\left(\theta^{nr}\right)\right). \tag{A9}$$

■

Proof of Proposition 2 We show this result in several steps. First, we show that for every strategic cutoff $\hat{\theta}$, there is a unique $\theta_f \in (\underline{\theta}, \overline{\theta})$, such that the bank fails for $\theta \leq \theta_f$ and survives otherwise. We also characterize the bank's optimal dividend policy. Next, we show some properties of $\hat{\pi}\left(x, \hat{\theta}\right)$ and conclude that there is a unique strategic cutoff $\hat{\theta}$. Finally, we argue using an interim rationalizability argument that the monotone strategy equilibrium is the unique equilibrium of the game.

A.2.1 Bank problem. The bank-owner solves

$$\tilde{W}(\theta) = \max_{d \in \left[0, \overline{\ell}(\theta)\right]} \left\{\lambda d + \mathbf{1}_{\left\{d + A\left(\theta, \hat{\theta}\right) \leq \overline{\ell}(\theta)\right\}} v\left(\theta, d + A\left(\theta, \hat{\theta}\right)\right)\right\}.$$

Let us define $\mathcal{D}\left(\theta, \hat{\theta}\right) = \left\{d : d \geq 0, d + A(\theta, \hat{\theta}) \leq \overline{\ell}(\theta)\right\} \subset \left[0, \overline{\ell}(\theta)\right]$. Given the properties of $\overline{\ell}(\theta)$ and $A\left(\theta, \hat{\theta}\right)$, $\mathcal{D}\left(\theta_1, \hat{\theta}\right) \subset \mathcal{D}\left(\theta_2, \hat{\theta}\right)$, $\forall \theta_1 < \theta_2$. Specifically, given the properties of $\overline{\ell}$ and A, there is a $\theta_0 \geq \underline{\theta}$, such that $A\left(\theta_0, \hat{\theta}\right) = \overline{\ell}(\theta_0)$,and

$$\mathcal{D}\left(\theta, \hat{\theta}\right) = \begin{cases} \emptyset & , \theta < \theta_0 \\ \left[0, \overline{\ell}(\theta) - A\left(\theta, \hat{\theta}\right)\right] & , \theta \geq \theta_0 \end{cases}.$$

If $\mathcal{D}\left(\theta, \hat{\theta}\right) = \emptyset$, then the bank cannot meet the withdrawals of lenders. In that case it is optimal for the bank to set $d = \overline{\ell}(\theta)$, the bank-owner obtains $\tilde{W}(\theta) = \lambda\overline{\ell}(\theta) + \kappa$, and the bank fails. If $\mathcal{D}\left(\theta, \hat{\theta}\right) \neq \emptyset$, then the bank can choose between:

- Setting $d = \overline{\ell}(\theta)$ and obtaining $\tilde{W}(\theta) = \lambda\overline{\ell}(\theta)$;

- Solving

$$\max_{d\in\mathcal{D}} \lambda d + v\left(\theta, d + A(\theta,\hat{\theta})\right). \tag{A10}$$

Two cases are possible depending on the parameters. In the first case, $\theta_0 \leq \theta^{nr}$, where θ^{nr} was defined in (6). In that case for $\theta \in [\theta_0, \theta^{nr}]$, $\lambda > -v_l\left(\theta, \overline{\ell}(\theta)\right) \geq -v_l\left(\theta, A\left(\theta,\hat{\theta}\right)\right)$ and so the value of d that maximizes (A10) is $d^* = \overline{\ell}(\theta) - A\left(\theta,\hat{\theta}\right)$. However, in that case it is clearly optimal for the bank-owner to choose $d = \overline{\ell}(\theta) > \overline{\ell}(\theta) - A\left(\theta,\hat{\theta}\right)$. Furthermore, for $\theta > \theta^{nr}$, the value of d that maximizes (A10) satisfies the first-order condition

$$\lambda = -v_l\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right). \tag{A11}$$

In the second case, $\theta_0 > \theta^{nr}$. In that case, there is a value of $\theta > \theta_0$, which we can denote by θ_1 such that $d_{nr}(\theta_1) = A\left(\theta_1,\hat{\theta}\right)$, where $d_{nr}(\theta)$ is defined in (7). In that case, for $\theta \in [\theta_0, \theta_1]$, the value of d that maximizes (A10) is $d^* = 0$, because $\lambda \leq -v_l\left(\theta, A(\theta,\hat{\theta})\right)$. For $\theta > \theta_1$, the value of d that maximizes (7) satisfies (A11).

Putting these two cases together, it follows that the value of d that maximizes (A10) in all relevant cases satisfies

$$\left[\lambda + v_l\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right)\right] d^* = 0. \tag{A12}$$

In those cases, the bank-owner compares

$$\lambda\overline{\ell}(\theta) \gtrless \lambda d^* + v\left(\theta, d^* + A(\theta,\hat{\theta})\right). \tag{A13}$$

Whenever the left-hand side is higher than the right-hand side, it sets $d = \overline{\ell}(\theta)$. Otherwise, it sets $d = d^*$.

Next, define

$$\varphi(\theta) \equiv \lambda\overline{\ell}(\theta) - \lambda d^* - v\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right), \tag{A14}$$

for $\theta \geq \max\{\theta_0, \theta^{nr}\}$, where d^* solves (A12), and let $\theta_f \geq \max\{\theta_0, \theta^{nr}\}$ solve

$$\varphi(\theta_f) = 0. \tag{A15}$$

The lower and upper dominance region assumptions ensure that θ_f exists. To show this, note that at $\theta = \theta_0$,

$$\varphi(\theta_0) = \lambda\bar{\ell}(\theta_0) - v\left(\theta_0, \bar{\ell}(\theta_0)\right) > 0. \tag{A16}$$

Also, for $\theta > \bar{\theta}$, the upper dominance region assumption implies that

$$\begin{aligned} \lambda\bar{\ell}(\theta) < v(\theta,1) &\leq \lambda\left(1 - A\left(\theta,\hat{\theta}\right)\right) + v(\theta,1) \\ &\leq \lambda d^* + v\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right), \end{aligned} \tag{A17}$$

where the next-to-last inequality in (A17) comes from observing that $A\left(\theta,\hat{\theta}\right) \leq 1$ and $v_l < 0$, while the last inequality comes from individual optimality and feasibility of choosing $d = 1 - A\left(\theta,\hat{\theta}\right)$ (revealed preference). Thus, $\varphi(\theta) < 0$ for $\theta > \bar{\theta}$.

Next, Assumption B1 ensures that θ_f is unique. To show this, first note that because the problem in (A10) is convex, the value function associated with it is differentiable and an envelope theorem holds. Therefore, $\varphi(\theta)$ is differentiable as well. Differentiating $\varphi(\theta)$ and applying the envelope theorem for (A10), we obtain

$$\varphi'(\theta) = \lambda\bar{\ell}'(\theta) - v_\theta\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right) - v_l\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right) A_\theta\left(\theta,\hat{\theta}\right). \tag{A18}$$

Using the first order condition $\lambda \leq -v_l\left(\theta, d^* + A(\theta,\hat{\theta})\right)$ and $\bar{\ell}' = -\frac{v_\theta}{v_l}$, we obtain

$$\begin{aligned} \varphi'(\theta) &\leq -v_l\left(\theta, d^* + A(\theta,\hat{\theta})\right)\bar{\ell}'(\theta) - v_\theta\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right) - v_l\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right) A_\theta\left(\theta,\hat{\theta}\right) \\ &= v_l\left(\theta, d^* + A(\theta,\hat{\theta})\right)\frac{v_\theta\left(\theta,\bar{\ell}(\theta)\right)}{v_l\left(\theta,\bar{\ell}(\theta)\right)} - v_\theta\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right) - v_l\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right) A_\theta\left(\theta,\hat{\theta}\right) \\ &= v_l\left(\theta, d^* + A(\theta,\hat{\theta})\right)\left(\frac{v_\theta\left(\theta,\bar{\ell}(\theta)\right)}{v_l\left(\theta,\bar{\ell}(\theta)\right)} - \frac{v_\theta\left(\theta, d^* + A\left(\theta,\hat{\theta}\right)\right)}{v_l\left(\theta, d^* + A(\theta,\hat{\theta})\right)} - A_\theta\left(\theta,\hat{\theta}\right)\right) < 0, \end{aligned} \tag{A19}$$

where the last inequality comes from Assumption B1 and from observing that $A_\theta < 0$.

Therefore, any bank with $\theta \leq \theta_f$ optimally sets $d = \bar{\ell}(\theta)$, while a bank with $\theta > \theta_f$ sets $d = d^*$ that solves (A12). Moreover, θ_f solves

$$\lambda\bar{\ell}(\theta_f) = \lambda d^*(\theta_f) - v\left(\theta_f, d^*(\theta_f) + A\left(\theta_f,\hat{\theta}\right)\right) \tag{A20}$$

Using (10), we have that $A\left(\theta_f, \hat{\theta}\right) = \Phi\left(\sqrt{\alpha_\theta}\left(\hat{\theta} - \theta_f\right)\right) = p$, so θ_f satisfies (9).

A.2.2 Lender's problem. We have

$$\begin{aligned}\hat{\pi}(x, \theta_f) &= p - \Pr\left\{\bar{\ell} - d > A | x\right\} \\ &= p - \Pr\left\{\theta > \theta_f | x\right\}.\end{aligned}$$

With a diffuse prior over θ, Bayes' rule implies that $\theta | x \sim N\left(x, \alpha_\theta^{-1}\right)$. Therefore,

$$\Pr\left\{\theta > \theta_f | x\right\} = 1 - \Phi\left(\sqrt{\alpha_\theta}\left(\theta_f - x\right)\right) = \Phi\left(\sqrt{\alpha_\theta}\left(x - \theta_f\right)\right).$$

Therefore, $\hat{\theta}$ satisfies

$$\Phi\left(\sqrt{\alpha_\theta}\left(\hat{\theta} - \theta_f\right)\right) = p. \tag{A21}$$

A.2.3 Unique monotone equilibrium. Note that (9) only depends on θ_f. Moreover,

$$\tilde{\varphi}\left(\theta_f\right) = \lambda\bar{\ell}\left(\theta_f\right) - \lambda d^*\left(\theta_f\right) - v\left(\theta_f, d^*\left(\theta_f\right) + p\right) \tag{A22}$$

is strictly decreasing in θ_f by Assumption B1 and so θ_f is unique. Finally, $\hat{\theta}$ is uniquely determined in (10), given θ_f.

A.2.4 Rationalizability. This part of the proof is standard, and, for brevity, it is included in the Online Appendix.

■

Proof of Proposition 3. The bank-owner solves

$$W(\theta) = \max_{d \in \left[0, \bar{\ell}(\theta)\right]} \left\{\lambda d + \mathbf{1}_{\left\{d + A\left(d, \hat{d}\right) \leq \bar{\ell}(\theta)\right\}} v\left(\theta, d + A\left(d, \hat{d}\right)\right)\right\}.$$

Let $d_{nr}^*(\theta)$ and $\tilde{W}_{nr}(\theta)$ denote that optimal dividend policy and value function for a bank that faces no run. Also, let θ_{nr}^* denote that value of θ for which $d_{nr}^*(\theta) = \bar{\ell}(\theta)$ (see Proposition 1). Additionally, let us define $\mathcal{D}\left(\theta, \hat{d}\right) = \left\{d : d \geq 0,\ d + A(d, \hat{d}) \leq \bar{\ell}(\theta)\right\} \subset \left[0, \bar{\ell}(\theta)\right]$. Given the properties of $\bar{\ell}(\theta)$, $\mathcal{D}\left(\theta_1, \hat{d}\right) \subset \mathcal{D}\left(\theta_2, \hat{d}\right)$, $\forall \theta_1 < \theta_2$. Because $d_{\min}$ is the global minimizer of

$d + A\left(d, \hat{d}\right)$, it follows that

$$\mathcal{D}\left(\theta, \hat{d}\right) = \begin{cases} \emptyset & , \ \theta < \theta_0 \\ \left[d_{\min}, \overline{d}(\theta)\right] & , \ \theta \geq \theta_0 \end{cases}, \tag{A23}$$

where $\overline{d}(\theta) > d_{\min}$ solves $\overline{d}(\theta) + A(\overline{d}(\theta), \hat{d}) = \overline{\ell}(\theta)$, and θ_0 solves

$$\overline{\ell}(\theta_0) = d_{\min} + A\left(d_{\min}, \hat{d}\right). \tag{A24}$$

If $\mathcal{D}\left(\theta, \hat{d}\right) = \emptyset$, then the bank cannot meet the withdrawals of lenders. In that case it is optimal for the bank to set $d = \overline{\ell}(\theta)$ and $g = 0$, the bank-owner obtains $\tilde{W}(\theta) = \lambda \overline{l}(\theta)$, and the bank fails. If $\mathcal{D}\left(\theta, \hat{d}\right) \neq \emptyset$, then the bank can choose between:

- Setting $d = \overline{\ell}(\theta)$ and obtaining $\tilde{W}(\theta) = \lambda \overline{\ell}(\theta)$
- Solving

$$\max_{d \in \left[d_{\min}, \overline{d}(\theta)\right]} \lambda d + v\left(\theta, d + A(d, \hat{d})\right). \tag{A25}$$

Taking the f.o.c. with respect to d, the optimal d^* satisfies

$$\lambda + v_l\left(\theta, d^* + A\left(d^*, \hat{d}\right)\right)\left(1 + A_d\left(d^*, \hat{d}\right)\right) + \kappa_{\overline{\ell}} \leq 0$$

where $\kappa_{\overline{\ell}}$ and d^* satisfy the complementary slackness condition $\kappa_{\overline{\ell}}\left(\overline{\ell}(\theta) - d^* - A(d^*, \hat{d})\right) = 0$.[27] Notice, however, that whenever, $d^* + A(d^*, \hat{d}) = \overline{\ell}(\theta)$, the bank is better off setting $d = \overline{\ell}(\theta)$ and $g = 0$, so one can disregard this case. Similarly, $d^* = d_{\min}$ only if $\overline{\ell}(\theta) = d_{\min}$ but in that case the bank is better off setting $d = \overline{\ell}(\theta)$ and $g = 0$ as well.

For a value of $d^* > d_{\min}$ that satisfies

$$\lambda + v_l\left(\theta, d^* + A\left(d^*, \hat{d}\right)\right)\left(1 + A_d\left(d^*, \hat{d}\right)\right) = 0, \tag{A27}$$

[27] It is straightforward to show that $d^* \leq d_{\min}$ also satisfies the second-order condition

$$v_{ll}(\theta, d^* + A)(1 + A_d) + v_l(\theta, d^* + A) A_{dd} < 0. \tag{A26}$$

the bank owner compares

$$\lambda\overline{\ell}\left(\theta\right) \gtrless \lambda d^{*} + v\left(\theta, d^{*} + A(d^{*}, \hat{d})\right). \tag{A28}$$

Whenever the left-hand side is higher than the right-hand side, the bank sets $d = \overline{\ell}\left(\theta\right)$ and $g = 0$. Otherwise, it sets $d = d^{*}$ and $g = A\left(d^{*}, \hat{d}\right)$.

Next, define

$$\varphi\left(\theta\right) \equiv \lambda\overline{\ell}\left(\theta\right) - \lambda d^{*} - v\left(\theta, d^{*} + A\left(\theta, \hat{\theta}\right)\right), \tag{A29}$$

for $\theta \geq \theta_0$, where d^{*} solves (A27), and let $\theta_f \geq \theta_0$ solve

$$\varphi\left(\theta_f\right) = 0. \tag{A30}$$

The lower and upper dominance region assumptions ensure that θ_f exists. To show this, note that at $\theta = \theta_0$,

$$\begin{aligned}\varphi\left(\theta_0\right) &= \lambda\overline{\ell}\left(\theta_0\right) - \lambda d_{\min} - v\left(\theta_0, \overline{\ell}\left(\theta_0\right)\right)\\ &= \lambda\overline{\ell}\left(\theta_0\right) - \lambda d_{\min} - \kappa > 0.\end{aligned} \tag{A31}$$

Also, for $\theta > \overline{\theta}$, the upper dominance region assumption implies that

$$\begin{aligned}\lambda\overline{\ell}\left(\theta\right) &< v\left(\theta, 1\right) \leq \lambda\tilde{d}_1 + v\left(\theta, 1\right)\\ &\leq \lambda d^{*} + v\left(\theta, d^{*} + A\left(d^{*}, \hat{d}\right)\right),\end{aligned} \tag{A32}$$

where $\tilde{d}_1 \geq d_{\min}$ solves $\tilde{d}_1 + A\left(\tilde{d}_1, \hat{d}\right) = 1$. The last inequality in (A32) comes from individual optimality and feasibility of choosing $d = \tilde{d}_1$ (revealed preference). Thus, $\varphi\left(\theta\right) < 0$ for $\theta > \underline{\theta}$.

Next, Assumption B1 ensures that θ_f is unique. To show this, first note that the problem (A25) is convex so the value function associated with it is differentiable and an envelope theorem holds. Therefore, $\varphi\left(\theta\right)$ is also differentiable. Next, notice that (A27) also implies that d^{*} is continuous in θ. Differentiating $\varphi\left(\theta\right)$ and applying the envelope theorem, we get

$$\varphi'\left(\theta\right) = \lambda\overline{\ell}'\left(\theta\right) - v_{\theta}\left(\theta, d^{*} + A\left(d^{*}, \hat{d}\right)\right). \tag{A33}$$

Using $\overline{\ell}' = -\frac{v_\theta}{v_l}$, we obtain

$$\begin{aligned}\varphi'(\theta) &= -\lambda \frac{v_\theta\left(\theta_0, \overline{\ell}(\theta_0)\right)}{v_l\left(\theta_0, \overline{\ell}(\theta_0)\right)} - v_\theta\left(\theta, d^* + A\left(d^*, \hat{d}\right)\right) \\ &= v_l\left(\theta, d^* + A(d^*, \hat{d})\right) \frac{v_\theta\left(\theta_0, \overline{\ell}(\theta_0)\right)}{v_l\left(\theta_0, \overline{\ell}(\theta_0)\right)} - v_\theta\left(\theta, d^* + A\left(d^*, \hat{d}\right)\right) \\ &= v_l\left(\theta, d^* + A(d^*, \hat{d})\right)\left(\frac{v_\theta\left(\theta_0, \overline{\ell}(\theta_0)\right)}{v_l\left(\theta_0, \overline{\ell}(\theta_0)\right)} - \frac{v_\theta\left(\theta, d^* + A\left(d^*, \hat{d}\right)\right)}{v_l\left(\theta, d^* + A(d^*, \hat{d})\right)}\right) < 0,\end{aligned} \tag{A34}$$

where the second line follows from the first order condition $\lambda = -v_l\left(\theta, d^* + A(d^*, \hat{d})\right)$, and the last inequality comes from Assumption B1.

Therefore, any bank with $\theta \leq \theta_f$ optimally sets $d = \overline{\ell}(\theta)$ and $g = 0$, while a bank with $\theta > \theta_f$ sets $d = d^*$ that solves (A27) and $g = A\left(d^*, \hat{d}\right)$.

Finally, d is discontinuous at $\theta = \theta_f$. with $d\left(\theta_f^-\right) > d\left(\theta_f^+\right)$. ■

Proof of Lemma 1 It will be useful to work with the posterior odds that the bank fails, that is,

$$\begin{aligned}h(d_i, \theta_f) \equiv \frac{\Pr\{\theta < \theta_f | d_i\}}{\Pr\{\theta > \theta_f | d_i\}} &= \frac{\int_{-K}^{K} f(d_i|\theta) f\left(\theta|\theta < \theta^f\right) d\theta \Pr\{\theta < \theta_f\}}{\int_{-K}^{K} f(d_i|\theta) f\left(\theta|\theta > \theta^f\right) d\theta \Pr\{\theta > \theta_f\}} \\ &= \frac{\int_{-K}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\overline{\ell}(\theta) - d_i\right)\right) d\theta}{\int_{\theta_f}^{K} \phi\left(\sqrt{\alpha}\left(d^*(\theta) - d_i\right)\right) d\theta},\end{aligned}$$

where the last line uses the symmetry of the normal pdf around the mean and an improper prior over θ. Let

$$N(d_i, \theta_f) \equiv \int_{-K}^{\theta_f} \sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(\overline{\ell}(\theta) - d_i\right)\right) d\theta,$$

and

$$D(d_i, \theta_f) \equiv \int_{\theta_f}^{K} \sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(d^*(\theta) - d_i\right)\right) d\theta.$$

Then

$$h(d_i, \theta_f) = \frac{N(d_i, \theta_f)}{D(d_i, \theta_f)},$$

and so

$$\log\left(h(d_i, \theta_f)\right) = \log\left(N(d_i, \theta_f)\right) - \log\left(D(d_i, \theta_f)\right).$$

Therefore, $h(d_i, \theta_f)$ is decreasing in d_i, iff $\log(h(d_i, \theta_f))$ is decreasing in d_i, which will be the case iff

$$\frac{N_{d_i}}{N} < \frac{D_{d_i}}{D}.$$

Note that

$$\begin{aligned}
\frac{N_{d_i}}{N} &= -\frac{\int_{-K}^{\theta_f} \phi'\left(\sqrt{\alpha}\left(\bar{\ell}(\theta) - d_i\right)\right) d\theta}{\int_{-K}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\bar{\ell}(\theta) - d_i\right)\right) d\theta} \\
&= \int_{-K}^{\theta_f} \alpha\left(\bar{\ell}(\theta) - d_i\right) \frac{\phi\left(\sqrt{\alpha}\left(\bar{\ell}(\theta) - d_i\right)\right)}{\int_{-K}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\bar{\ell}(\theta) - d_i\right)\right) dz} d\theta \\
&= \alpha\left\{E_{N,i}\left[\bar{\ell}(\theta)\right] - d_i\right\}.
\end{aligned}$$

Similarly,

$$\frac{D_x}{D} = \alpha\left\{E_{D,i}\left[d^*(\theta)\right] - d_i\right\}$$

Therefore, the comparison simplifies to

$$\alpha\left\{E_{N,i}\left[\bar{\ell}(\theta)\right] - d_i\right\} < \alpha\left\{E_{D,i}\left[d^*(\theta)\right] - d_i\right\}$$

or

$$E_{N,i}\left[\bar{\ell}(\theta)\right] < E_{D,i}\left[d^*(\theta)\right].$$

■

Proof of Proposition 4 A lender with signal $\hat{d}$ is indifferent between running and rolling over whenever

$$\Pr\left\{\theta < \theta_f | \hat{d}\right\} = 1 - p,$$

or equivalently,

$$\frac{\Pr\left\{\theta < \theta_f | \hat{d}\right\}}{\Pr\left\{\theta > \theta_f | \hat{d}\right\}} = \frac{1-p}{p}.$$

Next, notice that by the lower dominance assumption, $\bar{\ell}(\theta) = 0$, for $\theta \leq \underline{\theta}$. Therefore, we can rewrite $E_{N,i}\left[\bar{\ell}(\theta)\right]$ as

$$\begin{aligned} E_{N,i}\left[\bar{\ell}(\theta)\right] &= \left(1-\Psi_{N,i}(\underline{\theta})\right) E_{N,i}\left[\bar{\ell}(\theta) \,|\theta \in [\underline{\theta}, \theta_f]\right], \\ &\leq \left(1-\Psi_{N,i}(\underline{\theta})\right) \bar{\ell}(\theta_f) \leq 1-\Psi_{N,i}(\underline{\theta}) \end{aligned}$$

where $\Psi_{N,i}(x)$ denotes the cumulative distribution function of $\psi_{N,i}(x)$. The first inequality follows from the strict monotonicity of $\bar{\ell}(\theta)$ and the second inequality follows from the observation that $\theta_f \leq \bar{\theta}$ and the upper dominance region assumption. On the other hand, by Proposition 3, $d^*(\theta) > d_{\min}$, so $E_{D,i}[d^*(\theta)] > d_{\min}$. However, observe that

$$\begin{aligned} \Psi_{N,i}(\underline{\theta}) &= \frac{\int_{-K}^{\underline{\theta}} \phi\left(\sqrt{\alpha}\left(\bar{\ell}(z)-d_i\right)\right) dz}{\int_{-K}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\bar{\ell}(z)-d_i\right)\right) dz} \\ &= \frac{\phi\left(\sqrt{\alpha}(d_i)\right)(\underline{\theta}+K)}{\phi\left(\sqrt{\alpha}(d_i)\right)(\underline{\theta}+K) + \int_{\underline{\theta}}^{\theta_f} \phi\left(\sqrt{\alpha}\left(\bar{\ell}(z)-d_i\right)\right) dz} \\ &= \frac{1}{1+\frac{1}{\underline{\theta}+K}\int_{\underline{\theta}}^{\theta_f} \frac{\phi\left(\sqrt{\alpha}\left(\bar{\ell}(z)-d_i\right)\right)}{\phi\left(\sqrt{\alpha} d_i\right)} dz} \\ &\geq \frac{1}{1+\frac{\theta_f-\underline{\theta}}{\underline{\theta}+K}\max_{z\in[\underline{\theta},\theta_f]} \frac{\phi\left(\sqrt{\alpha}\left(\bar{\ell}(z)-d_i\right)\right)}{\phi\left(\sqrt{\alpha} d_i\right)}} \end{aligned}$$

Therefore, for sufficiently large values of K one can ensure that $E_{N,i}\left[\bar{\ell}(\theta)\right] < d_{\min} < E_{D,i}[d^*(\theta)]$, for any d_i. Therefore, by Lemma 1, $\Pr\{\theta < \theta_f | d_i\}$ is monotone decreasing in d_i, and so is $\frac{\Pr\{\theta<\theta_f|d_i\}}{\Pr\{\theta>\theta_f|d_i\}}$. Also, clearly, $\frac{\Pr\{\theta<\theta_f|d_i\}}{\Pr\{\theta>\theta_f|d_i\}}$ can be made arbitrarily large (arbitrarily close to 0) for sufficiently small (large) d_i. Therefore, by the intermediate value theorem, there exists a unique marginal lender with signal $\hat{d}$ that satisfies (20). By the strict monotonicity of $\frac{\Pr\{\theta<\theta_f|d_i\}}{\Pr\{\theta>\theta_f|d_i\}}$, for any lender with $d_i < \hat{d}$, $\frac{\Pr\{\theta<\theta_f|d_i\}}{\Pr\{\theta>\theta_f|d_i\}} < \frac{1-p}{p}$, so that lender is strictly better off attacking. Similarly, any lender with $d_i > \hat{d}$ is strictly better off not attacking. ■

Proof of Proposition 5. Consider the condition for the marginal lender (20). First, let us multiply both the numerator and denominator on the left-hand side by $\sqrt{\alpha}$. Next, notice that both $\bar{\ell}(\theta)$ and $d^*(\theta)$ are differentiable, by the Implicit function theorem. Also, $\bar{\ell}(\theta)$ is strictly monotone on $[\underline{\theta}, \theta_f]$ and also $d^*(\theta)$ is strictly monotone for $\theta > \theta_f$ for sufficiently large α. To see the latter, note that by the implicit function theorem, from (15) we have that

$$\begin{aligned} d^{*\prime}(\theta) &= \frac{v_{l\theta}(\theta, d^* + A)}{-v_{ll}(\theta, d^* + A)(1 + A_d) - v_l \frac{A_{dd}}{1+A_d}} \\ &= - \frac{v_{l\theta}}{\frac{v_l^2}{\lambda}\alpha^{3/2}\left(d^* - \hat{d}\right)\phi\left(\sqrt{\alpha}\left(d^* - \hat{d}\right)\right) - \lambda\frac{v_{ll}}{v_l}}, \end{aligned}$$

where the second line uses condition (15) and the observation that

$$A_{dd} = \alpha\left(d^* - \hat{d}\right) - \alpha^{3/2}\left(d^* - \hat{d}\right)\phi\left(\sqrt{\alpha}\left(d^* - \hat{d}\right)\right),$$

and note that $\lim_{\alpha\to\infty}\alpha A_d = \lim_{\alpha\to\infty}\alpha^{3/2}\phi\left(\sqrt{\alpha}\left(d^* - \hat{d}\right)\right) = 0$ for any $d^* > \hat{d}$. Therefore, we can use a change of variable to rewrite the left-hand side of (20) as

$$\frac{\sqrt{\alpha}\phi\left(\hat{d}\right)(\underline{\theta} + K) + \int_0^{\bar{\ell}(\theta_f)} \frac{1}{\bar{\ell}'\left(\bar{\ell}^{-1}(x)\right)}\sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(x - \hat{d}\right)\right)dx}{\int_{d^*(\theta_f)}^{d^*(K)} \frac{1}{d^{*\prime}(d^{*-1}(x))}\sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(x - \hat{d}\right)\right)dx}.$$

Using integration by parts, we further obtain[28]

$$\begin{aligned} &\frac{\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}\right)(\underline{\theta} + K) + \frac{\Phi\left(\sqrt{\alpha}\left(\bar{\ell}(\theta_f) - \hat{d}\right)\right)}{\bar{\ell}'(\theta_f)} - \frac{\Phi\left(\sqrt{\alpha}\left(-\hat{d}\right)\right)}{\bar{\ell}'(\underline{\theta})} - \int_0^{\bar{\ell}(\theta_f)} \Phi\left(\sqrt{\alpha}\left(x - \hat{d}\right)\right)\frac{\partial}{\partial x}\left(\frac{1}{\bar{\ell}'\left(\bar{\ell}^{-1}(x)\right)}\right)dx}{\frac{\Phi\left(\sqrt{\alpha}\left(d^*(K) - \hat{d}\right)\right)}{d^{*\prime}(K)} - \frac{\Phi\left(\sqrt{\alpha}\left(d^*(\theta_f) - \hat{d}\right)\right)}{d^{*\prime}(\theta_f)} - \int_{d^*(\theta_f)}^{d^*(K)} \Phi\left(\sqrt{\alpha}\left(x - \hat{d}\right)\right)\frac{\partial}{\partial x}\left(\frac{1}{d^{*\prime}(d^{*-1}(x))}\right)dx} \\ &= \frac{\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}\right)(\underline{\theta} + K) + \frac{1 - A\left(\bar{\ell}(\theta_f), \hat{d}\right)}{\bar{\ell}'(\theta_f)} - \frac{1 - A\left(0, \hat{d}\right)}{\bar{\ell}'(\underline{\theta})} - \int_0^{\bar{\ell}(\theta_f)}\left(1 - A\left(x, \hat{d}\right)\right)\frac{\partial}{\partial x}\left(\frac{1}{\bar{\ell}'\left(\bar{\ell}^{-1}(x)\right)}\right)dx}{\frac{1 - A\left(d^*(K), \hat{d}\right)}{d^{*\prime}(K)} - \frac{1 - A\left(d^*(\theta_f), \hat{d}\right)}{d^{*\prime}(\theta_f)} - \int_{d^*(\theta_f)}^{d^*(K)}\left(1 - A\left(x, \hat{d}\right)\right)\frac{\partial}{\partial x}\left(\frac{1}{d^{*\prime}(d^{*-1}(x))}\right)dx} \\ &= \frac{\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}\right)(\underline{\theta} + K) + \frac{1 - A\left(\bar{\ell}(\theta_f), \hat{d}\right)}{\bar{\ell}'(\theta_f)} - \frac{1 - A\left(0, \hat{d}\right)}{\bar{\ell}'(\underline{\theta})} - \int_0^{\bar{\ell}(\theta_f)}\left(1 - A\left(x, \hat{d}\right)\right)\frac{\partial}{\partial x}\left(\frac{1}{\bar{\ell}'\left(\bar{\ell}^{-1}(x)\right)}\right)dx}{\frac{1 - A\left(d^*(K), \hat{d}\right)}{d^{*\prime}(K)} - \frac{1 - A\left(d^*(\theta^f), \hat{d}\right)}{d^{*\prime}(\theta^f)} - \left(\frac{1}{d^{*\prime}(K)} - \frac{1}{d^{*\prime}(\theta_f)}\right) + \int_{d^*(\theta_f)}^{d^*(K)} A\left(x, \hat{d}\right)\frac{\partial}{\partial x}\left(\frac{1}{d^{*\prime}(d^{*-1}(x))}\right)dx} \\ &= \frac{\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}\right)(\underline{\theta} + K) + \frac{1 - A\left(\bar{\ell}(\theta_f), \hat{d}\right)}{\bar{\ell}'(\theta_f)} - \frac{1 - A\left(0, \hat{d}\right)}{\bar{\ell}'(\underline{\theta})} - \int_0^{\bar{\ell}(\theta_f)}\left(1 - A\left(x, \hat{d}\right)\right)\frac{\partial}{\partial x}\left(\frac{1}{\bar{\ell}'\left(\bar{\ell}^{-1}(x)\right)}\right)dx}{\frac{A\left(d^*(K), \hat{d}\right)}{d^{*\prime}(K)} + \frac{A\left(d^*(\theta_f), \hat{d}\right)}{d^{*\prime}(\theta_f)} + \int_{d^*(\theta_f)}^{d^*(K)} A\left(x, \hat{d}\right)\frac{\partial}{\partial x}\left(\frac{1}{d^{*\prime}(d^{*-1}(x))}\right)dx}, \end{aligned}$$

[28] We implicitly assume that v is differentiable of sufficient order for the expression below.

where we use $\Phi\left(\sqrt{\alpha}\left(x-\hat{d}\right)\right)=1-\Phi\left(\sqrt{\alpha}\left(\hat{d}-x\right)\right)=1-A\left(x,\hat{d}\right)$ to substitute for the fraction of lenders attacking for a given dividend level x. Notice that from the bank's problem, $\overline{\ell}\left(\theta_f\right)\geq d^*\left(\theta^f\right)>d_{\min}>\hat{d}$, for sufficiently large α. Also, the integrals in the numerator and denominator exist for any α, and in the limit, as $\alpha\to\infty$, and lenders are perfectly coordinated.

$$A\left(x,\hat{d}\right)=\begin{cases}0 & ,\ x>\hat{d}\\ [0,1] & ,\ x=\hat{d}\\ 1 & ,\ x<\hat{d}\end{cases}$$

Thus,

$$\lim_{\alpha\to\infty}\frac{\int_{-K}^{\theta_f}\phi\left(\sqrt{\alpha}\left(\overline{\ell}\left(\theta\right)-\hat{d}\right)\right)d\theta}{\int_{\theta_f}^{K}\phi\left(\sqrt{\alpha}\left(d^*\left(\theta\right)-\hat{d}\right)\right)d\theta}=\frac{\lim_{\alpha\to\infty}\frac{1}{\overline{\ell}'\left(\overline{\ell}^{-1}(\hat{d})\right)}}{\lim_{\alpha\to\infty}\frac{A\left(d^*\left(\theta_f\right),\hat{d}\right)}{d^{*\prime}\left(\theta^f\right)}}=\frac{1-p}{p}$$

or

$$\lim_{\alpha\to\infty}\frac{A\left(d^*\left(\theta_f\right),\hat{d}\right)}{d^{*\prime}\left(\theta_f\right)}=\frac{p}{1-p}\lim_{\alpha\to\infty}\frac{1}{\overline{\ell}'\left(\overline{\ell}^{-1}\left(\hat{d}\right)\right)}.$$

Because $\lim_{\alpha\to\infty}A\left(d^*\left(\theta_f\right),\hat{d}\right)=0$, it follows that $d^{*\prime}\left(\theta_f\right)\to 0$, as well.

Next, consider the bank's problem. For $\theta>\theta_f$, we can combine conditions (15) and (7) and write condition (15) as

$$\frac{v_l\left(\theta,d_{nr}\left(\theta\right)\right)}{v_l\left(\theta,d^*\left(\theta\right)+A\left(d^*\left(\theta\right),\hat{d}\right)\right)}=1+A_d\left(d^*\left(\theta\right),\hat{d}\right). \tag{A35}$$

In the limit, as $\alpha\to\infty$ and lenders become perfectly coordinated, so $A_d\left(d^*,\hat{d}\right)\to 0$ for $d^*>\hat{d}$. Therefore, from (A35) we obtain

$$\frac{v_l\left(\theta,d_{nr}\left(\theta\right)\right)}{v_l\left(\theta,d^*\left(\theta\right)\right)}\to 1,$$

and so $d^*\left(\theta\right)\to d_{nr}\left(\theta\right)$. In addition, in the limit, the marginal bank that is indifferent between failing and surviving experiences no run in equilibrium, because $\lim_{\alpha\to\infty}A\left(d^*\left(\theta_f\right),\hat{d}\right)=0$. Therefore, condition (14) implies that

$$\lambda\overline{\ell}\left(\theta_f\right)=\lambda d^*\left(\theta_f\right)+v\left(\theta_f,d^*\left(\theta_f\right)\right).$$

However, by the definition of θ^* in (6), this in turn implies that $\theta_f\to\theta^*$ and $d^*\left(\theta_f\right)\to\overline{\ell}\left(\theta^*\right)$.

Finally, note that

$$d^{*'}(\theta_f) = -\frac{v_{l\theta}}{\frac{v_l^2}{\lambda}\alpha^{3/2}\left(d^*(\theta_f)-\hat{d}\right)\phi\left(\sqrt{\alpha}\left(d^*(\theta_f)-\hat{d}\right)\right)-\lambda\frac{v_{ll}}{v_l}} \to 0$$

implies that $\alpha^{3/2}\left(d^*(\theta_f)-\hat{d}\right)\phi\left(\sqrt{\alpha}\left(d^*(\theta_f)-\hat{d}\right)\right) \to \infty$, which can only be the case if $\hat{d} \to d^*(\theta_f)$. ■

Proof of Proposition 6 First, notice that we can treat both the failure threshold θ_f^P and the dividend cutoff $\hat{d}^P$ as choice variables for the policy maker, subject to two constraints. First, it must be feasible for banks with $\theta > \theta_f^P$ to survive given the dividend payout $d^P(\theta)$. The minimum such payout for surviving banks is given by $d_{\min}^P = \arg\min_d \left\{d + A\left(d, \hat{d}^P\right)\right\}$. Second, the dividend cutoff $\hat{d}^P$ must satisfy Equation (20) given θ_f^P and $d^P(\theta)$. Given these observations, we can write the policy maker's problem as

$$\min_{\theta_f^P, \hat{d}^P, d_{\min}^P, \{d^P(\theta)\}} \theta_f^P \tag{A36}$$

$$s.t.\ \theta_f^P \geq \bar{\ell}^{-1}\left(d_{\min}^P + A\left(d_{\min}^P, \hat{d}^P\right)\right), \tag{A37}$$

$$\frac{\int_{-K}^{\theta_f^P}\phi\left(\sqrt{\alpha}\left(d^P(\theta)-\hat{d}^P\right)\right)d\theta}{\int_{\theta_f^P}^{K}\phi\left(\sqrt{\alpha}\left(d^P(\theta)-\hat{d}^P\right)\right)d\theta} = \frac{1-p}{p}, \tag{A38}$$

$$d_{\min}^P = \arg\min_d \left\{d + A\left(d, \hat{d}^P\right)\right\}. \tag{A39}$$

$$d^P(\theta) \in \left[d_{\min}^P, \bar{\ell}(\theta)\right], \forall\theta > \theta_f^P, \tag{A40}$$

$$d^P(\theta) \in \left[0, \bar{\ell}(\theta)\right], \forall\theta \leq \theta_f^P, \tag{A41}$$

where $\bar{d}(\theta)$ solves $\bar{d}(\theta) + A\left(\bar{d}(\theta), \hat{d}^P\right) = \bar{\ell}(\theta)$.

We will first simplify the policy maker's problem (A36). Note that $d_{\min}^P = \hat{d}^P + C_0$, where $C_0 = \frac{1}{\sqrt{\alpha}}\phi_+^{-1}\left(\frac{1}{\sqrt{\alpha}}\right)$, and $\phi_+^{-1}(.)$ denotes the inverse of $\phi(.)$ over the positive part of the domain, which is a well-defined function. Similarly, $A\left(d_{\min}^P, \hat{d}^P\right) = C_1 = \Phi\left(\phi_+^{-1}\left(\frac{1}{\sqrt{\alpha}}\right)\right)$, so the feasibility constraint (A37) can be written as,

$$\theta_f^P \geq \bar{\ell}^{-1}\left(\hat{d}^P + C\right), \tag{A42}$$

where $C = C_0 + C_1$. Next, notice that $\frac{\partial \hat{d}^P}{\partial \theta_f^P} > 0$, for sufficiently large K (see the proof of Proposition 9). Therefore, the constraint (A37) must be binding at the optimum; otherwise, one can decrease θ_f^P and achieve a relaxation of the problem at the same time. Thus, we can substitute for $\theta_f^P = \bar{\ell}^{-1}\left(\hat{d}^P + C\right)$. Furthermore, notice that $\bar{\ell}^{-1}(.)$ is monotone increasing, so minimizing θ_f^P is equivalent to minimizing $\hat{d}^P$. Therefore, the policy maker's problem simplifies to[29]

$$\min_{\hat{d}^P, \{d^P(\theta)\}} \hat{d}^P \tag{A43}$$

$$s.t. \frac{\int_{-K}^{\bar{\ell}^{-1}(\hat{d}^P+C)} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta}{\int_{\bar{\ell}^{-1}(\hat{d}^P+C)}^{K} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta} = \frac{1-p}{p}, \tag{A44}$$

$$d^P(\theta) \in \left[\hat{d} + C_0, \bar{\ell}(\theta)\right], \forall \theta > \theta_f^P, \tag{A45}$$

$$d^P(\theta) \in \left[0, \bar{\ell}(\theta)\right], \forall \theta \le \theta_f^P, \tag{A46}$$

Hence, the policy maker's problem boils down to choosing $d^P(\theta)$ to induce the smallest $\hat{d}^P$ that is consistent with the lenders' inference and lender optimality. Furthermore, notice that the optimization over $\left\{d^P(\theta)\right\}$ is pointwise.[30]

Next, we will show that for sufficiently large values of α, $\partial \hat{d}^P / \partial d^P(\theta) > 0$, iff $d^P(\theta) < \hat{d}^P$, for $\theta < \theta_f^P$ and $\partial \hat{d}^P / \partial d^P(\theta) > 0$, iff $d^P(\theta) > \hat{d}$, for $\theta > \theta_f^P$. To show this, consider Equation (A44) and let

$$\Phi \equiv \frac{\int_{-K}^{\bar{\ell}^{-1}(\hat{d}^P+C)} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta}{\int_{\bar{\ell}^{-1}(\hat{d}^P+C)}^{K} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta}. \tag{A47}$$

denote its left-hand side. Therefore, $\partial \hat{d}^P / \partial d^P(\theta) = -\frac{\partial \Phi / \partial d^P(\theta)}{\partial \Phi / \partial \hat{d}^P(\theta)}$.[31] Consider first the sign of the denominator of this expression. For brevity, we will use again $\theta_f^P = \bar{\ell}^{-1}\left(\hat{d}^P + C\right)$ in the limits of the integrals in (A47). Also, to establish the sign of $\partial \Phi / \partial \hat{d}^P(\theta)$ we will consider the sign of

[29] Assumptions B3 and B4 ensure that $\hat{d} \in (0,1)$. Those assumptions hold also for the optimal dividend policy.

[30] Technically, for $\theta > \theta_f^P$, the choice of one value of d^P influences the feasible set for other values of d^P via its effect on $\hat{d}$. However, as we will see below even if we disregard the effect on the feasibility constraint, we still obtain that it is optimal to be at the lowest feasible value for d^P for any $\theta > \theta_f^P$.

[31] Technically, we cannot apply the implicit function theorem because $d^P(\theta)$ is infinite-dimensional. However, one can invoke the theorem under the assumption that the optimal policy $d^P(\theta)$ is a step function consisting of a large but finite number of steps, denoted by N, where the optimization is over the values d^P takes on disjoint intervals $\{I_i\}_{i=1}^N$ that cover $[-K, K]$. In that case, we let $\partial \hat{d}^P / \partial d^P(\theta)$ denote the partial derivative of $\hat{d}^P$ with respect to the value d^P takes over the interval I_i that θ lies in.

$\partial \log \Phi / \partial \hat{d}^P$. Notice that

$$\frac{d \log \Phi}{d\hat{d}^P} = \alpha \left[E_{N,\hat{d}} \left[d^P(\theta) \right] - E_{D,\hat{d}} \left[d^P(\theta) \right] \right] +,$$
$$+ \left[\frac{\phi\left(\sqrt{\alpha}\left(d^P\left(\theta_f^P\right) - \hat{d}^P\right)\right)}{\int_{-K}^{\theta_f^P} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta} + \frac{\phi\left(\sqrt{\alpha}\left(d^{P,+}\left(\theta_f^P\right) - \hat{d}^P\right)\right)}{\int_{\theta_f^P}^{K} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta} \right] \frac{\partial \theta_f^P}{\partial \hat{d}}$$

where $E_{N,\hat{d}}[.]$ and $E_{D,\hat{d}}[.]$ are defined immediately before Lemma 1. Furthermore, using (A44) and the mean-value theorem, we can rewrite the second line as

$$\frac{d \log \Phi}{d\hat{d}^P} = \alpha \left[E_{N,\hat{d}} \left[d^P(\theta) \right] - E_{D,\hat{d}} \left[d^P(\theta) \right] \right] +$$
$$+ \left[\frac{\phi\left(\sqrt{\alpha}\left(\bar{\ell}\left(\theta_f^P\right) - \hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\left(0 - \hat{d}^P\right)\right)(\underline{\theta} + K) + \phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right) - \hat{d}^P\right)\right)\left(\theta_f^P - \underline{\theta}\right)} \right.$$
$$\left. + \frac{1-p}{p} \frac{\phi\left(\sqrt{\alpha}\left(d^{P,+}\left(\theta_f^P\right) - \hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\left(0 - \hat{d}^P\right)\right)(\underline{\theta} + K) + \phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right) - \hat{d}^P\right)\right)\left(\theta_f^P - \underline{\theta}\right)} \right] \frac{\partial \theta_f^P}{\partial \hat{d}^P},$$

for $\tilde{\theta}_1 \in \left(\underline{\theta}, \theta_f^P\right)$. First, note that $\bar{\ell}\left(\theta_f^P\right) \geq d^{P,+}\left(\theta_f^P\right)$. Therefore, $\phi\left(\sqrt{\alpha}\left(\bar{\ell}\left(\theta_f^P\right) - \hat{d}^P\right)\right) \leq \phi\left(\sqrt{\alpha}\left(d^{P,+}\left(\theta_f^P\right) - \hat{d}^P\right)\right)$. Next, notice that

$$\frac{\phi\left(\sqrt{\alpha}\left(d^{P,+}\left(\theta_f^P\right) - \hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\left(0 - \hat{d}^P\right)\right)(\underline{\theta} + K) + \phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right) - \hat{d}^P\right)\right)\left(\theta_f^P - \underline{\theta}\right)}$$
$$\leq \frac{\phi\left(\sqrt{\alpha}\left(d^P_{\min} - \hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\left(0 - \hat{d}^P\right)\right)(\underline{\theta} + K) + \phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right) - \hat{d}^P\right)\right)\left(\theta_f^P - \underline{\theta}\right)}$$
$$= \frac{1}{(\underline{\theta} + K) \frac{\phi\left(\sqrt{\alpha}\left(0 - \hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\left(d^P_{\min} - \hat{d}^P\right)\right)} + \left(\theta_f^P - \underline{\theta}\right) \frac{\phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right) - \hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\left(d^P_{\min} - \hat{d}^P\right)\right)}}$$
$$= \frac{1}{(\underline{\theta} + K)\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}^P\right) + \left(\theta_f^P - \underline{\theta}\right)\sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right) - \hat{d}^P\right)\right)},$$

where in the last line we use $\phi\left(\sqrt{\alpha}\left(d^P_{\min} - \hat{d}^P\right)\right) = \phi\left(\sqrt{\alpha}\frac{1}{\sqrt{\alpha}}\phi_+^{-1}\left(\frac{1}{\sqrt{\alpha}}\right)\right) = \frac{1}{\sqrt{\alpha}}$ and the symmetry of the standard normal density. Let $\tilde{d}^P \geq \hat{d}^P$ solve

$$\frac{\int_{-K}^{\underline{\theta}} \phi\left(\sqrt{\alpha}\left(0-\tilde{d}^P\right)\right) d\theta + \int_{\underline{\theta}}^{\overline{\ell}^{-1}\left(\tilde{d}^P+C\right)} \phi\left(\sqrt{\alpha}\left(d^P(\theta)-\tilde{d}^P\right)\right) d\theta}{\int_{\overline{\ell}^{-1}\left(\tilde{d}^P+C\right)}^{K} \phi\left(\sqrt{\alpha}\left(\tilde{d}_{\min}-\tilde{d}^P\right)\right) d\theta} = \frac{1-p}{p},$$

where $\tilde{d}_{\min} = \arg\min_d \left\{d + A\left(d, \tilde{d}^P\right)\right\} \geq d_{\min}$. Suppose that $\hat{d}^P = \tilde{d}^P$. Then, we have that

$$\begin{aligned}\frac{1-p}{p} &= \frac{\int_{-K}^{\underline{\theta}} \phi\left(\sqrt{\alpha}\hat{d}^P\right) d\theta + \int_{\underline{\theta}}^{\overline{\ell}^{-1}\left(\hat{d}^P+C\right)} \phi\left(\sqrt{\alpha}\left(d^P(\theta)-\hat{d}^P\right)\right) d\theta}{\int_{\theta_f^P}^{K} \phi\left(\sqrt{\alpha}\left(d_{\min}^P-\hat{d}^P\right)\right) d\theta} = \\ &= \frac{\left(\underline{\theta}+K\right)\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}^P\right) + \left(\theta_f^P-\underline{\theta}\right)\sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right)-\hat{d}^P\right)\right)}{K-\theta_f^P}.\end{aligned}$$

Therefore,

$$\frac{1-p}{p}\frac{\phi\left(\sqrt{\alpha}\left(d^{P,+}\left(\theta_f^P\right)-\hat{d}^P\right)\right)}{\phi\left(\sqrt{\alpha}\hat{d}^P\right)\left(\underline{\theta}+K\right)+\phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right)-\hat{d}^P\right)\right)\left(\theta_f^P-\underline{\theta}\right)} = \frac{1}{K-\theta_f^P}. \tag{A48}$$

and so

$$\frac{d\log\Phi}{d\hat{d}^P} \leq \alpha\left[E_{N,\hat{d}}\left[d^P(\theta)\right] - E_{D,\hat{d}}\left[d^P(\theta)\right]\right] + \frac{1}{K-\theta_f^P}\frac{1}{1-p}\frac{\partial\theta_f^P}{\partial\hat{d}}.$$

Because $E_{N,\hat{d}}\left[d^P(\theta)\right] - E_{D,\hat{d}}\left[d^P(\theta)\right] < 0$ for sufficiently large K (see the proof of Proposition 4), it follows that $\frac{d\log\Phi}{d\hat{d}^P} < 0$ for sufficiently large values of α.

Suppose instead that $0 < \hat{d}^P < \tilde{d}^P$. Therefore, $\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}^P\right) > \sqrt{\alpha}\phi\left(\sqrt{\alpha}\tilde{d}^P\right) \geq 0$, and hence

$$\frac{1}{\left(\underline{\theta}+K\right)\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}^P\right)+\left(\theta_f^P-\underline{\theta}\right)\sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(d^P\left(\tilde{\theta}_1\right)-\hat{d}^P\right)\right)} \leq M$$

for $M \geq 0$. In that case

$$\frac{d\log\Phi}{d\hat{d}^P} \leq \alpha\left[E_{N,\hat{d}}\left[d^P(\theta)\right] - E_{D,\hat{d}}\left[d^P(\theta)\right]\right] + \frac{M}{1-p}\frac{\partial\theta_f^P}{\partial\hat{d}},$$

and again $\frac{d\log\Phi}{d\hat{d}^P} < 0$, for sufficiently large values of α.

Next, notice that for $\theta < \theta_f^P$, $\partial\Phi/\partial d^P(\theta) > 0$, iff $d^P(\theta) < \hat{d}^P$, while for $\theta > \theta_f^P$, $\partial\Phi/\partial d^P(\theta) > 0$, iff $d^P(\theta) > \hat{d}^P$. Therefore, we consider three cases:

1. For $\theta > \theta_f^P$, $d^P(\theta) \geq d_{\min} > \hat{d}^P$, so it follows that $\frac{\partial \hat{d}^P}{\partial d^P(\theta)} > 0$.
2. For $\theta < \overline{\ell}^{-1}\left(\hat{d}^P\right) < \theta_f^P$, $d^P(\theta) < \hat{d}^P$,so $\frac{\partial \hat{d}^P}{\partial d^P(\theta)} > 0$, as well.
3. For $\theta \in \left[\overline{\ell}^{-1}\left(\hat{d}^P\right), \theta_f^P\right)$, $\frac{\partial \hat{d}^P}{\partial d^P(\theta)} > 0$ or $\frac{\partial \hat{d}^P}{\partial d^P(\theta)} < 0$, depending on whether $d^P(\theta) < \hat{d}^P$ or $d^P(\theta) > \hat{d}^P$.

For cases (1) and (2), it is optimal to set $d^P(\theta)$ to its lowest feasible value, namely, $d^P(\theta) = d_{\min} = \hat{d} + C_0$ for $\theta > \theta_f^P$ and $d^P(\theta) = 0$, for $\theta < \overline{\ell}^{-1}\left(\hat{d}^P\right)$. For case 3) it is still the case that optimality implies that $d^P(\theta)$ is at a corner. However, it is unclear whether $d^P(\theta) = 0$ or $d^P(\theta) = \overline{\ell}(\theta)$ is optimal. Putting these three cases together we arrive at (22). ■

Proof of Proposition 7 First, notice that with the optimal dividend policy given in (22), the left-hand side of (20) becomes

$$\frac{\int_{-K}^{\theta_f^P} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta}{\int_{\theta_f^P}^{K} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta} = \frac{\int_{-K}^{\overline{\ell}^{-1}(\hat{d})} \phi\left(\sqrt{\alpha}\left(0 - \hat{d}^P\right)\right) d\theta + \int_{\overline{\ell}^{-1}(\hat{d})}^{\theta_f^P} \phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta}{\int_{\theta_f^P}^{K} \phi\left(\sqrt{\alpha}\left(d_{\min}^P - \hat{d}^P\right)\right) d\theta}.$$

Next, notice that $\phi\left(\sqrt{\alpha}\left(d_{\min}^P - \hat{d}^P\right)\right) = \phi\left(\sqrt{\alpha}\frac{1}{\sqrt{\alpha}}\phi_+^{-1}\left(\frac{1}{\sqrt{\alpha}}\right)\right) = \frac{1}{\sqrt{\alpha}}$,so the denominator of the above expression is $(K - \theta_f)\frac{1}{\sqrt{\alpha}}$. Similarly, the first term in the numerator is $\phi\left(-\sqrt{\alpha}\hat{d}^P\right)\left(\overline{\ell}^{-1}\left(\hat{d}^P\right) + K\right) = \phi\left(\sqrt{\alpha}\hat{d}^P\right)\left(\overline{\ell}^{-1}\left(\hat{d}^P\right) + K\right)$ given the symmetry of the standard normal density around 0. Therefore, the equation becomes

$$\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}^P\right)\frac{\overline{\ell}^{-1}\left(\hat{d}^P\right) + K}{K - \overline{\ell}^{-1}\left(\hat{d}^P + C\right)} + \frac{\int_{\overline{\ell}^{-1}(\hat{d}^P)}^{\overline{\ell}^{-1}(\hat{d}^P + C)} \sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(d^P(\theta) - \hat{d}^P\right)\right) d\theta}{K - \overline{\ell}^{-1}\left(\hat{d}^P + C\right)} = \frac{1-p}{p}. \quad \text{(A49)}$$

Next, notice that $\lim_{\alpha\to\infty}\sqrt{\alpha}\phi\left(\sqrt{\alpha}\hat{d}^P\right) = 0$ for $\hat{d}^P > 0$. Also, $\lim_{\alpha\to\infty} C = 0$ and the integrand in the second term on the left-hand side is bounded, so the second term converges to zero as $\alpha \to \infty$. Therefore, it must be the case that $\hat{d}^P \to 0$. The rest of the proposition then follows directly. ■

Proof of Proposition 8

A.3 Comparative Statics with Respect to p Disregarding the effects through changes in $d^*(\theta)$ for now, we have that

$$\frac{d\hat{d}}{dp}=\frac{\partial\hat{d}}{\partial p}+\frac{d\theta_f}{dp}\frac{\partial\hat{d}}{\partial\theta^f}=\frac{\partial\hat{d}}{\partial p}+\frac{d\hat{d}}{dp}\frac{\partial\theta^f}{\partial\hat{d}}\frac{\partial\hat{d}}{\partial\theta^f},$$

so

$$\frac{d\hat{d}}{dp}=\frac{\frac{\partial\hat{d}}{\partial p}}{1-\frac{\partial\theta^f}{\partial\hat{d}}\frac{\partial\hat{d}}{\partial\theta^f}}.$$

Next, note that $\frac{\partial\hat{d}}{\partial p}>0$, because the left-hand side of (20) is increasing in $\hat{d}$ for sufficiently large K (by Lemma 1). Also, note that $\frac{\partial\theta^f}{\partial\hat{d}}=-\frac{v_l}{v_\theta}>0$ (see the proof of Proposition 9). Furthermore, it is bounded (because θ lies in a compact set and v is continuously differentiable). Finally, taking logs on both sides of (20) and defining the left-hand side by $\log\Phi$, we have that

$$\frac{\partial\hat{d}}{\partial\theta^f}=-\frac{\partial\log\Phi/\partial\theta_f}{\partial\log\Phi/\partial\hat{d}}>0. \tag{A50}$$

The numerator of this expression equals,

$$\frac{\partial\log\Phi}{\partial\theta_f}=\frac{\phi\left(\sqrt{\alpha}\left(\bar{\ell}\left(\theta_f\right)-\hat{d}\right)\right)}{\int_{-K}^{\theta_f}\phi\left(\sqrt{\alpha}\left(\bar{\ell}\left(\theta\right)-\hat{d}\right)\right)d\theta}+\frac{\phi\left(\sqrt{\alpha}\left(d^*\left(\theta_f\right)-\hat{d}\right)\right)}{\int_{\theta_f}^{K}\phi\left(\sqrt{\alpha}\left(d^*\left(\theta\right)-\hat{d}\right)\right)d\theta} \tag{A51}$$

and is bounded above (see the proof of Proposition 6). On the other hand, the denominator is

$$\frac{\partial\log\Phi}{\partial\hat{d}}=\alpha\left[E_{N,\hat{d}}\left[\bar{\ell}\left(\theta\right)\right]-E_{D,\hat{d}}\left[d^*\left(\theta\right)\right]\right], \tag{A52}$$

where $E_{N,\hat{d}}[.]$ and $E_{D,\hat{d}}[.]$ are defined immediately before Lemma 1. It follows that $\frac{\partial\hat{d}}{\partial\theta^f}$ can be made arbitrarily small for sufficiently large values of α and, hence, $\frac{d\hat{d}}{dp}>0$. Finally, because $d^*(\theta)>d_{\min}$ is determined by

$$\lambda=-v_l\left(\theta,d^*\left(\theta\right)+A\left(d^*\left(\theta\right),\hat{d}\right)\right)\left[1+A_d\left(d^*\left(\theta\right),\hat{d}\right)\right], \tag{A53}$$

it follows that

$$\frac{\partial d^*\left(\theta\right)}{\partial\hat{d}}=\frac{v_{ll}\left[1+A_d\right]A_{\hat{d}}+v_lA_{d\hat{d}}}{v_{ll}\left[1+A_d\right]^2+v_lA_{dd}}.$$

However, $A_{\hat{d}} = \sqrt{\alpha}\phi\left(\sqrt{\alpha}\left(\hat{d} - d^*(0)\right)\right) \to 0$ as $\alpha \to \infty$, because $d^* > \hat{d}$. Also,

$$A_{d\hat{d}} = \alpha^{3/2}\phi\left(\sqrt{\alpha}\left(\hat{d} - d^*(\theta)\right)\right)\left(\hat{d} - d^*(\theta)\right) \to 0,$$

as $\alpha \to \infty$. On the other hand, $v_{ll}\left[1 + A_d\right]^2 \neq 0$ for any α and $d^* > d_{\min}$. Therefore, $\lim_{\alpha\to\infty} \frac{\partial d^*(\theta)}{\partial \hat{d}} = 0$ for any $\theta > \theta_f$. Because p only affects $d^*(\theta)$ through $\hat{d}$, it follows that disregarding the feedback effects of $d^*(\theta)$ on $\hat{d}$ is valid in the limit as $\alpha \to \infty$ and, so, $\lim_{\alpha\to\infty} \frac{d\hat{d}}{dp} > 0$. Also, $\lim_{\alpha\to\infty} \frac{d\theta_f}{dp} = \lim_{\alpha\to\infty} \frac{d\hat{d}}{dp}\frac{\partial\theta_f}{\partial\hat{d}} = \left(\lim_{\alpha\to\infty} \frac{d\hat{d}}{dp}\right)\left(\lim_{\alpha\to\infty} \frac{\partial\theta_f}{\partial\hat{d}}\right) > 0$.

A.4 Comparative Statics with Respect to b Note that for $b \neq 1$, the condition (14) for θ_f becomes

$$\lambda\bar{\ell}(\theta_f) = \lambda d^*(\theta_f) + v\left(\theta_f, d^*(\theta_f) + bA\left(d^*(\theta_f), \hat{d}\right)\right),$$

where $d^*(\theta) > d_{\min}$ satisfies the condition

$$\lambda = -v_l\left(\theta, d^*(\theta) + bA\left(d^*(\theta), \hat{d}\right)\right)\left(1 + bA_d\left(d^*(\theta), \hat{d}\right)\right), \tag{A54}$$

and $d_{\min}$ satisfies $1 + bA_d = 0$, such that $\hat{d} < d_{\min}$. As with the comparative statics for p, we first disregard the effects through changes in $d^*(\theta)$. Therefore,

$$\frac{d\hat{d}}{db} = \frac{\partial\hat{d}}{\partial b} + \frac{d\theta_f}{db}\frac{\partial\hat{d}}{\partial\theta^f} = \frac{\partial\hat{d}}{\partial b} + \left(\frac{\partial\theta_f}{\partial b} + \frac{d\hat{d}}{db}\frac{\partial\theta_f}{\partial\hat{d}}\right)\frac{\partial\hat{d}}{\partial\theta_f},$$

so

$$\frac{d\hat{d}}{db} = \frac{\frac{\partial\hat{d}}{\partial b} + \frac{\partial\hat{d}}{\partial\theta_f}\frac{\partial\theta_f}{\partial b}}{1 - \frac{\partial\theta_f}{\partial\hat{d}}\frac{\partial\hat{d}}{\partial\theta_f}}.$$

Next, note that $\frac{\partial\hat{d}}{\partial b} \geq 0$. First of all, changes in b have no direct effect on $\hat{d}$, so $\frac{\partial\hat{d}}{\partial b} = 0$. Second, in our partially microfounded example in the Online Appendix, we have that p depends on b. Moreover $\frac{\partial p}{\partial b} > 0$ in that case. Because $\frac{\partial\hat{d}}{\partial p} > 0$ from the proof of Proposition 8, it follows that $\frac{\partial\hat{d}}{\partial b} > 0$.

Next, by the implicit function theorem and envelope theorem,

$$\frac{\partial\theta_f}{\partial b} = -\frac{v_l A}{v_\theta\left(\frac{v_l+\lambda}{v_l}\right)}, \tag{A55}$$

and note that $\lim_{\alpha\to\infty}\frac{\partial\theta_f}{\partial b}=0$, because $\lim_{\alpha\to\infty} A \to 0$ for $d^*(\theta) > \hat{d}$. Finally, using the same argument as in the proof of Proposition 8 we have that $\frac{\partial\hat{d}}{\partial\theta^f}$ can be made arbitrarily small for sufficiently large values of α and, hence, $\frac{d\hat{d}}{db}$. Also, as in Proposition 8 one can indeed disregard the feedback effects of $d^*(\theta)$ on $\hat{d}$ in the limit as $\alpha\to\infty$ and so $\lim_{\alpha\to\infty}\frac{d\hat{d}}{db} > 0$.

Finally, note that

$$\begin{aligned}\lim_{\alpha\to\infty}\frac{d\theta_f}{db} &= \lim_{\alpha\to\infty}\frac{d\hat{d}}{db}\frac{\partial\theta_f}{\partial\hat{d}}\\ &= \left(\lim_{\alpha\to\infty}\frac{d\hat{d}}{db}\right)\left(\lim_{\alpha\to\infty}\frac{\partial\theta_f}{\partial\hat{d}}\right) \geq 0.\end{aligned}$$

■

References

Acharya, V., H. S. Shin, and I. Gujral. 2009. Bank dividends in the crisis: A failure of governance.

Acharya, V. V., I. Gujral, N. Kulkarni, and H. S. Shin. 2011. Dividends and bank capital in the financial crisis of 2007-2009. National Bureau of Economic Research Working Paper No. 16896.

Acharya, V. V., H. T. Le, and H. S. Shin. 2016. Bank capital and dividend externalities. *Review of Financial Studies* 30:988–1018.

Ahnert, T., and A. Kakhbod. 2017. Information choice and amplification of financial crises. *Review of Financial Studies* 30:2130–2178.

Ahnert, T., and D. Martinez-Miera. 2019. Bank competition, Bank runs, and Opacity. Mimeo.

Angeletos, G., and A. Pavan. 2013. Selection-Free Predictions in Global Games with Endogenous Information and Multiple Equilibria. *Theoretical Economics* 8:3:883–938.

Angeletos, G.-M., C. Hellwig, and A. Pavan. 2006. Signaling in a global game: Coordination and policy traps. *Journal of Political Economy* 114:452–484.

Angeletos, G.-M., and C. Lian. 2018. Forward guidance without common knowledge. *American Economic Review* 108:2477–2512.

Angeletos, G.-M., and A. Pavan. 2007. Efficient use of information and social value of information. *Econometrica* 75:1103–1142.

Baker, M., B. Mendel, and J. Wurgler. 2016. Dividends as reference points: A behavioral signaling approach. *Review of Financial Studies* 29:697–738.

Bhattacharya, S. 1979. Imperfect information, dividend policy, and "the bird in the hand" fallacy. *Bell Journal of Economics* 10:259–270.

Bigio, S. 2012. Financial Risk Capacity. Mimeo.

Bouvard, M., P. Chaigneau, and A. d. Motta. 2015. Transparency in the financial system: Rollover risk and crises. *Journal of Finance* 70:1805–1837.

Carlsson, H., and E. van Damme. 1993. Global Games and Equilibrium Selection. *Econometrica* 61:989–1018.

Cziraki, P., C. Laux, and G. Loranth. 2016. Bank Payout Policy, Performance, and Insider Trading in the Financial Crisis of 2007-2009. Mimeo.

Duffie, D. 2010. *How big banks fail and what to do about it.* Princeton: Princeton University Press.

Edmond, C. 2013. Information manipulation, coordination, and regime change. *Review of Economic Studies* 80:1422–1458.

Faria-e Castro, M., J. Martinez, and T. Philippon. 2016. Runs versus lemons: information disclosure and fiscal capacity. *Review of Economic Studies* 84:1683–1707.

Floyd, E., N. Li, and D. J. Skinner. 2015. Payout policy through the financial crisis: The growth of repurchases and the resilience of dividends. *Journal of Financial Economics* 118:299–316.

Gaballo, G. 2016. Rational Inattention to News: The Perils of Forward Guidance. *American Economic Journal: Macroeconomics* 8:42–97.

Goldstein, I., and C. Huang. 2016a. Bayesian Persuasion in Coordination Games. *American Economic Review* 106:592–596.

———. 2016b. Credit Rating Inflation and Firms Investment Behavior. Mimeo.

Goldstein, I., and Y. Leitner. 2018. Stress tests and information disclosure. *Journal of Economic Theory* 177:34–69.

Goldstein, I., and A. Pauzner. 2005. Demand–deposit contracts and the probability of bank runs. *Journal of Finance* 60:1293–1327.

Goodhart, C., M. U. Peiris, D. Tsomocos, and A. Vardoulakis. 2010. On dividend restrictions and the collapse of the interbank market. *Annals of Finance* 6:455–473.

Guttman, I., O. Kadan, and E. Kandel. 2010. Dividend stickiness and strategic pooling. *Review of Financial Studies* 23:4455–4495.

Hausch, D. B., and J. K. Seward. 1993. Signaling with dividends and share repurchases: A choice between deterministic and stochastic cash disbursements. *Review of Financial Studies* 6:121–154.

He, Z., and A. Manela. 2016. Information acquisition in rumor-based bank runs. *The Journal of Finance* 71:1113–1158.

Hirtle, B. 2014. Bank holding company dividends and repurchases during the financial crisis. *FRB of New York Staff Report* .

Holden, S., G. J. Natvik, and A. Vigier. 2018. Credit Rating and Debt Crises. *International Economic Review* 59:973 – 987.

Iachan, F. S., and P. T. Nenov. 2015. Information quality and crises in regime-change games. *Journal of Economic Theory* 158:739–768.

John, K., and J. Williams. 1985. Dividends, dilution, and taxes: A signalling equilibrium. *Journal of Finance* 40:1053–1070.

Kamenica, E., and M. Gentzkow. 2011. Bayesian persuasion. *American Economic Review* 101:2590–2615.

Kolbin, S. 2015. Precision of Communication in Coordination Games of Regime Change. Columbia University mimeo.

Miller, M. H., and K. Rock. 1985. Dividend policy under asymmetric information. *Journal of Finance* 40:1031–1051.

Moreno, D., and T. Takalo. 2016. Optimal bank transparency. *Journal of Money, Credit, and Banking* 48:1:203–231.

Morris, S., and H. Shin. 2003. Global Games: Theory and Applications*In Advances in Economics and Econometrics, (Proceedings of the Eighth World Congress of the Econometric Society)*. Eds. M. Dewatripont, L.-P. Hansen and S. Turnovsky. Cambridge, England: Cambridge University Press.

———. 2004. Coordination Risk and the Price of Debt. *European Economic Review* 48:133–153.

Morris, S., and H. S. Shin. 1998. Unique equilibrium in a model of self-fulfilling currency attacks. *American Economic Review* 88:587–597.

Myatt, D. P., and C. Wallace. 2012. Endogenous information acquisition in coordination games. *Review of Economic Studies* 79:340–374.

———. 2014. Central bank communication design in a Lucas-Phelps economy. *Journal of Monetary Economics* 63:64–79.

Nissim, D., and A. Ziv. 2001. Dividend changes and future profitability. *Journal of Finance* 56:2111–2133.

Rochet, J.-C., and X. Vives. 2004. Coordination failures and the lender of last resort: was Bagehot right after all? *Journal of the European Economic Association* 2:1116–1147.

Scharfstein, D. S., and J. C. Stein. 2008. This bailout doesn't pay dividends. *New York Times* .

Shapiro, J., and D. Skeie. 2015. Information management in banking crises. *The Review of Financial Studies* 28:2322–2363.

Sims, C. 2003. Implications of Rational Innatention. *Journal of Monetary Economics* 50:665–690.

Szkup, M., and I. Trevino. 2015. Information acquisition in global games of regime change. *Journal of Economic Theory* 160:387–428.

The Economist. 2010. Base camp Basel.

Vives, X. 2014. Strategic complementarity, fragility, and regulation. *Review of Financial Studies* 27:3547–3592.

Woodford, M. 2002. Imperfect Common Knowledge and the Effects of Monetary Policy*In Knowledge, Information, and Expectations in Modern Macroeconomics*. Eds. P. Aghion, R. Frydman, J. Stiglitz and M. Woodford. Princeton: Princeton University Press.

Yang, M. 2015. Coordination with flexible information acquisition. *Journal of Economic Theory* 158:721–738.

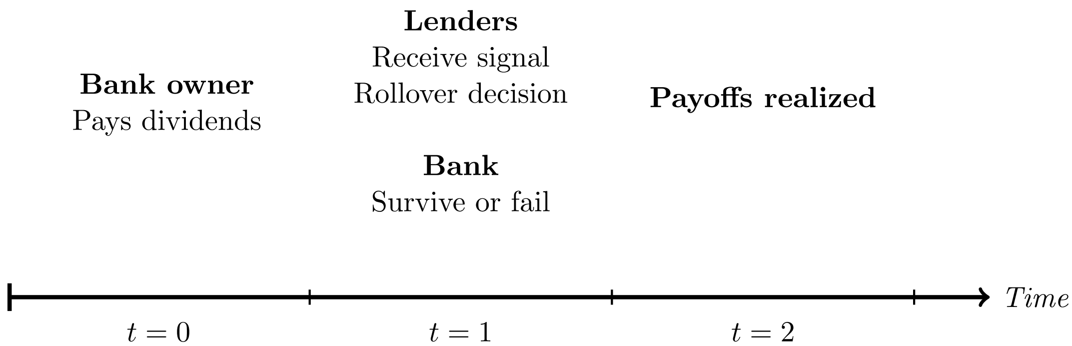

Figure 1. Timing of events

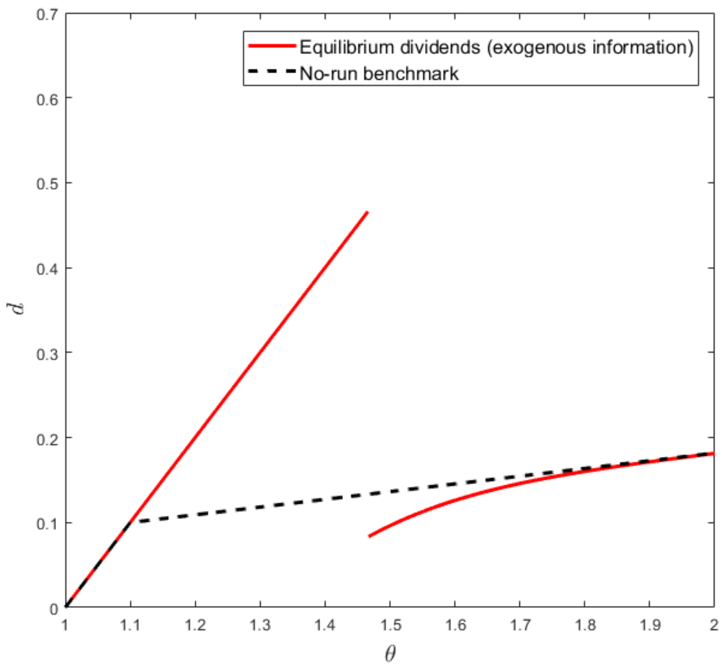

Figure 2. Exogenous information and the no-run benchmark

This figure shows the equilibrium dividend policies under the no-run benchmark (black, dashed line) and the exogenous information case (solid-red line).

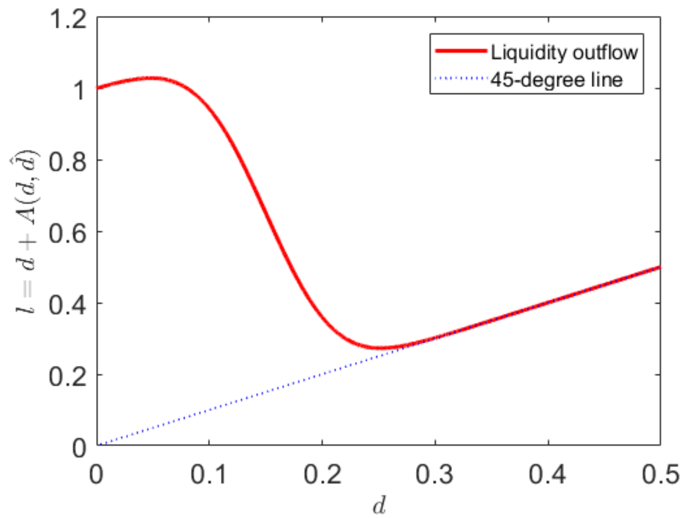

Figure 3. Liquidity outflow as a function of dividends paid

This figures shows the total liquidity outflow $d+A\left(d,\hat{d}\right)$, for a given $\hat{d}$, as a function of the dividend d. In this case, α is sufficiently high so that the liquidity outflow is decreasing in a region around $\hat{d}$.

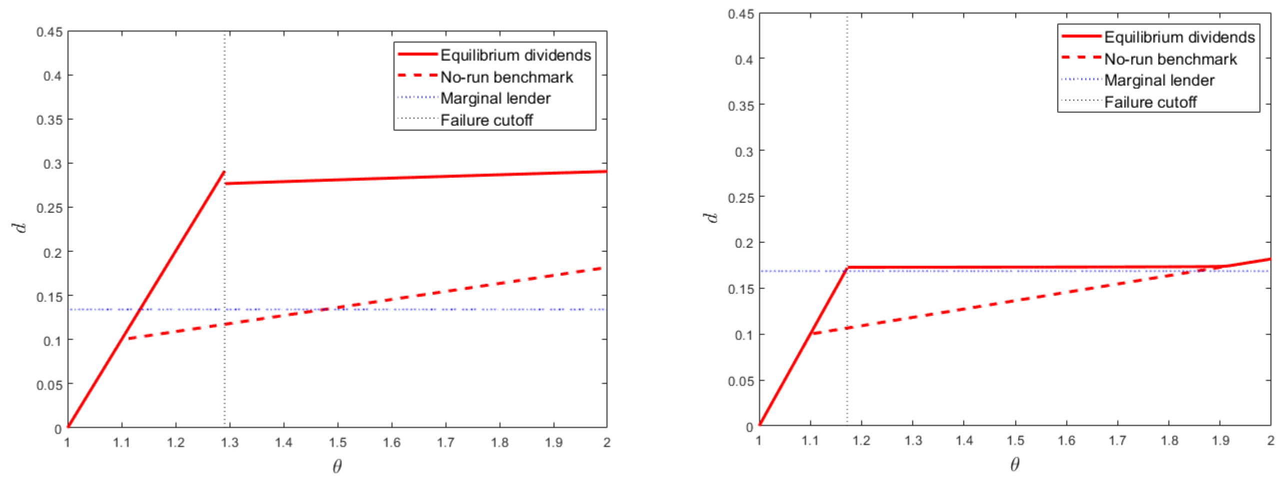

Figure 4. Equilibrium dividend policies for low (left panel) and high (right panel) dividend signal precisions

This figure shows the equilibrium dividend policy in the no-run benchmark (red, dashed lines) and the dividend signaling case (solid-red lines). In the left panel, $\alpha = 400$; in the right panel, $\alpha = 1,000,000$. See the Online Appendix for additional details.

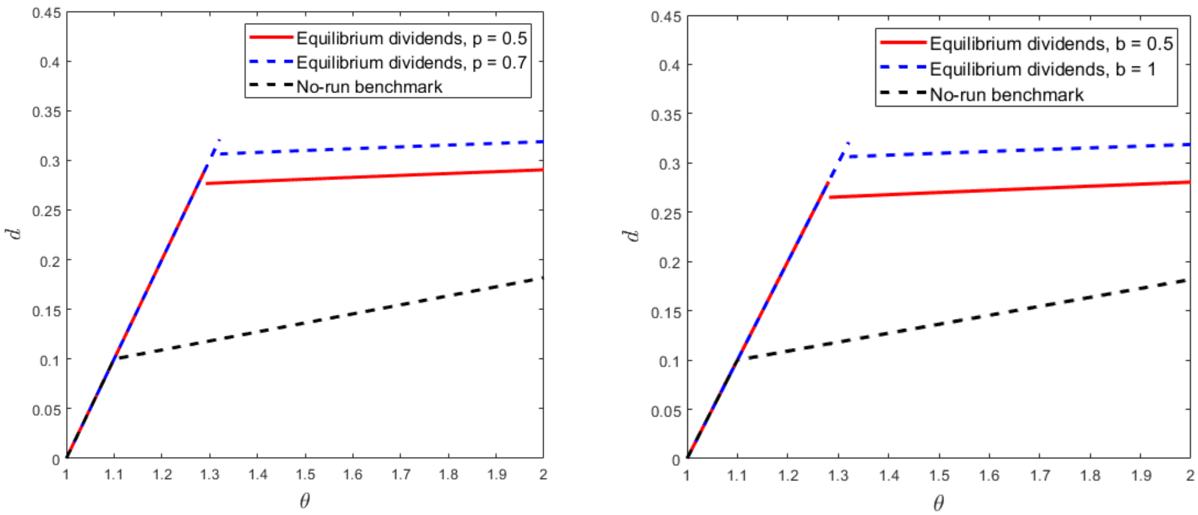

Figure 5. Dividend policy comparative statics with respect to p (left panel) and b (right panel)

This figure shows the optimal dividend policy with dividend signaling for different values of p and b. The left panel considers two different values of p ($p = 0.5$ for the solid-red line, and $p = 0.7$ for the blue dashed line), and the right panel shows the equilibrium for two different values of b ($b = 0.5$ for the solid-red line, and $b = 0.5$ for the blue dashed line). In both panels, the black dashed line is the equilibrium under the no-run benchmark.

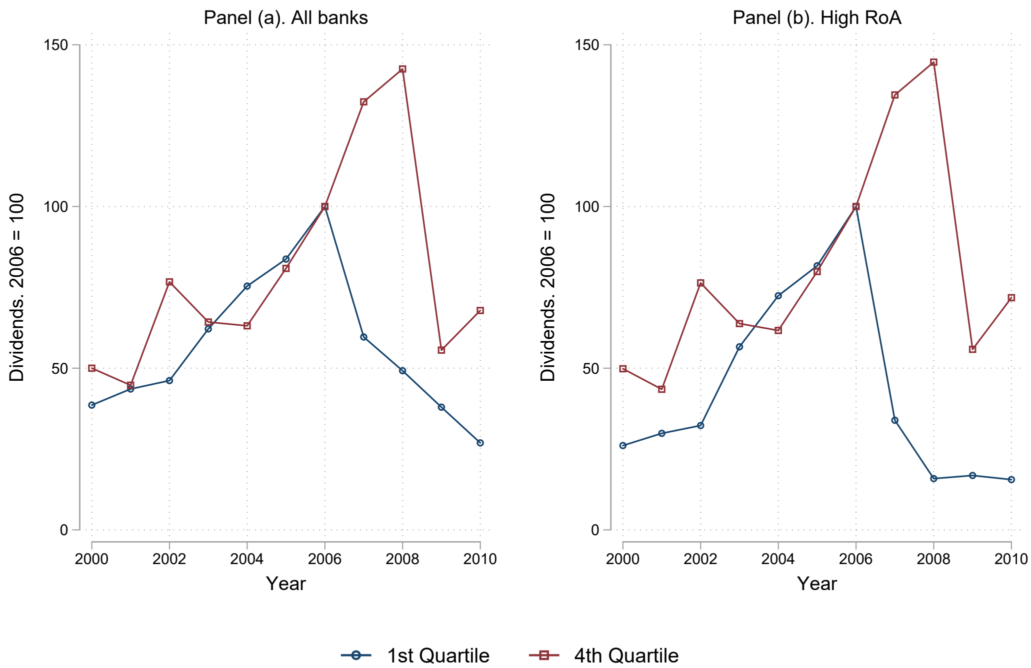

Figure 6. Yearly nominal dividend payments for large U.S. banks with different reliance on short-term debt

The figure shows the evolution of dividend payouts for U.S banks. In each panel, we split banks into two groups, based on their degree of short-term funding. We follow Hirtle (2014) and focus on large banks, defined as bank holding companies with more than \$500 million in assets as of Q12006. Bank holding companies are then grouped into four quartiles based on their short-term debt relative to total liabilities in 2006. The figure compares the dividend payments of the 1st and the 4th quartiles. Short-term debt is defined as the sum of repurchase agreements, time deposits above \$100,000, and federal funds. Left panel: All banks. Right panel: Only banks with average RoA in 2009 above the median. *Source*: Y-9C reports of bank holding companies.

Figure 7. Industry-level standard deviation of dividend growth and short-term debt reliance.

The figure shows a binned scatter plot of industry-level short-term debt share (short-term debt as share of total assets) (x-axis) plotted against the standard deviation of that industry's dividend growth. Short-term debt is defined as current liabilities. The industry-level correspond to 4-digit SIC code, excluding financials (SIC codes 6000–6999) and utilities (SIC codes 4900–4949). *Sources*: CRSP and Compustat.

Figure legends

Figure 1: Timing of events.

This figure outlines the timing in our model.

Figure 2: Exogenous information and the no-run benchmark.

This figure shows the equilibrium dividend policies under the no-run benchmark (black, dashed line) and the exogenous information case (red solid line).

Figure 3: Liquidity outflow as a function of dividends paid.

This figures shows the total liquidity outflow $d+A\left(d,\hat{d}\right)$, for a given $\hat{d}$, as a function of the dividend d. In this case, α is sufficiently high so that the liquidity outflow is decreasing in a region around $\hat{d}$.

Figure 4: Equilibrium dividend policies for low (left panel) and high (right panel) dividend signal precisions

This figure shows the equilibrium dividend policy in the no-run benchmark (red, dashed lines) and the dividend signaling case (red solid lines). In the left panel, $\alpha = 400$ and in the right panel $\alpha = 1000000$. See the Online Appendix for additional details.

Figure 5: Dividend policy comparative statics with respect to p (left panel) and b (right panel).

This figure shows the optimal dividend policy with dividend signaling for different values of p and b. The left panel considers two different values of p ($p = 0.5$ for the red solid line, and $p = 0.7$ for the blue dashed line) while the right panel shows the equilibrium for two different values of b ($b = 0.5$ for the red solid line, and $b = 0.5$ for the blue dashed line). In both panels, the black dashed line is the equilibrium under the no-run benchmark.

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