Unstable Funding as a Source of Bank Liquidity*

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Abstract

Why do banks fund illiquid, informationally sensitive assets with unstable short-term debt? We develop a model in which banks' reliance on unstable funding makes their assets *more liquid*. Because banks monitor and collect information about borrowers, it is difficult to raise new funds against their assets due to adverse selection. However, deposits force banks to seek external funds whenever creditors demand liquidity, thereby disguising their motives for trade and mitigating the adverse selection problem. This creates a novel synergy between the asset and liability sides of banks' balance sheets: the informational frictions created by lending are mitigated by the instability of short-term funding. However, while in normal times, unstable funding creates a liquidity benefit, in crises, it can make banks' assets less liquid when creditors' refinancing decisions are informed. Our model provides a new mechanism through which capital and liquidity requirements can reduce bank lending.

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1 Introduction

Banks perform two core functions: they provide liquidity services by issuing short-term, often demandable, debt, and they make long-term loans to firms and individuals. While the separate benefits of each of these functions are well established[1], it is unclear why banks should perform them both simultaneously. On the asset side, banks generate information to screen and monitor borrowers, which makes their assets illiquid due to adverse selection.[2] At the same time, on the liability side, demandable debt exposes banks to random withdrawals, forcing them to continually raise funds against these illiquid assets. Why, then, do banks, whose assets are opaque and difficult for outsiders to value, voluntarily finance themselves with such unstable forms of debt?

In this paper, we show that rather than being a detriment, such unstable funding actually makes banks' assets *more* liquid. The constant refinancing of banks' liabilities due to liquidity demand introduces noise into banks' motives for raising new capital, reducing the adverse selection problem that arises from banks' private information about their existing assets. This creates a novel synergy between banks' assets and liabilities: the informational frictions *created* by their assets are *mitigated* by their liabilities.

Formally, we develop a three-date model in which a bank raises funds at $t = 0$ to finance a long-term project that pays off at $t = 2$. Project quality is unknown when the initial investment is undertaken at $t = 0$, but is privately observed by the bank at the interim date, $t = 1$. At that date, the bank also receives an NPV-positive follow-on investment opportunity that requires external financing. This financing is raised in an anonymous competitive market in which the total amount raised by the bank is not observable.[3] Because the quality of the bank's existing assets is private information, there is an adverse selection problem: when the bank's asset value is sufficiently high, the resulting mispricing deters it from raising funds,

[1] See Diamond and Dybvig (1983) and Diamond (1984) for separate models of bank liquidity creation and long-term lending, respectively.

[2] For example, Vanasco (2017) shows that screening/information production by intermediaries hinders secondary market trade due to adverse selection.

[3] As we show below, this assumption simplifies the analysis but is not necessary for the mechanism.

causing it to forgo the NPV-positive follow-on investment. The potential for this interim underinvestment problem reduces the bank's ex-ante value.

In this model, we analyze how the bank's ex-ante capital structure choice at $t = 0$ – that is, its mix of equity, long-term debt and short-term debt – affects its ability to finance the new project at the interim date. We assume that outside investors are subject to liquidity shocks that force the bank to refinance its maturing short-term debt at $t = 1$ in a competitive market. We first show that long-term debt weakens the banks' investment incentives at $t = 1$ through debt overhang and is therefore not used in equilibrium.

Short-term debt generates a different distortion at the interim date, $t = 1$, akin to debt overhang: new outside investors appropriate part of the return from the bank's follow-on investment because the market price does not fully incorporate the value created by the project, given that investors cannot distinguish between financing raised for investment or to meet liquidity needs.

Short-term debt, however, also has an important benefit. By forcing the bank to refinance at the interim date, short-term debt can induce high-quality banks to enter the market, thereby improving the average quality of the borrowing pool. This, in turn, raises the price of newly issued securities and mitigates the adverse selection problem. Specifically, we show that short-term debt raises the market price at $t = 1$ when adverse selection is sufficiently severe, in the sense that the dispersion in the value of assets in place is large relative to the NPV of the follow-on project. In this case, the bank optimally chooses a capital structure consisting of equity and short-term debt at $t = 0$. By contrast, when the dispersion in the value of existing assets is low relative to the project's NPV, the bank finances itself entirely with equity.

Importantly, the benefit of short-term debt in our model cannot be replicated by trading low-risk longer-term securities, e.g., treasuries, in secondary markets. These securities may provide liquidity services to investors by being information-insensitive and easy to trade (e.g., Gorton and Pennacchi (1990)). But this form of liquidity does not force banks themselves to re-enter funding markets frequently. In our model, it is exactly the liquidity-driven refinancing generated by short-term debt that obscures banks' issuance motives and thereby mitigates the adverse selection problem in primary markets.

Although the model's core mechanism could, in principle, apply to any firm facing adverse selection when raising external capital, several features make it particularly relevant to banks. First, adverse selection is a first-order concern for banks because it emerges endogenously from their core role in screening and monitoring borrowers (e.g., Diamond (1984), Sharpe (1990), Rajan (1992) and Weitzner, Beyhaghi, and Howes (2022)).

Second, our mechanism requires that the value of assets in place be only weakly correlated with new investment opportunities. Intuitively, the pooling benefit of short-term debt arises only when refinancing needs reveal little about the value of existing assets. In that case, short-term debt facilitates interim investment. When this correlation is high, however, we show that short-term debt exacerbates adverse selection and discourages investment at the interim date. In practice, this correlation is likely to be lower for banks than for nonfinancial firms. A bank may hold a high-quality loan portfolio, yet face limited new lending opportunities, or vice versa, because lending opportunities depend primarily on borrowers' investment demand rather than on the quality of the bank's existing assets. This weak correlation is central to our mechanism: it allows funding needs to arise for reasons largely unrelated to fundamentals, thereby generating a pooling benefit of short-term debt. In contrast, for nonfinancial firms, asset quality and investment opportunities are more likely to be positively correlated, as firms with stronger fundamentals tend to obtain more attractive follow-on investment opportunities (e.g., Berk, Green, and Naik (1999)).

Third, our model predicts that the benefit of short-term debt is greatest when the NPV of new investment is small relative to the dispersion in the value of existing assets. This condition is likely to be especially relevant for banks. Because financial markets are considered fairly competitive, the surplus generated by any individual loan is often small, while banks' existing portfolios are significantly larger.

Finally, unlike nonfinancial firms, whose investment opportunities are typically more lumpy, banks have a steadier flow of new lending opportunities. While our model features only a single interim date, in practice, short-term debt repeatedly brings banks to funding markets for reasons unrelated to private information. As a result, even a small reduction in adverse selection from the use of short-term debt can be extremely valuable.

In the baseline model, short-term lenders trade for liquidity reasons, that are unrelated to the bank's fundamentals. However, during periods of financial distress, creditors may refuse to roll over debt due to private information about the quality of the bank's assets rather than pure liquidity needs. For example, during the financial crisis, many repo and interbank lenders declined to roll over their counterparties' debt because of concerns about credit quality.[4] We show that in such cases, a need for external financing becomes a negative signal, since it reveals that short-term debtholders declined to roll over their claims for informational rather than liquidity reasons. This cream-skimming worsens the pool of banks seeking interim funding, and depresses market prices. Thus, although short-term debt can mitigate adverse selection in normal times by promoting pooling, it can exacerbate it in crises, when rollover decisions themselves convey information.

We are not the first to propose a synergy between banks' assets and liabilities. One class of explanations emphasizes the disciplinary and commitment roles of short-term debt. Calomiris and Kahn (1991) argue that informed depositors monitor banks and withdraw when they detect misbehavior, while Diamond and Rajan (2000) and Diamond and Rajan (2001) show that the fragility of demandable deposits helps banks commit to not renegotiate with creditors ex-post.[5] Yet agency problems are not unique to banks: non-financial firms face similar

[4]For example, regarding Bear Stearns in 2008, "prime brokerage clients withdrew their cash and unencumbered securities at a rapid and increasing rate; repo market lenders declined to roll over or renew repo loans RepoWatch and Fricker (2010)." The SEC also noted that, "some large and important money funds, including Fidelity and Mellon, had told Bear after the close of business Wednesday they 'might be hesitant to roll some funding tomorrow.' and 'though they believed the amounts were 'very manageable (between \$1 and \$2 billion),' the withdrawals would not send a helpful signal to the market Financial Crisis Inquiry Commission (2011)." More broadly, during the financial crisis, banks faced substantial stigma when raising funds from the discount window (Armantier et al. (2015)), consistent with seeking outside funds as a negative signal, as incumbent lenders are unwilling to roll over their debt.

[5]See also de Souza, Koufopoulos, and Trigilia (2025) who show that fragile liabilities can be optimal for banks, but through a commitment-to-liquidate channel that screens low-quality borrowers, rather than through the pooling mechanism we identify. Donaldson and Piacentino (2022) show that demandability raises the secondary-market resale price of bank debt, since the redemption option strengthens the holder's bargaining

frictions, while short-term demandable debt remains concentrated in banks.[6] Moreover, debt is not the only way to discipline banks. For example, compensation contracts can serve a similar role, and as Admati et al. (2010) argue, debt can be a poor disciplining device for financial firms because it encourages asset substitution (Myers and Rajan (1998)).[7] Finally, deposit insurance attenuates the run threat that is central to these mechanisms, as also emphasized by Admati et al. (2010). By contrast, our mechanism continues to operate, and even potentially strengthens, when deposits are fully insured.[8]

A second class of explanations emphasizes the diversification synergies between deposits and bank assets. Kashyap, Rajan, and Stein (2002) argue that, because deposit withdrawals and credit-line drawdowns are imperfectly correlated, banks can economize on costly liquid asset holdings by jointly providing both activities within the same institution. Their mechanism relies on the fact that deposit withdrawals and credit-line drawdowns are imperfectly correlated, allowing banks to share a common liquidity buffer across activities. By contrast, in our model, it is the randomness created by liquidity shocks that makes short-term debt increase the liquidity of banks' assets, without requiring randomness per se on both sides of the balance sheet. Moreover, their mechanism applies most directly to deposits and credit lines, and hence, does not by itself explain the broader reliance of banks on short-term debt to fund term loans. Finally, this synergy arises through coninsurance; it could be reproduced through contractual or market-based sharing of liquidity risk rather than by combining both activities within a single institution.

A related recent explanation emphasizes the role of deposits in hedging interest-rate risk on the asset side of banks' balance sheets (Drechsler, Savov, and Schnabl, 2021).[9] Specifically,

position even when it is never exercised.

[6]Moreover, the Diamond and Rajan (2001) mechanism applies specifically to relationship lenders, yet heavy reliance on short-term debt is prevalent among other types of financial intermediaries, such as shadow banks, that do not engage in relationship lending but nonetheless hold informationally sensitive assets.

[7]Relatedly, Guennewig and Mitkov (2025) show that the Diamond and Rajan (2001) mechanism does not require fragility and is actually detrimental.

[8]To the extent that deposit insurance reduces the information content of withdrawal decisions, deposit insurance would strengthen our mechanism.

[9]Similarly, Hanson et al. (2015) argue that stable deposit funding allows banks to act as patient holders of illiquid assets. Again, the synergy depends on the stability of deposits rather than their short-term or

the stability and rate insensitivity of deposits—that is, the deposit franchise—provide a hedge against the interest-rate exposure of banks' long-duration assets. This synergy also does not require that deposits and loans sit under the same institution: interest-rate risk management could also be done through swaps or long-term fixed-rate funding.[10] In contrast, our mechanism operates through the informational effects of short-term funding and therefore cannot be replicated through standard market-based hedging arrangements.

Finally, a related literature shows that keeping assets on banks' balance sheets and withholding information about them can facilitate risk-sharing (Breton (2003) and Dang et al. (2017)).[11] However, these models do not explain why the institutions that provide liquidity services are so often the same institutions that monitor borrowers and engage in opaque lending. A narrow bank invested in safe, transparent assets could also issue information-insensitive liabilities, so the mechanism does not, by itself, explain the coexistence of liquidity creation and opaque lending within the same institution. Nor does it explain why such liabilities should be short-term: information-insensitive debt could equally well be long-term, whereas our mechanism relies specifically on the short-term nature of bank funding. More generally, our model shows that short-term debt can be valuable even in the absence of any risk-sharing motive.

More broadly, none of the existing explanations explains why opaque, informationally sensitive assets are optimally financed with short-term debt. In our model, short-term debt is valuable because it mitigates the adverse-selection problem generated by banks' information production. If banks held only transparent, easily valued assets, short-term debt would no longer serve a useful purpose. The synergy arises because banks' information production creates a friction that their liability structure can alleviate. Moreover, the model predicts

demandable nature.

[10] Moreover, the deposit franchises may cease to be good hedges for banks' assets when they become runnable (Drechsler et al. (2023)), and recent work questions whether the deposit franchise is actually a hedge for interest rate risk to begin with (e.g., DeMarzo, Krishnamurthy, and Nagel (2024), Lu and Wu (2026) and Benetton, Hébert, and McQuade (2025)).

[11] A separate literature argues that deposit relationships provide banks with information about borrowers (Black (1975), Mester, Nakamura, and Renault (2007), and Norden and Weber (2010)). While this channel may generate complementarities between deposit-taking and lending, it does not explain why deposits need to be short-term or demandable.

that banks' finance themselves with short-term debt and equity, with no long-term debt, similar to the liability structure banks use in practice.

Our paper also relates to the literature on adverse selection and the role of trading motives in shaping market liquidity (e.g., Akerlof (1978), Milgrom and Stokey (1982), Glosten and Milgrom (1985) and Kyle (1985)). A key insight from this literature is that market liquidity improves when trade is driven by factors unrelated to private information, because counterparties have less reason to infer negative information from the decision to sell. Our mechanism applies this logic to banks' liabilities: short-term debt creates refinancing needs that brings banks to funding markets for reasons not directly tied to fundamentals, thereby reducing the informational content of issuance and improving market liquidity. In this sense, our paper is related to Malherbe (2014), who shows that cash holdings can make market access more informative and thereby worsen adverse selection. In his model, agents with more cash have less need to trade, so market access becomes a stronger negative signal about asset quality, potentially giving rise to self-fulfilling liquidity dry-ups. By contrast, our mechanism operates through the maturity structure of liabilities: short-term debt generates recurrent refinancing needs that bring banks to the market for reasons unrelated to fundamentals, thereby improving pooling and primary-market liquidity. This allows us to speak both to the synergy between liquidity provision and lending and to banks' optimal capital structure. Accordingly, our model yields new predictions about the types of firms for which short-term debt is most valuable. As noted above, these benefits are greatest for firms that (i) access funding markets frequently, (ii) have new financing needs that are weakly correlated with the value of assets already in place, and (iii) undertake new projects with relatively low NPV relative to the scale of existing assets—features that naturally fit banks.

Finally, a large literature studies how to design securities that are information-insensitive and thereby mitigate adverse selection (e.g., Myers and Majluf (1984), Gorton and Pennacchi (1990), Nachman and Noe (1994), DeMarzo and Duffie (1999), DeMarzo (2005), Dang, Gorton, and Holmstrom (2009), Dang, Gorton, and Holmström (2013), Yang (2020), Weitzner

(2020)).[12] This literature focuses on how to design securities whose payoffs are least sensitive to private information, which often take the form of standard debt contracts.[13] We introduce a complementary mechanism: rather than changing the payoffs of securities, we show that the composition of a firm's *liability base* can itself reduce information sensitivity by disguising the motive for trade.[14] In our model, the benefit arises not because information-insensitive securities can be easily traded in the secondary market, but because short-term debt creates refinancing needs that repeatedly bring banks to funding markets for non-informational reasons, thereby reducing the informational content of trade and improving primary market liquidity.

2 Model Setup

We consider a three-date, risk-neutral economy where the risk-free rate is normalized to zero. At $t = 0$, a bank undertakes an investment of size I_0 that pays R at $t = 2$ with probability θ and zero otherwise. The bank's type, θ, is unknown at $t = 0$ and is uniformly distributed on $[\mu - \sigma, \mu + \sigma]$, where $\mu \geq \sigma$ and $\mu + \sigma \leq 1$. At $t = 1$, the bank privately observes θ.[15] We assume that $\mu R > I_0$, so the initial investment has positive expected net present value.

At $t = 1$, the bank receives a follow-on investment opportunity. By investing an additional amount I_1, it increases the probability of receiving R by Δ_I. We assume that $\Delta_I R > I_1$, so the follow-on investment has positive net present value, and that $\Delta_I + \mu + \sigma \leq 1$, so that the project's success probability can never exceed one. The terms of the follow-on investment

[12] A related literature examines debt maturity under asymmetric information. Flannery (1986) and Diamond (1991) show that high-quality firms may prefer short-term debt to benefit from future repricing as information is exogenously revealed, while Geelen (2019) considers a dynamic version of these models. Koufopoulos, Trigilia, and Zryumov (2023) show that short-term debt can generate underinvestment when firms use forgone growth options to signal asset quality. Our mechanism, which arguably applies more to banks than non-financial firms, differs in that short-term debt facilitates rather than deters investment: recurring refinancing needs pool with new investment demands, reducing adverse selection.

[13] Another way to mitigate adverse selection is to pool or bundle underlying cash flows (e.g., Gorton and Pennacchi (1991), Subrahmanyam (1991) and DeMarzo (2005)). Our mechanism is different in that we fix the set of assets backing a security and focus on how the maturity of a firm's liability structure affects the adverse selection problem.

[14] In the above models, the motive for trade, e.g., investment or liquidity needs, is typically known.

[15] In the context of banks, this information may be acquired by monitoring borrowers.

opportunity are common knowledge.

To finance the initial investment I_0 at $t = 0$, the bank issues, in a competitive financial market, a combination of equity, long-term debt maturing at $t = 2$ with face value δ_2, and short-term debt maturing at $t = 1$ with face value δ_1. We assume that short-term debtholders do not roll over their claims, i.e., they face a certain liquidity shock, so the bank must refinance the full face value δ_1 in the market at $t = 1$.[16] We also assume that the bank cannot raise and retain cash at $t = 0$ to pre-fund the follow-on investment. This assumption can be motivated by the agency and tax costs of holding excess liquidity, particularly for opaque intermediaries (Kashyap, Rajan, and Stein, 2002), as well as by uncertainty about the timing and scale of future investment opportunities. We discuss these considerations further in Section 4.

If the bank chooses to undertake the follow-on investment I_1 at $t = 1$, it must therefore return to the market to finance it. At that time, the bank's initial capital structure, chosen at $t = 0$, is observable, but investors observe neither whether the bank undertakes the follow-on investment nor the total amount it raises at $t = 1$.[17] We assume that the bank cannot distribute cash to equityholders at $t = 1$. This assumption prevents a low-type bank from issuing overpriced claims at $t = 1$ in an attempt to benefit from the pooling subsidy. Specifically, in equilibrium, any funds raised at $t = 1$ in excess of the amount needed to finance the follow-on investment and to refinance maturing short-term debt would be returned at $t = 2$ to the investors who provided them. Because the risk-free rate is zero, a claim backed by this retained cash is fairly priced regardless of the bank's type, so issuing beyond the financing need yields no surplus.

Finally, we make the following assumption:

$$\frac{\Delta_I R}{I_1} < 1 + \frac{\sigma}{\mu + \Delta_I}. \tag{1}$$

[16] We later relax this assumption by supposing that each debtholder experiences a liquidity shock at $t = 1$ with probability less than one. Debtholders that do not experience a liquidity shock may then choose whether to roll over their claims.

[17] Assuming that the total amount raised at $t = 1$ is unobservable simplifies the analysis but is not necessary for our main results, as we show in Section 5.3.

This assumption ensures that adverse selection at $t = 1$ is sufficiently severe that the highest type, $\mu+\sigma$, is unwilling to undertake the follow-on investment even if every lower type invests.[18] Consequently, even the most favorable market beliefs consistent with all lower types investing do not induce the highest type to invest.[19]

3 Model Analysis

We begin by considering the bank's investment decision at $t = 1$. Let p_1 denote the price of a security issued at $t = 1$ by the bank that promises one unit at $t = 2$.[20] We restrict attention to debt financing (δ_1, δ_2) that is feasible: the total promised repayment on new securities issued to repay maturing debt and fund the follow-on investment at $t = 1$ does exceed the investment's payoff at $t = 2$,

$$\delta_2 + \frac{\delta_1 + I_1}{p_1} \leq R. \tag{2}$$

As shown below, this condition is endogenously satisfied when banks choose their financing decisions at $t = 0$.

A bank of type θ chooses to invest at $t = 1$ if and only if the following condition is satisfied:[21]

$$(\theta + \Delta_I)\left(R - \delta_2 - \frac{\delta_1 + I_1}{p_1}\right) > \theta\left(R - \delta_2 - \frac{\delta_1}{p_1}\right). \tag{3}$$

In words, if the bank invests at $t = 1$, then with probability $\theta + \Delta_I$, it generates payoff R. It then must repay its long term debt, δ_2, as well as $(\delta_1 + I_1)/p_1$ on the securities issued at $t = 1$ to refinance the short-term debt and to fund the new investment. Alternatively, if the bank does not invest at $t = 1$, then with probability θ, it generates payoff R. It must then repay

[18] To see this, suppose that investors expect all types other than the highest type to invest. The price of a claim promising one unit at $t = 2$ is then $1/(\mu+\Delta_I)$, whereas the highest type's true probability of repayment after investing is $\mu+\sigma+\Delta_I$. The highest type, therefore, incurs underpricing of $\left[(\mu+\sigma+\Delta_I)/(\mu+\Delta_I)-1\right]I_1 = I_1\sigma/(\mu + \Delta_I)$. The assumption in (1) states that this underpricing exceeds the investment's net surplus, $\Delta_I R - I_1$.

[19] Since $\mu \geq \sigma$, the assumption in (1) also implies that $\Delta_I R/I_1 < 2$, placing an upper bound on the value of the follow-on investment opportunity.

[20] Given the binary payoff of the investment, there is no distinction between debt or equity securities at $t = 1$.

[21] We assume that, when indifferent between investing and not investing, the bank does not invest.

δ_2 on the long-term debt issued at $t = 0$, as well as δ_1/p_1 on the securities issued at $t = 1$ to refinance the short-term debt due at $t = 1$.

The investment condition in Eq. 3 can be rearranged as

$$p_1 > \frac{(\theta + \Delta_I)\, I_1 + \Delta_I \delta_1}{\Delta_I\, (R - \delta_2)}. \tag{4}$$

Intuitively, type θ is only willing to invest at $t = 1$ if the price, p_1, is sufficiently high. Moreover, the feasibility assumption in Eq. 2 implies that $R > \delta_2$, so the right-hand side of Eq. 4 is increasing in θ. That is, the minimum price at which a type is willing to invest rises with θ, so higher types require a higher price to invest. Hence, at any given market price, if a type θ is unwilling to invest, then any higher type is also unwilling to invest. This implies that any equilibrium has a cutoff structure: for any market price, the bank invests for sufficiently low values of θ and does not invest for sufficiently high values of θ.

Formally, for a given initial capital structure (δ_1, δ_2) chosen at $t = 0$, a $t = 1$ equilibrium consists of a market conjecture $\hat{\theta}$, a price p_1, and an investment threshold θ^* such that: (i) investors believe that the bank invests if and only if $\theta < \hat{\theta}$; (ii) the price p_1 equals the expected repayment probability of a security issued at $t = 1$ given this conjecture; (iii) given this price, the bank invests if and only if $\theta < \theta^*$; and (iv) the conjecture is correct, i.e., $\hat{\theta} = \theta^*$.

We now derive the price of securities issued at $t = 1$. The expected amount of funds raised by the bank at $t = 1$ is:

$$\mathbb{E}[Q] = \delta_1 + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1. \tag{5}$$

The first term in Eq. 5 arises because the bank must always roll over its short-term debt which has face-value δ_1. The second term reflects the expected amount raised to finance the new investment, conditional on the market conjecture that the bank invests whenever $\theta < \hat{\theta}$. The price p_1 is then equal to the expected probability of repayment at $t = 2$ per unit of funds raised at $t = 1$. Given the conjectured investment threshold $\hat{\theta}$, a bank with $\theta < \hat{\theta}$ raises $\delta_1 + I_1$, while a bank with $\theta \geq \hat{\theta}$ raises only δ_1. Hence,

$$p_1(\hat{\theta}, \delta_1) = \frac{(\delta_1 + I_1) \int_{\mu-\sigma}^{\hat{\theta}} \frac{\theta+\Delta_I}{2\sigma} d\theta + \delta_1 \int_{\hat{\theta}}^{\mu+\sigma} \frac{\theta}{2\sigma} d\theta}{\mathbb{E}[Q]}. \tag{6}$$

We use notation $p_1(\hat{\theta}, \delta_1)$ to highlight that p_1 depends on the conjectured cutoff, $\hat{\theta}$, and on the short-term debt, δ_1. However long-term debt, δ_2, only affects p_1 indirectly, through its effect on $\hat{\theta}$.

Note that if $(\hat{\theta}, \delta_1) = (\mu-\sigma, 0)$, no securities are issued on path at $t = 1$, so $p_1(\mu-\sigma, 0)$ is not pinned down by Bayes' rule. Moreover, $\lim\limits_{\hat{\theta}\downarrow\mu-\sigma} p_1(\hat{\theta}, 0) = \mu - \sigma + \Delta_I$ and $\lim\limits_{\delta_1\downarrow 0} p_1(\mu - \sigma, \delta_1) = \mu$, implying a discontinuity at $(\hat{\theta}, \delta_1) = (\mu - \sigma, 0)$. We set $p_1(\mu - \sigma, 0) = \mu - \sigma + \Delta_I$, which corresponds to the belief that, if a bank with no short-term debt unexpectedly issues securities at $t = 1$, it does so to finance the follow-on investment, and the deviating issuer is the lowest type, $\mu - \sigma$. Under this belief, the lowest type is willing to invest under all-equity financing as the follow-on investment is NPV-positive, i.e., $\Delta_I R > I_1$.

We next characterize the equilibrium investment threshold at $t = 1$ under all-equity financing at $t = 0$, i.e., $\delta_1 = \delta_2 = 0$, which we denote by $\theta_0^* \equiv \theta^*(0, 0)$. This intermediate result will be useful for determining when the bank chooses to issue debt at $t = 0$. Given a conjectured investment cutoff $\hat{\theta}$, only banks with $\theta < \hat{\theta}$ raise funds at $t = 1$. Hence, from Eq. 5 and Eq. 6,

$$p_1(\hat{\theta}, 0) = \int_{\mu-\sigma}^{\hat{\theta}} \frac{\theta + \Delta_I}{\hat{\theta} - \mu + \sigma} d\theta = \frac{\hat{\theta} + \mu - \sigma}{2} + \Delta_I. \tag{7}$$

In an interior equilibrium, the market conjecture is correct, and the marginal type θ_0^* is indifferent between investing and not investing. Thus, using Eq. 4 with $\delta_1 = \delta_2 = 0$,

$$p_1(\theta_0^*, 0) = \frac{(\theta_0^* + \Delta_I) I_1}{\Delta_I R}. \tag{8}$$

Combining Eq. 8 and Eq. 7 yields the equilibrium cutoff. The following proposition shows that this cutoff is the unique equilibrium under all-equity financing.

Proposition 1 *If $\delta_1 = \delta_2 = 0$, there is a unique equilibrium such that a bank invests at $t = 1$ if and only if $\theta < \theta_0^*$ where*

$$\theta_0^* := \frac{\Delta_I - \frac{I_1}{R} + \frac{\mu-\sigma}{2}}{\frac{I_1}{\Delta_I R} - \frac{1}{2}} \in (\mu - \sigma, \mu + \sigma). \tag{9}$$

The equilibrium investment threshold θ_0^* is decreasing in σ, the degree of adverse selection at $t = 1$, and increasing in Δ_I, the value of the follow-on investment opportunity. Hence, when adverse selection is severe relative to the investment surplus, when $\sigma > \Delta_I$, the threshold θ_0^* is low and underinvestment is more severe.[22]

We now proceed to characterize the equilibrium threshold at $t = 1$ with debt, $\theta^*(\delta_1, \delta_2)$, and the bank's optimal capital structure at $t = 0$, (δ_1^*, δ_2^*). At $t = 0$, the bank chooses the capital structure (δ_1^*, δ_2^*) that maximizes its value, which is equivalent to the capital structure that maximizes the probability of making the follow-on investment at $t = 1$:

$$\max_{\delta_1, \delta_2} \theta^*(\delta_1, \delta_2). \tag{10}$$

Note that $\theta^*(\delta_1^*, \delta_2^*) \in (\mu - \sigma, \mu + \sigma)$. On the one hand, since the bank can always choose all-equity financing at $t = 0$, $\theta^*(\delta_1^*, \delta_2^*) \geq \theta_0^* > \mu - \sigma$. On the other hand, the assumption in Eq. 3 implies that the highest type $\mu + \sigma$ never invests at $t = 1$, so $\theta^*(\delta_1^*, \delta_2^*) < \mu + \sigma$.

Since $p_1(\hat{\theta}, \delta_1)$ in Eq. 6 depends on the face value of the long-term debt, δ_2, only indirectly through its effect on the conjectured investment threshold $\hat{\theta}$, the next proposition shows that because long-term debt lowers this threshold, it is never optimal to issue it, $\delta_2^* = 0$. Rather than solving for the $t = 1$ subgame with arbitrary amounts of debt and then optimizing at $t = 0$, it is simpler to first establish $\delta_2^* = 0$; then, fixing $\delta_2^* = 0$, solve the $t = 1$ subgame for any given δ_1; and finally solve for the optimal δ_1^* at $t = 0$.

Proposition 2 *The bank does not issue long-term debt at $t = 0$, $\delta_2^* = 0$.*

[22] As we show below, this is also the parameter region in which the pooling effect of short-term debt raises the price at $t = 1$.

The bank does not issue long-term debt at $t = 0$ because it creates debt overhang at $t = 1$: part of the follow-on investment payoff accrues to existing long-term debtholders, lowering the equityholders' private return from undertaking the investment. This reduced incentive to invest results in a lower investment threshold at $t = 1$, reducing the bank's ex-ante objective (see Eq. 10). Since $\delta_2^* = 0$, we can focus in equilibria of type $\theta^*(\delta_1, 0) =: \theta^*(\delta_1)$.

We next analyze the effect of short-term debt on the probability of investing at $t = 1$. We begin by establishing the following lemma which characterizes the direct effect of short-term debt, δ_1, on the funding price $p_1(\hat{\theta}, \delta_1)$:

Lemma 1 *For any $\hat{\theta} \in (\mu - \sigma, \mu + \sigma)$, $\frac{\partial p_1(\hat{\theta}, \delta_1)}{\partial \delta_1} > 0$ if and only if $\sigma > \Delta_I$.*

An increase in δ_1 makes it more likely that funds raised at $t = 1$ reflect liquidity needs, rather than investment needs. This weakens the adverse selection problem in the new issuance market. In the absence of a liquidity motive, only low-type banks, those with $\theta < \theta^*$, find it worthwhile to undertake the follow-on investment, so issuance signals low-quality assets in place. Short-term debt, hence results in outside investors attributing issuance less to low asset quality and more to liquidity-driven refinancing needs. Through this pooling channel, short-term debt raises the $t = 1$ issuance price when $\sigma > \Delta_I$, that is, when adverse selection concerning the value of assets in place, measured by σR, is sufficiently large relative to the scale of the follow-on investment opportunity, measured by $\Delta_I R$.

Intuitively, liquidity-motivated issuance pools banks across the entire distribution of types. Banks with $\theta \in [\hat{\theta}, \mu + \sigma]$ do not invest, but their success probabilities remain relatively high because their assets in place are more valuable. Banks with $\theta \in [\mu - \sigma, \hat{\theta})$ undertake the follow-on investment, which raises their success probabilities to $\theta + \Delta_I$, but their assets in place are less valuable. When $\sigma > \Delta_I$, the type advantage of banks in the high-θ region outweighs the investment gain from banks in the low-θ region. More specifically, when $\sigma > \Delta_I$,

$$\mathbb{E}\left[\theta \mid \theta \geq \hat{\theta}\right] > \mathbb{E}\left[\theta + \Delta_I \mid \theta < \hat{\theta}\right]. \tag{11}$$

We next characterize the equilibrium cutoff at $t = 1$ for a given amount of short-term debt.

Proposition 3 *(i) If $\frac{\Delta_I R}{I_1} > 1 + \frac{\Delta_I(\delta_1/I_1)}{\mu-\sigma+\Delta_I}$, there is a unique equilibrium threshold $\theta^*(\delta_1)$. This equilibrium is interior, $\theta^*(\delta_1) \in (\mu - \sigma, \mu + \sigma)$, stable, and is the solution to*

$$p_1(\theta^*, \delta_1) = \frac{(\theta^* + \Delta_I) I_1 + \Delta_I \delta_1}{\Delta_I R}. \tag{12}$$

(ii) If $\frac{\Delta_I R}{I_1} \leq 1 + \frac{\Delta_I(\delta_1/I_1)}{\mu-\sigma+\Delta_I}$, there is a stable equilibrium with no investment at $t = 1$, $\theta^* = \mu - \sigma$.

The condition in Proposition 3,

$$\frac{\Delta_I R}{I_1} > 1 + \frac{\Delta_I (\delta_1/I_1)}{\mu - \sigma + \Delta_I}, \tag{13}$$

guarantees that, given a positive amount of short-term debt, the lowest bank type, $\mu - \sigma$, is willing to invest at $t = 1$ even if no other type does. Specifically, the investment condition in Eq. 4, evaluated at the lowest bank type, requires

$$p_1(\mu - \sigma, \delta_1) > \frac{(\mu - \sigma + \Delta_I) I_1 + \Delta_I \delta_1}{\Delta_I R}. \tag{14}$$

For $\delta_1 > 0$, $p_1(\mu - \sigma, \delta_1) = \mu$ and thus the left-hand side does not vary with δ_1, whereas the right-hand side increases with δ_1. The condition in Eq. 13 therefore imposes an upper bound on δ_1: short-term debt must remain low enough not to deter the lowest-type bank from investing.

If the condition in Proposition 3 is satisfied, part (i) of the proposition establishes that there is a unique equilibrium cutoff and that it is interior and stable. If the condition is not satisfied, part (ii) establishes that there exists at least one stable equilibrium in which the bank never undertakes the follow-on investment. As we show later in the proof of Proposition 4, however, the optimal level of short-term debt issued at $t = 0$, δ_1^*, does not deter the lowest-type bank, $\mu - \sigma$, from investing at $t = 1$. Thus, the relevant case is the equilibrium in part (i).[23]

Having characterized the equilibrium threshold at $t = 1$ for a given δ_1, we now analyze the bank's optimal capital structure at $t = 0$. While banks avoid long-term debt because of its adverse effect on investment incentives at $t = 1$ (see Proposition 2), the effect of short-term debt is, a priori, ambiguous. On the one hand, short-term debt increases the right-hand side of the investment condition in Eq. 4—the required issue price that makes investment worthwhile—which discourages the bank from making the follow-on investment at $t = 1$. The intuition is that the bank's motive for trade, i.e., whether it is refinancing short-term debt or investing, depends on its type θ, which outside investors cannot observe. When the bank issues new securities to invest, this investment raises the probability of success, and thus the value of the newly issued claims, yet the issue price does not reflect this. Part of the gain from investment is therefore captured by new claimants through a higher probability of repayment, which weakens the bank's incentives to invest.

On the other hand, the price on the left-hand side of Eq. 4 also depends on δ_1. Specifically, an increase in δ_1 leads to more liquidity-driven trading, which affects the price directly (see Lemma 1), but also indirectly through a shift in the conjectured investment threshold $\hat{\theta}$.[24] Taking into account these effects of short-term debt, the bank chooses δ_1 to maximize $\theta^*(\delta_1)$.

Proposition 4 *There is a unique optimal capital structure at $t = 0$. When $\sigma > \Delta_I$, there exists*

$$\theta^T := \frac{\mu - \sigma + \frac{R}{I_1}(\sigma - \Delta_I)(\mu + \sigma)}{1 + \frac{R}{I_1}(\sigma - \Delta_I)} \in (\mu - \sigma, \mu + \sigma). \tag{15}$$

such that, if $\theta_0^* < \theta^T$, the bank chooses $\delta_1^* > 0$ at $t = 0$, and the resulting investment threshold at $t = 1$ satisfies $\theta^*(\delta_1^*, 0) > \theta_0^*$. Otherwise, the bank chooses $\delta_1^* = 0$, and the investment threshold at $t = 1$ is θ_0^*.

Threshold θ^T in Proposition 4 is the critical value of the all-equity equilibrium threshold, θ_0^*,

[23] Specifically, the proof of Proposition 4 shows that if δ_1 is high enough that the condition in Eq. 13 is not satisfied, any equilibrium cutoff satisfies that $\theta^*(\delta_1) < \theta_0^*$, so it is not optimal to issue short-term debt at $t = 0$ in the first place.

[24] From rational expectations, in equilibrium $\hat{\theta} = \theta^*(\delta_1)$.

below which a marginal increase in short-term debt from zero raises the equilibrium investment threshold at $t = 1$, $\theta^*(\delta_1)$. Formally, $\theta_0^* < \theta^T$ if and only if

$$\left.\frac{d\theta^*(\delta_1)}{d\delta_1}\right|_{\delta_1=0} > 0. \tag{16}$$

Proposition 4 therefore shows that short-term debt is optimal at $t = 0$ when all-equity financing leads to a sufficiently low investment threshold, that is, when $\theta_0^* < \theta^T$. The low investment threshold θ_0^* is the by-product of a severe adverse selection problem at $t = 1$, which discourages the bank from investing except at sufficiently low realizations of θ. In that case, short-term debt, by forcing high types to access the market at $t = 1$, increases the price of issued securities and thereby encourages higher-type banks to invest, so that $\theta^*(\delta_1^*) > \theta_0^*$.

Importantly, when $\theta_0^* < \theta^T$, the optimal capital structure features a combination of short-term debt and equity. Specifically, for $\delta_1 \in [0, \delta_1^*)$, $\theta^*(\delta_1)$ is increasing in δ_1 because of the the pooling effect of short-term debt: by forcing more banks to refinance, it makes market access less informative and improves the terms at which funds can be raised. However, this benefit of short-term debt is diminishing, since once refinancing-motivated trade is already sufficiently prevalent, further increases in δ_1 have little effect on prices. At the same time, the dilution effect grows with δ_1: investment raises the value of all claims issued at $t = 1$, including those used to refinance existing short-term debt, but the market price does not fully adjust to reflect this. Consequently, for sufficiently large δ_1, the dilution effect dominates, so short-term debt discourages investment and $\theta^*(\delta_1)$ becomes decreasing in δ_1. Formally, δ_1^* is the point at which $\theta^*(\delta_1)$ is maximized, i.e.,

$$\left.\frac{d\theta^*(\delta_1)}{d\delta_1}\right|_{\delta_1=\delta_1^*} = 0. \tag{17}$$

Finally, note that both θ_0^* (see Proposition 2) and θ^T depend on the model's underlying parameters. The next proposition characterizes the comparative statics for when $\theta_0^* < \theta^T$ is more likely to hold and, hence, when it is optimal to issue short-term debt at $t = 0$.

Proposition 5 *(i) An increase in σ or a decrease in Δ_I decreases θ_0^* and increases θ^T, thereby making short-term debt more likely to be optimal. (ii) An increase in $\frac{R}{I_1}$ holding fixed the gross return per unit invested $\frac{\Delta_I R}{I_1}$, decreases θ_0^* and increases θ^T, thereby making short-term debt more likely to be optimal. (iii) θ^T increases with μ at a rate of 1, while θ_0^* increases in μ at a rate greater than 1. Hence, an increase in μ makes short-term debt less likely to be optimal.*

Proposition 1 implies that θ_0^* decreases in σ and increases in Δ_I, while Proposition 5 shows that θ^T moves in the opposite direction. Hence, an increase in the severity of adverse selection, σ, or a decrease in the value of the investment opportunity, Δ_I, widens the gap between the two thresholds and so makes the condition $\theta_0^* < \theta^T$ more likely to hold. Thus, short-term debt is more likely to be optimal when the degree of underinvestment is important relative to the value of the follow-on investment opportunity.

Proposition 5, part (ii), separates the scale of the follow-on investment opportunity from its return per dollar invested. Holding $\frac{\Delta_I R}{I_1}$ fixed, an increase in $\frac{R}{I_1}$, can be interpreted as a reduction in the scale of the follow-on investment relative to the bank's existing payoff, with its profitability unchanged. The investment opportunity then becomes less important relative to the bank's assets in place, while the amount of external financing—and hence the dilution associated with refinancing short-term debt—declines. Both effects make the pooling benefit of short-term debt more likely to dominate.

Finally, part (iii) shows that an increase in μ makes short-term debt less likely to be optimal. A higher μ raises the expected repayment of each security and therefore reduces the number of securities the bank must issue to raise a given amount of funds, thereby reducing the dilution generated by adverse-selection-driven mispricing.

Taken together, the three sets of comparative statics show that short-term debt is more likely to be optimal when private information about the assets in place creates substantial financing distortions relative to the value and scale of the follow-on investment opportunity.

We next discuss several of the model's main assumptions and how to interpret them.

4 Model Discussion and Interpretation

What is the economic interpretation of $t = 1$? Although the model has a single interim date, $t = 1$ should be interpreted broadly as the bank's day-to-day operating environment rather than as a one-time financing event. In the ordinary course of business, new lending opportunities arise, and lenders may withdraw or decline to roll over their claims. The model's message is that, because these funding and investment needs arise randomly and continually, outside investors cannot attribute any particular issuance to a specific motive. Short-term debt, therefore, creates liquidity-driven financing needs that pool with investment-driven needs to mitigate adverse selection.

In the model, the form of financing is irrelevant at $t = 1$; however, we interpret it as an interbank loan or some form of wholesale funding. Indeed, Bluhm, Georg, and Krahnen (2016) show that deposit outflows lead German banks to borrow in the interbank market, and in the Online Appendix, we show that a large portion of deposit outflows are refinanced with wholesale funding among US banks.[25]

Unobservability of aggregate financing at $t = 1$. In the baseline model, issuance volume is unobservable at $t = 1$, in the spirit of Malherbe (2014). This assumption is a convenient way to ensure that outside investors cannot distinguish refinancing needs from new investment needs; however, as we show in Section 5.3, our main mechanism persists when issuance volume is observable, provided that the underlying uses of funds cannot be perfectly distinguished. This may arise, for example, because the size and timing of liquidity shocks and investment opportunities are stochastic or imperfectly observed.

This interpretation is especially natural in banking. Regulatory filings provide periodic snapshots of bank balance sheets, but interim financing activity—particularly in interbank and short-term wholesale markets—is much harder to observe in real time. Rochet and Tirole (1996), for example, emphasize that interbank transactions complicate the measurement of

[25] Deposits are considered fairly inelastic in the short run, so it is difficult to quickly raise new deposits to finance the outflow of existing ones.

banks' liquidity and solvency positions even for prudential supervisors; more broadly, Caskey, Huang, and Saavedra (2020) document substantial noncompliance with loan-disclosure requirements outside banking. The gap between relatively transparent ex-ante balance sheets and opaque interim funding decisions is therefore not merely a modeling convenience.

Relatedly, we assume that outsiders cannot contract on the use of interim funds. In practice, capital is fungible within banks, and loans to banks are rarely tied in a verifiable way to a particular loan or project.

Why not use secured financing project finance for the interim investment? Secured borrowing does not necessarily eliminate the friction. When collateral values are uncertain, lenders are still exposed to counterparty risk and must evaluate the borrower's broader balance sheet.

Our model assumes no asymmetric information about the follow-on investment; hence, if possible, project finance would fully solve the interim adverse selection problem. However, in practice, banks are likely to have private information about follow-on investments. Hence, to the extent that follow-on projects and assets in place are imperfectly correlated, project finance is likely more subject to asymmetric information than lending against the bank's full balance sheet (e.g., Gorton and Pennacchi (1991), Subrahmanyam (1991) and DeMarzo (2005)). Moreover, some follow-on investments may not be fully separable from assets in place (e.g., a second production line, a plant expansion, or an investment that uses the same management, collateral, customers, or internal cash flows). In these cases, the relevant cash flows cannot be cleanly pledged to a separate project vehicle, and the distinction between project finance and balance-sheet lending becomes blurred.

Why not prefund the investment? A bank could, in principle, raise excess cash at $t = 0$ and use it to finance future lending. Cash, however, can aggravate agency problems (Jensen, 1986), especially for financial institutions, where funds can be redeployed quickly (Myers and Rajan, 1998). Cash holdings may additionally be costly for tax and balance-sheet reasons (Kashyap, Rajan, and Stein, 2002). Moreover, in practice, the size and timing of future investment opportunities are uncertain, exacerbating these aforementioned costs.[26] Finally,

[26]A credit line arranged at $t = 0$ can generate agency costs similar to those associated with holding cash.

to the extent that asymmetric information is present at $t = 0$, raising additional funds upfront may be costly, as we discuss next.

What if asymmetric information is present at $t = 0$? We assume that there is no asymmetric information at $t = 0$; however, our mechanism does not require this. What matters is that the bank returns to the market at $t = 1$ for liquidity-driven reasons. If anything, initial asymmetric information strengthens the case for short-term debt. In Flannery (1986), high-quality firms use short-term debt so that their claims can be repriced once information is revealed. Ours operates through the information content of market access: liquidity-driven refinancing makes subsequent issuance less revealing about assets in place. The two are distinct and can coexist, so introducing adverse selection at $t = 0$ need not eliminate the pooling mechanism. We abstract from it only to isolate that mechanism cleanly.

Why do withdrawals create external funding needs? The model requires that liquidity shocks create aggregate financing needs for the bank. If withdrawals were independent across a sufficiently diffuse funding base (e.g., small depositors), they would have no effect on the banks' aggregate financing needs. In practice, short-term bank funding is concentrated, so creditor-level shocks generate variable bank-level funding needs. Copeland, Martin, and Walker (2014) show that the tri-party repo market is highly concentrated, while Krishnamurthy, Nagel, and Orlov (2014) document that twenty fund families account for more than 80% of money market fund assets. Interbank markets display similar concentration (Afonso, Kovner, and Schoar, 2013; Craig and Ma, 2018). Consistent with the model, Beaumont, Libert, and Hurlin (2019) provide evidence that funding concentration generates undiversifiable variation in bank-level financing needs, and Bluhm, Georg, and Krahnen (2016) show that deposit outflows lead banks to borrow in interbank markets. We also provide direct evidence for the lack of full diversification in the Online Appendix. Specifically, we find that US banks' aggregate

To mitigate these costs, credit line agreements often include covenants and other contractual conditions that give lenders some discretion over whether to fund a draw (Sufi, 2009; Acharya et al., 2014). When the bank's asset quality is private information at $t = 1$, however, the credit-line provider may face an adverse-selection problem similar to that faced by other outside investors when exercising this discretion. The firm could also enter into a contract promising to deliver funds in the future; however, in practice, the timing and size of investments are uncertain.

deposit base varies substantially from quarter to quarter—the within-bank standard deviation of deposit flows is roughly four percent of assets—that the large majority of this variation is bank-specific rather than a common aggregate movement, that it does not diminish with bank size, and that deposit outflows are systematically associated with increased wholesale borrowing.

Why banks rather than nonfinancial firms? Two features make the mechanism particularly relevant for banks. First, banks access funding markets frequently, while the use of funds is difficult to verify because capital is fungible and lending is continuous. Nonfinancial firms more often raise capital in connection with large, discrete projects, making market access more informative about its purpose.

Second, banks' interim financing needs may be only weakly correlated with the quality of their existing assets. New lending opportunities depend largely on borrowers' demand for credit and need not move closely with the performance of the bank's legacy loan portfolio. For many nonfinancial firms, by contrast, strong assets in place are more likely to coincide with strong investment opportunities. Market access then reveals more about fundamentals, and short-term debt can intensify rather than mitigate adverse selection, as we show in Section 5.1. Frequent financing and a weak link between new opportunities and legacy assets together explain why the pooling channel is especially plausible in banking.

A natural concern is that banks can mitigate asymmetric information by diversifying their assets (e.g., Diamond (1984)). First, banks' private information may not be entirely idiosyncratic. For example, many banks specialize in particular industries or locations (Paravisini, Rappoport, and Schnabl, 2023). Second, some exposures, e.g., interest rate risk, are common to the entire portfolio, cannot be diversified away at the loan level, and are not readily observable. Consistent with this, banks seem to be difficult to evaluate relative to non-financial firms (Morgan, 2002). Indeed, there is ample evidence of adverse selection inducing rationing in the interbank markets (e.g., Furfine (2001), King (2008), Angelini, Nobili, and Picillo (2011), Afonso, Kovner, and Schoar (2011), Acharya and Merrouche (2013)).

Informed lenders. The pooling benefit requires short-term lenders' trading decisions to be driven primarily by liquidity needs rather than by information about bank quality. When lenders become informed, rollover decisions themselves reveal fundamentals. Outside financing then becomes a negative signal, and the same liability structure that supports lending in normal times can exacerbate adverse selection in crises, as we show in Section 5.2.

This distinction separates our mechanism from theories in which short-term debt is valuable because the threat of runs disciplines or commits the bank, such as Calomiris and Kahn (1991), Diamond and Rajan (2000), and Diamond and Rajan (2001). Here, short-term debt is valuable when lenders' reasons for withdrawing are uninformative about asset quality. Holding other effects fixed, deposit insurance can therefore strengthen rather than weaken our mechanism by reducing incentives to acquire information and making withdrawals less sensitive to fundamentals. The central trade-off is thus state dependent: liquidity-driven withdrawals create pooling, whereas information-driven withdrawals create fragility.

What about runs? Because we have a deep competitive financial market, there is no possibility of bank runs in our model (e.g., Diamond and Dybvig (1983)). However, to the extent that short-term debt can trigger panic-driven runs, this would be another cost of using it. Runs driven by creditors' information about fundamentals are in some ways similar to the informed rollover decisions we analyze in Section 5.2. In this extension, rollover decisions can turn market access into a negative signal and reverse the benefit of short-term debt. Note also that deposit insurance eliminates the run cost precisely on the liabilities for which the pooling benefit is strongest.

5 Extensions

We next consider three extensions of the baseline model. First, in Section 5.1, we allow the follow-on investment opportunity to be correlated with the value of the assets in place. Second, in Section 5.2, we allow lenders to become informed about the bank's type. Finally, in Section 5.3, we show that our main mechanism persists when we relax the assumption that interim volume is unobservable.

5.1 Correlated Investment Opportunities

In Sections 2 and 3, the follow-on investment is completely independent of the bank's type. In this section, we relax this assumption to show that the less correlated the asset's in place are with new investment opportunities, the stronger our mechanism is. As we argue below, this implies that the benefits of short-term debt are higher for banks than nonfinancial firms.

To model this correlation, we assume that only banks with type $\theta \geq \theta_I$ receive the investment opportunity at $t = 1$.[27]

When banks issue short-term debt at $t = 0$, types below θ_I must return to the market at $t = 1$ to refinance it, even though they have no investment opportunity to fund. These banks' issuance lowers the average quality of securities sold at $t = 1$, depresses the price, and weakens the incentive for higher types to invest.

Proposition 6 *There exists a $\widetilde{\theta} \in (\mu - \sigma, \mu + \sigma)$ such that for all $\theta_I > \widetilde{\theta}$, $\delta_1^* = 0$.*

The proposition illustrates that, as follow-on opportunities become more concentrated among higher realizations of bank type, short-term debt becomes less effective at supporting investment and may eventually reduce it. The pooling benefit thus requires that assets in place be only weakly correlated with future investment opportunities, so that refinancing needs are relatively uninformative about fundamentals.

This condition is more naturally satisfied for banks than for nonfinancial firms. A bank's new lending opportunities depend primarily on borrowers' demand for credit and are therefore only weakly correlated with the quality of its existing loan portfolio: short-term funding needs arise for reasons largely orthogonal to fundamentals, allowing the pooling channel to operate. For nonfinancial firms, by contrast, stronger assets in place are typically associated with better follow-on opportunities, which weakens this channel (e.g., Berk, Green, and Naik (1999)).

[27] The leading case studied in Sections 2 and 3 is nested at $\theta_I = \mu - \sigma$.

Our mechanism thus predicts that short-term debt should be more prevalent in bank capital structures than in those of nonfinancial firms.

Although the model has only a single interim period, banks in practice repeatedly roll over short-term liabilities while continuously receiving new lending opportunities. Because refinancing and new investment arise together on a recurring basis, and because neither is tightly linked to the quality of existing assets, short-term debt can repeatedly mitigate adverse selection and support lending without revealing much about fundamentals. Nonfinancial firms' investment projects and financing needs, by contrast, tend to be lumpy and episodic: such firms access funding markets less frequently and in larger discrete amounts, limiting the extent to which short-term debt can generate a sustained pooling benefit.

5.2 Informed Roll-Over Decisions

In Sections 2 and 3, short-term debtholders do not roll over their debt, so the bank must raise δ_1 at $t = 1$ from new investors to meet their liquidity demand. Hence, whenever banks refinance existing short-term debt, their trading motive is unrelated to thier type.

In this section, we assume a fraction $\alpha_l \in (0, 1)$ of short-term debtholders face liquidity shocks, which force the bank to raise $\alpha_l \delta_1$ from new investors to meet their withdrawals. The remaining fraction of short-term debtholders, $\alpha_I = 1 - \alpha_l$, become informed about θ at $t = 1$.[28] These informed investors roll over their claims at price p_1 if $\theta + \Delta_I \geq p_1$ for $\theta < \theta^*$, and if $\theta \geq p_1$ for $\theta \geq \theta^*$, where, as in Section 3, θ^* denotes the investment threshold.[29] Otherwise, if $\theta + \Delta_I < p_1$ for $\theta < \theta^*$, and if $\theta < p_1$ for $\theta \geq \theta^*$, informed investors do not roll over their claims at maturity, and the bank must raise the additional $\alpha_I \delta_1$ from new investors at price p_1. Finally, we assume that rollover decisions are not observable, so interim market participants cannot distinguish between a bank that raises only $\alpha_l \delta_1$ to meet liquidity-driven withdrawals

[28] We could also have a fraction of short-term debtholders not face a liquidity shock and not become informed, but this would just further complicate the analysis without adding any additional insights.

[29] Notice that this implies that these investors have all the bargaining power. We also assume that existing investors are not willing or able to provide funding for the new investment, either because they do not have the necessary funds, or because they are not willing to take the additional risk exposure.

and one that must raise the full δ_1 because informed investors also refuse to roll over.[30]

Proposition 4 establishes that a necessary condition for short-term debt financing to be optimal at $t = 0$ is $\sigma > \Delta_I$. When a fraction of short-term debtholders become informed, it reduces the attractiveness of short-term debt. Hence, if short-term debt is not optimal baseline model, it cannot become optimal in their presence. We therefore restrict attention, without loss of generality, to the case $\sigma > \Delta_I$.

Let $p_1(\theta^*, \delta_1, \alpha_I)$ denote the equilibrium price at $t = 1$, which depends on the investment threshold θ^*, the amount of short-term debt δ_1, and the proportion of informed investors α_I. The next proposition shows that short-term debt is never optimal once sufficiently many short-term debtholders are informed.

Proposition 7 *Assume that $\sigma > \Delta_I$. There exists a threshold $\overline{\alpha}_I \in (0, 1)$ such that, for every $\alpha_I > \overline{\alpha}_I$ and every $\delta_1 > 0$, $p_1(\theta^*, 0, \alpha_I) > p_1(\theta^*, \delta_1, \alpha_I)$. Hence, when $\alpha_I > \overline{\alpha}_I$, short-term debt depresses investment at $t = 1$ and is therefore not part of the optimal capital structure.*

Proposition 7 shows that the optimality of short-term debt hinges on whether creditor withdrawals reflect liquidity needs or private information. When withdrawals are liquidity driven, banks of all types must raise funds from new investors for reasons unrelated to the quality of their assets. This draws high-type banks into the market even when they do not undertake the follow-on investment, thereby improving the average quality of the securities issued at $t = 1$. When α_I is sufficiently small, this pooling effect dominates, and $p_1(\theta^*, \delta_1, \alpha_I)$ increases with δ_1. As α_I rises, however, withdrawals increasingly convey negative information about bank quality: informed debtholders decline to roll over when fundamentals are weak, leaving the outside market populated by an adversely selected set of issuers. Once α_I exceeds $\overline{\alpha}_I$, this adverse-selection effect dominates, so $p_1(\theta^*, \delta_1, \alpha_I)$ decreases with δ_1, and short-term debt discourages investment. Because α_I measures how much of the bank's short-term funding is held by informed rather than uninformed creditors, what determines the pooling benefit is the composition of short-term debt, not only its maturity.

[30] Firms do not issue long-term debt, $\delta_2 = 0$, because, as we have shown, long-term debt always lowers the ex-post incentives to invest. (See Proposition 2.)

Sustaining this benefit requires that a sufficiently large share of short-term creditors remain uninformed—a further reason, distinct from those discussed in Section 5.1, why our mechanism applies naturally to banks rather than to nonfinancial firms. Banks are especially likely to satisfy this condition because many of their short-term claims are held by retail depositors whose withdrawal decisions reflect payment or consumption needs rather than information about the quality of the bank's assets. Such depositors may lack both the expertise and the scale required to monitor an opaque balance sheet. The interpretation has a less natural counterpart for nonfinancial firms, whose short-term claims are more likely to be held by sophisticated investors than by a broad base of retail depositors.

This extension also highlights a new benefit of deposit insurance. Whereas the conventional market-discipline view emphasizes that deposit insurance weakens depositor monitoring (see, for example, Calomiris and Kahn, 1991), our analysis points to an offsetting advantage: information-insensitive deposit funding helps sustain the pooling benefit of short-term debt. This benefit is also distinct from the one stressed in the information-insensitivity literature (e.g., Gorton and Pennacchi, 1990; Dang, Gorton, and Holmström, 2013). There, keeping creditors uninformed preserves the value stability of a tradable short-term claim, so that it can serve as a medium of exchange without uninformed holders being picked off by privately informed counterparties. In our model, the relevant claims are not traded among creditors; uninformed creditors are valuable because their rollover decisions remain uncorrelated with bank fundamentals, which keeps high-quality banks in the pool of issuers. The benefit thus operates through the bank's adverse-selection problem when raising outside finance, rather than through the tradability of an information-insensitive security.

Finally, Proposition 7 suggests that the effect of short-term debt can be state-dependent. In normal times, when concerns about bank fundamentals are limited, withdrawals are more likely to reflect liquidity needs, allowing short-term debt to support pooling and investment. During financial crises, by contrast, uninsured or sophisticated creditors have stronger incentives to acquire and act on information about bank quality. Rollover decisions then become informative, outside financing becomes a negative signal, and the same liability structure that supports investment in normal times can instead intensify adverse selection and depress investment. This state dependence reflects a deeper tension: some adverse selection in outside issuance is precisely what makes short-term debt valuable, since it is the mispricing of outside financing that the pooling of liquidity- and investment-driven issuance helps to alleviate. Yet if the underlying adverse-selection problem became severe enough, it would also raise creditors' incentives to acquire information, pushing α_I upward and eroding the very pooling benefit that short-term debt provides. The same friction that makes short-term debt useful could therefore, if strong enough, undermine it.

The informed rollover mechanism can also explain why wholesale funding dries up in crises (e.g., Pérignon, Thesmar, and Vuillemey (2018)). It can also rationalize why banks tend to rely more on insured deposits for funding.[31]

5.3 Observable Trading Volume

In our baseline setup, we assume that short-term debtholders never roll over their debt, so the bank must always raise δ_1 at $t = 1$ to satisfy its liquidity needs. We also assume that the amount of funding raised by the bank at $t = 1$ is not observable, so outside investors cannot distinguish funding raised to meet rollover needs from funding raised to finance the follow-on investment. This assumption should be understood as a convenient reduced-form way of capturing the more general idea that refinancing and investment needs are not perfectly observable. This is plausible for banks, which recurrently access funding markets for liquidity reasons while also facing recurrent lending opportunities, with total funding needs that are themselves stochastic. To illustrate this point, in this section we assume that the amount of funding raised by the bank at $t = 1$ is observable. However, we now assume that, with

[31] One may argue that because wholesale funding is more unstable, it would be *more* valuable for banks. However, in the model, what matters is the total amount the bank must raise at $t = 1$ relative to its balance sheet. Wholesale funding is more volatile than deposits relative to its own base, but deposits make up much more of banks' balance sheets, so the dollar variation banks must refinance is dominated by deposits. See the Online Appendix for more details. Moreover, a larger share of the total volatility in wholesale funding is likely to be informative, which works against the pooling mechanism, compared with insured retail deposits.

probability q_l, short-term debtholders do not roll over their debt, so the bank must raise funds from new investors at $t = 1$ to repay them.

Furthermore, to simplify the analysis, we impose two additional assumptions. First, existing short-term debtholders cannot finance the follow-on investment; otherwise, they could take advantage of private information about whether the bank has been hit by a liquidity shock. Second, short-term debtholders who do not experience a liquidity shock may roll over their debt at a price p_r, specified in the original debt contract at $t = 0$. This contractual arrangement simplifies the problem by avoiding bargaining under asymmetric information between the bank and its short-term creditors at $t = 1$. It is also optimal in our setting, since the value of short-term debt is that it generates a trading motive that is orthogonal to the bank's underlying fundamentals.

Finally, as in the baseline setup, we impose that the highest-type bank, $\theta = \mu + \sigma$, does not invest even if all lower types do (see Eq. 1). To simplify the analysis, we also assume that $\mu = \sigma$ and that $(\mu/2)\, R > I_1$. When $\mu = \sigma$, the lowest-type bank, $\theta = 0$, invests at $t = 1$ even if no other type does, provided it is able to raise the required financing. Under $(\mu/2)\, R > I_1$, the lowest-type bank strictly prefers to raised I_1 and invest at $t = 1$ when it it has outstanding short-term debt $\delta_1 = I_1$ and has not experienced a liquidity shock even if no other type invests.[32]

Since the benefit of short-term debt in our model is to generate a funding motive that is orthogonal to the bank's fundamentals, thereby masking whether issuance at $t = 1$ reflects rollover needs or the desire to finance the follow-on investment, the optimal choice of short-term debt when issuance volume is observable is necessarily extreme. Specifically, the bank raises either 0 or I_1.[33] When $\delta_1 = I_1$, funding raised to repay maturing debt is observationally

[32]If $R \leq 2I_1/\mu$ the equityholders of the lowest-type bank are indifferent between investing and not investing when no other type invests, i.e., when the investment threshold is $\theta^{\delta} = 0$. If the bank does not invest, its payoff is zero with probability one. If it does invest, it generates R with probability Δ_I,but equityholders receive no residual payoff because the face value of total debt due at $t = 2$, $2I_1/\mu$ due at $t = 2$ would weakly greater than R.

[33]In reality, both investment sizes and refinancing needs are more continuous, so there will be some pooling with different levels of short-term debt. We maintain the assumption that the investment size follows a binomial distribution to keep the analysis as simple as possible.

identical to funding raised to undertake the new investment, so issuance volume conveys no additional information. By contrast, any other level of short-term debt would make issuance volume partially informative and therefore would not have the pooling benefit that gives short-term debt its value.[34]

Consider first the case without short-term debt, $\delta_1 = 0$. Let $\theta^{n\delta}$ denote the equilibrium investment threshold such that, at $t = 1$, a bank invests only if its type satisfies $\theta < \theta^{n\delta}$. The price at $t = 1$ of a security that promises one unit at $t = 2$, conditional on the bank raising I_1 and on the market conjecturing an investment threshold $\hat{\theta}^{n\delta}$ is given by:

$$p_1^{n\delta}(\hat{\theta}^{n\delta}) = \Delta_I + E[\theta \mid \theta \leq \hat{\theta}^{n\delta}] = \Delta_I + \frac{\hat{\theta}^{n\delta}}{2}. \tag{18}$$

Given the price $p_1^{n\delta}(\hat{\theta}^{n\delta})$, a bank of type θ that has not suffered a liquidity shock invests at $t = 1$ if

$$\theta R < (\theta + \Delta_I)\left(R - \frac{I_1}{p_1^{n\delta}(\hat{\theta}^{n\delta})}\right). \tag{19}$$

The assumption in Eq. 1 implies that the highest type, $\theta = 2\mu$, does not invest at $t = 1$ even if every other bank does, that is, when $\hat{\theta}^{n\delta} = 2\mu$. Furthermore, for $\theta = 0$, Eq. 19 becomes

$$0 < \Delta_I\left(R - \frac{I_1}{p_1^{n\delta}(\hat{\theta}^{n\delta})}\right), \tag{20}$$

which is satisfied because $p_1^{n\delta}(\hat{\theta}^{n\delta}) \geq \Delta_I$ and $\Delta_I R - I_1 > 0$. Therefore, the lowest type always invests. It follows that any equilibrium threshold must satisfy $\theta^{n\delta} \in (0, 2\mu)$. The next proposition shows that this equilibrium threshold exists and is uniquely determined by the following equilibrium condition under rational expectations, $\hat{\theta}^{n\delta} = \theta^{n\delta}$:

$$\theta^{n\delta} R = (\theta^{n\delta} + \Delta_I)\left(R - \frac{I_1}{p_1^{n\delta}(\theta^{n\delta})}\right). \tag{21}$$

[34] When issuance volume is observable, $\delta_1 = 0$ dominates any $\delta_1 > 0$ with $\delta_1 \neq I_1$, and may strictly dominate if it discourages investment at $t = 1$.

Proposition 8 *If $\delta_1 = 0$, there exists a unique equilibrium threshold $\theta^{n\delta} \in (0, 2\mu)$ such that the bank invests whenever $\theta < \theta^{n\delta}$, where*

$$\theta^{n\delta} = \frac{\Delta_I \left(\frac{\Delta_I R}{I_1} - 1 \right)}{1 - \frac{1}{2} \frac{\Delta_I R}{I_1}}. \tag{22}$$

Consider now the case in which banks issue short-term debt $\delta_1 = I_1$ maturing at $t = 1$. In this case, the volume of external finance raised by the bank at $t = 1$, V_δ, can take three values: 0 if the bank neither experiences a liquidity shock nor invests; I_1 if it either experiences a liquidity shock or invests; and $2I_1$ if it both experiences a liquidity shock and invests.

Assume that the market expects no bank to both invest and raise finance at $t = 1$, so that any attempt to raise $2I_1$ is interpreted as coming from the lowest type, $\theta = 0$. Such a bank, if it invests, generates R with probability Δ_I. Because Eq. 1 implies that $\Delta_I R < 2I_1$, it cannot successfully raise $2I_1$. Therefore, there always exists an equilibrium in which the bank does not invest when it experiences a liquidity shock $t = 1$.

Proposition 9 *If $\delta_1 = I_1$, there exists an equilibrium in which the bank does not invest at $t = 1$ when it experiences a liquidity shock.*

Although other equilibria may exist in which the bank successfully raises $2I_1$, we focus on the worst-case equilibrium in which it does not. Our goal in this section is to establish that the pooling benefits of short-term debt identified in the baseline case persist even when issuance volume is observable. We show that, even in this case, issuing short-term debt can still generate pooling benefits that support expected investment at $t = 1$.

Let θ^δ denote the equilibrium investment threshold at $t = 1$such that the bank invests whenever $\theta < \theta^\delta$, provided it does not experience a liquidity shock. The price at $t = 1$ of a security that promises to pay one unit at $t = 2$, conditional on the bank raising I_1 and on the market conjecturing an investment threshold $\hat{\theta}^\delta$ is given by:

$$p_1^\delta(\hat{\theta}^\delta) = \frac{(1-q_l)\frac{\hat{\theta}^\delta}{2\mu}\left(\Delta_I + \frac{\hat{\theta}^\delta}{2}\right) + q_l\mu}{(1-q_l)\frac{\hat{\theta}^\delta}{2\mu} + q_l} \tag{23}$$

In words, when the market observes a bank raising I_1, it assings probability $q_l\left((1-q_l)\frac{\hat{\theta}^\delta}{2\mu} + q_l\right)^{-1}$ to the event that the bank has experienced a liquidity shock, in which case it generates R with probability μ at $t = 2$. It assigns the complementary probability, $1 - q_l\left((1-q_l)\frac{\theta^\delta}{2\mu} + q_l\right)^{-1}$ to the event that the bank has not experienced a liquidity shock and is raising funds to invest, in which case it generates R with expected probability $\Delta_I + \frac{\theta^\delta}{2}$. The assumption in Eq. 1 guarantees that $\hat{\theta}^\delta < 2\mu$ and $\mu = \sigma$, guarantees that $\hat{\theta}^\delta > 0$.

Given price $p_1^\delta(\hat{\theta}^\delta)$, a bank of type θ that has not experienced a liquidity shock at $t = 1$ if

$$(\theta + \Delta_I)\left(R - \frac{I_1}{p_r(\hat{\theta}^\delta)} - \frac{I_1}{p_1^\delta(\hat{\theta}^\delta)}\right) \geq \theta\left(R - \frac{I_1}{p_r(\hat{\theta}^\delta)}\right) \tag{24}$$

where $p_r(\hat{\theta}^\delta)$ denotes the price, set $t = 0$, at which short-term debtholders roll over their debt at $t = 1$when they do not experience a liquidity shock, and which may depend on the conjectured investment threshold $\hat{\theta}^\delta$. The equilibrium threshold exists and is uniquely determined by the following equilibrium condition under rational expectations, $\hat{\theta}^\delta = \theta^\delta$

$$\left(\theta^\delta + \Delta_I\right)\left(R - \frac{I_1}{p_r(\theta^\delta)} - \frac{I_1}{p_1^\delta(\theta^\delta)}\right) = \theta^\delta\left(R - \frac{I_1}{p_r(\theta^\delta)}\right) \tag{25}$$

Finally, for a given $p_r(\theta^\delta)$, short-term debtholders who do not experience a liquidity shock roll over their debt at $t = 1$, if they expect other short-term debtholders to do the same when $p_r(\theta^\delta) \leq \mu + \Pr(\theta \leq \theta^\delta)\Delta_I$. If instead they expect the other short-term debtholders not to roll over, they roll over only if $p_r(\theta^\delta) \leq \mu$. Hence, assuming that debtholders roll over when indifferent, whenever

$$p_r(\theta^\delta) \in (\mu, \mu + \Pr(\theta \leq \theta^\delta)\Delta_I], \tag{26}$$

there are multiple equilibria: debtholders roll over if and only if they expect the others to do so.

Since the purpose of short-term debt is to disguise the bank's motive for raising funds at $t = 1$, it is important that rollover decisions retain some randomness. This requires that short-term debtholders roll over their debt whenever they do not experience a liquidity shock. We set $p_r(\theta^\delta) = \mu$, which is the highest rollover price consistent with debtholders rolling over at $t = 1$ even in the worst-case scenario in which each debtholder expects the others not to roll over within the multiple-equilibrium region. At any higher price, debtholders would never roll over their short-term debt, and short-term debt would therefore cease to be useful for disguising the bank's motive for raising funds when the volume raised at $t = 1$ is observable.

Under rational expectations $\hat{\theta}^\delta = \theta^\delta$, Eq. 23 and Eq. 25 determine the equilibrium when the bank issues short-term debt with face value $\delta_1 = I_1$.[35]

Proposition 10 *If $\delta_1 = I_1$, then for any $q_l > 0$, a unique equilibrium θ^δ exists, and it satisfies $0 < \theta^\delta < 2\mu$.*

Having characterized the cases $\delta_1 = 0$ and $\delta_1 = I_1$, we next compare the ex-ante probability that the bank invests at $t = 1$. When $\delta_1 = 0$, investment occurs for all types $\theta < \theta^{n\delta}$, implying an investment probability of $\theta^{n\delta}/2\mu$. When $\delta_1 = I_1$, investment occurs for all types $\theta < \theta^\delta$, conditional on not being hit by a liquidity shock, implying an investment probability of $(1 - q_l)\theta^\delta/2\mu$. Hence, short-term debt with face value $\delta_1 = I_1$ is optimal if and only if

$$(1 - q_l)\theta^\delta \geq \theta^{n\delta}. \tag{27}$$

When $q_l > 0$ and $\frac{\Delta_I R}{I_1} = 1$, we have $(1 - q_l)\theta^\delta > \theta^{n\delta} = 0$. On the other hand, for $\frac{\Delta_I R}{I_1}$ large enough $\theta^{n\delta} \to 2\mu$ so that $(1 - q_l)\theta^\delta < \theta^{n\delta}$. This suggests that when $\Delta_I R/I_1$ is small enough, yet greater than one, so that adverse selection keeps $\theta^{n\delta}$ is low in the absence on debt, issuing short-term debt is optimal. The next proposition establishes this result formally.

[35]Note that $p_r(\theta^\delta) = \mu$ so that $R - \frac{I_1}{p_r} \geq R - \frac{I_1}{\mu} > 0$, where the second inequality follows from the assumption that $\mu R > 2I_1$. Therefore, for any $\theta^\delta > 0$, the equilibrium condition in Eq. 25 guarantees that $R - \frac{I_1}{p_r} - \frac{I_1}{p_1^\delta(\theta^\delta)}$ so that financing given θ^δ is feasible.

Proposition 11 *For every $q_l \in (0,1)$, there exist a $T \in \left(1, \frac{2\mu+\Delta_I}{\mu+\Delta_I}\right)$ such that it is optimal to issue short-term debt with face value $\delta_1 = I_1$ if and only if $\frac{\Delta_I R}{I_1} \leq T$.*

The proposition shows that short-term debt can be optimal even when issuance volume is observable, as long as there is some uncertainty in rollover decisions, $q_l \in (0,1)$, and adverse selection in the absence of debt is sufficiently severe. Importantly, this section considers a worst-case scenario by focusing on an equilibrium in which firms hit by a liquidity shock cannot refinance their debt and therefore cannot undertake the follow-on investment. Even in this case, short-term debt may still be optimal whenever rollover decisions are not fully deterministic.

6 Empirical and Policy Implications

While the focus of our paper is on short-term debt, our mechanism applies to any bank liability that generates unpredictable funding needs, such as credit lines. When a borrower draws on a credit line, the bank must finance it, potentially forcing it to raise new funds for liquidity reasons.[36] Like deposit withdrawals, credit line drawdowns create noise in the bank's motive for borrowing, strengthening the pooling benefit. This suggests that banks with greater credit line exposure, relative to their balance sheet, should face better terms when raising new funds, controlling for other characteristics. This prediction also offers a new perspective on the complementarity between deposits and credit lines identified by Kashyap, Rajan, and Stein (2002). In their framework, the synergy arises because deposits and loan commitments both demand liquidity, and banks can economize on cash reserves by serving both functions. In ours, the synergy arises because each additional source of unpredictable funding needs, whether from deposit withdrawals, credit line drawdowns, margin calls, or payment obligations, makes it less likely that the market draws negative inferences when the bank borrows. The diversity of banking activities matters not because of operational synergies

[36] Brown, Gustafson, and Ivanov (2021) provide evidence that firms draw down their credit lines for liquidity reasons.

or diversification, but because it obscures the motives for accessing capital markets.

Although our model focuses on the benefits of short-term debt for raising new capital via new securities, the same mechanism applies to the sale of existing assets. Banks are active participants in secondary markets for loans and securities, yet adverse selection arising from their private information about asset quality impedes such trade (e.g., Vanasco (2017)). In our framework, short-term debt would mitigate this friction in the same way: deposit outflows force banks to sell assets for reasons unrelated to asset quality, making it difficult for market participants to infer whether a given sale is liquidity-driven or information-driven. This pooling of motives improves the terms at which banks can off-load assets, suggesting that the liquidity benefits of unstable funding extend beyond new lending to secondary market activity more broadly.

Our model also predicts that the benefits of short-term funding can reverse during crises. In normal times, deposit withdrawals are driven by liquidity needs and therefore uninformative about asset quality. However, during periods of financial stress, short-term lenders may become informed about the quality of the bank's assets. When this happens, the decision to withdraw is no longer noise: it signals negative information, and the pooling benefit unravels. Rather than obscuring the motive for borrowing, refinancing needs now amplify adverse selection. This is consistent with the pattern observed during the 2008 financial crisis, when prime brokerage clients and repo lenders rapidly withdrew funding from institutions perceived to be weak. More broadly, this prediction distinguishes our mechanism from theories in which short-term debt is either always stabilizing or always destabilizing in our framework, the same liability structure that improves market liquidity in normal times can accelerate its breakdown when lenders become informed.

Our paper has implications for deposit insurance. In our model, depositors withdraw for exogenous liquidity reasons unrelated to the bank's asset quality. Deposit insurance, therefore, does not interfere with the mechanism: it neither changes the frequency of withdrawals nor alters their informational content, since withdrawals are uninformative to begin with. Moreover, deposit insurance may actively strengthen the mechanism by preventing the reversal we identify in our crisis extension. Deposit insurance can deter informed withdrawals by ensuring depositors have no reason to act on negative information about the bank, preserving the pooling benefit of short-term debt.

Our model also contributes to the debate on bank capital regulation. A long-standing puzzle is why banks maintain such high leverage and resist financing themselves with more equity, even when doing so would reduce the risk of financial distress. Admati et al. (2010) argue that banks' claims about the high cost of equity capital are largely fallacious and reflect banks' private costs, rather than social costs. In our model, replacing short-term debt with equity or long-term debt can entail a genuine social cost. Short-term debt generates refinancing needs that increase market liquidity and thereby facilitate the financing of new lending, whereas equity and long-term debt, while reducing rollover risk, eliminate this pooling benefit. This does not imply that existing leverage levels are optimal, but it does suggest that the social cost of bank capital is not zero and that constraints on banks' capital structure can lead to reductions in productive lending.

Our model also speaks to the debate on narrow banking, which dates back to the Chicago Plan of the 1930s and has been revived more recently by, e.g., Cochrane (2014). Proponents argue that deposit-taking and lending should be separated, with deposits backed entirely by safe, liquid assets. A common explanation for why banks nevertheless combine these functions is the implicit subsidy from deposit insurance. However, deposit insurance was itself a response to the fragility created by combining short-term funding with illiquid lending, but it does not explain why the combination arises in the first place. Our model provides such an explanation: separating deposits from lending eliminates the forced refinancing that supports bank liquidity and subsequent lending volume.

Finally, our model speaks to post-crisis liquidity regulations reforms, such as the Liquidity Coverage Ratio and the Net Stable Funding Ratio, which require banks to hold liquid assets against potential outflows and penalize reliance on short-term wholesale funding. In our framework, these requirements can be counterproductive: by insulating banks from deposit shocks, they reduce the frequency with which banks access the interbank market for non-informational reasons, worsening adverse selection among the remaining borrowers.[37] Consistent with this channel, Heider, Hoerova, and Holthausen (2015) note that central bank liquidity injections did little to restart interbank lending during the crisis. Similarly, after the crisis, Banerjee and Mio (2018) find that the implementation of liquidity coverage ratios reduced short-term interbank lending volumes.

7 Conclusion

We provide a new explanation for why banks simultaneously issue unstable short-term debt while holding opaque, informationally sensitive assets. Rather than being a detriment, banks' unstable funding makes their assets *more* liquid.

Our mechanism works as follows. Short-term debt forces banks to seek refinance whenever their lenders demand liquidity. This reduces the information content of banks' issuance decisions, which mitigates the adverse-selection problem that arises from banks' assets. Put simply, unstable funding *enhances* the liquidity of opaque assets.

We offer four main explanations for why short-term debt is particularly valuable for banks, rather than for non-financial firms. First, banks' screening and monitoring generate private information, which makes banks' assets subject to adverse selection. Second, banks continually access funding markets, making the adverse selection problem particularly relevant. Third, banks' loan opportunities are only weakly correlated with the value of existing assets. Fourth, due to competition, the profits from individual bank loans are small relative to the scale of their assets in place.

Our model also shows how capital, liquidity and stable funding requirements can reduce

[37] In a monetary model, Hollifield and Zetlin-Jones (2017) also find that liquidity requirements can be counterproductive, though through a different channel: by discouraging the maturity transformation that makes bank liabilities useful as a medium of exchange, rather than by increasing the informativeness of banks' funding needs.

lending. To the extent that these policies make banks' financing decisions more informative, they can exacerbate adverse selection problems and result in lower aggregate lending volumes.

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Appendix

Proof of Lemma 1

$$p_1(\hat{\theta}, \delta_1) = \frac{\delta_1(\mu + \sigma - \hat{\theta})\,\frac{1}{2}\left(1 - \frac{\Delta_I}{\sigma}\right)}{\delta_1 + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1} \tag{A.1}$$

$$\frac{\partial p_1(\hat{\theta}, \delta_1)}{\partial \delta_1} = \frac{(\sigma - \Delta_I)\,(\mu + \sigma - \hat{\theta})(\hat{\theta} - \mu + \sigma) I_1}{8\sigma^2 \left(\delta_1 + \frac{\theta - \mu + \sigma}{2\sigma} I_1\right)^2}. \tag{A.2}$$

which is positive for any $\hat{\theta} \in (\mu - \sigma, \mu + \sigma)$ iff $\sigma > \Delta_I$ and negative iff $\sigma < \Delta_I$. **QED**

Additional Properties of $p_1(\hat{\theta}, \delta_1)$

Lemma A.1 *(i) sign* $\left\{\frac{\partial^2 p_1(\hat{\theta}, \delta_1)}{\partial \hat{\theta}^2}\right\} = sign\left\{\sigma - \Delta_I\right\}$; *(ii) sign* $\left\{\frac{\partial p_1(\hat{\theta}, \delta_1)}{\partial \delta_1}\right\} = -sign\left(\frac{\partial^2 p_1(\hat{\theta}, \delta_1)}{\partial^2 \delta_1}\right) = sign\left\{\sigma - \Delta_I\right\}$.

Proof. (i)

$$p_1(\hat{\theta}, \delta_1) = \frac{\delta_1\left(\mu + \frac{\hat{\theta} - \mu + \sigma}{2\sigma}\Delta_I\right) + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1 \left(\frac{\hat{\theta} + \mu - \sigma}{2} + \Delta_I\right)}{\delta_1 + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1} \tag{A.3}$$

$$p_1(\hat{\theta}, \delta_1) = \frac{\delta_1(\mu + \sigma - \hat{\theta})\,\frac{1}{2}\left(1 - \frac{\Delta_I}{\sigma}\right)}{\delta_1 + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1} + \frac{\hat{\theta} + \mu - \sigma}{2} + \Delta_I \tag{A.4}$$

$$\frac{\partial p_1(\hat{\theta}, \delta_1)}{\partial \hat{\theta}} = \frac{\Delta_I \delta_1 + \left[\Delta_I + \hat{\theta} - p_1(\hat{\theta}, \delta_1)\right] I_1}{2\sigma\delta_1 + (\hat{\theta} - \mu + \sigma) I_1} \tag{A.5}$$

$$\frac{\partial^2 p_1(\hat{\theta}, \delta_1)}{\partial \hat{\theta}^2} = \frac{\delta_1 I_1(\delta_1 + I_1)(\sigma - \Delta_I)}{2\sigma^2 \left(\delta_1 + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1\right)^3} \tag{A.6}$$

which is positive for any $\hat{\theta} \geq \mu - \sigma$ iff $\sigma > \Delta_I$ and negative iff $\sigma < \Delta_I$.

(ii)

$$p_1(\hat{\theta}, \delta_1) = \frac{\delta_1(\mu + \sigma - \hat{\theta})\,\frac{1}{2}\left(1 - \frac{\Delta_I}{\sigma}\right)}{\delta_1 + \frac{\hat{\theta} - \mu + \sigma}{2\sigma} I_1} \tag{A.7}$$

$$\frac{\partial p_1(\hat{\theta}, \delta_1)}{\partial \delta_1} = \frac{(\sigma - \Delta_I)\,(\mu + \sigma - \hat{\theta})(\hat{\theta} - \mu + \sigma) I_1}{8\sigma^2 \left(\delta_1 + \frac{\theta - \mu + \sigma}{2\sigma} I_1\right)^2}. \tag{A.8}$$

which is positive for any $\hat{\theta} \in (\mu - \sigma, \mu + \sigma)$ iff $\sigma > \Delta_I$ and negative iff $\sigma < \Delta_I$. Note also that

$$sign\left(\frac{\partial^2 p_1(\hat{\theta}, \delta_1)}{\partial^2 \delta_1}\right) = -sign\left(\frac{\partial p_1(\hat{\theta}, \delta_1)}{\partial \delta_1}\right) \tag{A.9}$$

and hence, if $\sigma > \Delta_I$, then $p_1(\hat{\theta}, \delta_1)$ is increasing in δ_1 and concave and if $\sigma < \Delta_I$, then $p_1(\hat{\theta}, \delta_1)$ is decreasing in δ_1 and convex. ■

Proof of Proposition 1

The equilibrium condition for $\delta_1 = \delta_2 = 0$ is

$$p_1(\theta_0^*, 0) = \frac{(\theta_0^* + \Delta_I)\, I_1}{\Delta_I R} \Rightarrow \tag{A.10}$$

$$\frac{\theta_0^* + \mu - \sigma}{2} + \Delta_I = \frac{(\theta_0^* + \Delta_I)\, I_1}{\Delta_I R} \Rightarrow \tag{A.11}$$

$$\theta_0^* = \frac{\Delta_I - \frac{I_1}{R} + \frac{\mu - \sigma}{2}}{\frac{I_1}{\Delta_I R} - \frac{1}{2}} \tag{A.12}$$

Note that the assumption in Eq. 1 implies that $\frac{\Delta_I R}{I_1} < 2$ and that

$$p_1\left(\mu + \sigma, 0\right) = \mu + \Delta_I > \frac{(\mu + \sigma + \Delta_I)\, I_1}{\Delta_I R} \tag{A.13}$$

Furthermore if we assume that $p_1(\mu-\sigma,0)=\Delta_I+\mu-\sigma$, it follows that

$$p_1(\mu+\sigma,0)=\Delta_I+\mu-\sigma>\frac{(\mu-\sigma+\Delta_I)\,I_1}{\Delta_I R} \tag{A.14}$$

Since $\frac{\partial^2 p_1(\hat{\theta},\delta_1)}{\partial\hat{\theta}^2}$ is either concave or convex (see Lemma A.1), $\theta_0^*\in(\mu-\sigma,\mu+\sigma)$ as unique $p_1(\theta^*,\delta_1)=\frac{(\theta^*+\Delta_I)I_1+\Delta_I\delta_1}{\Delta_I R}$. **QED**

Proof of Proposition 2

A bank of type θ invest at $t=0$ for a given $\theta^*(\delta_1,\delta_2)$ if

$$p_1(\theta^*(\delta_1,\delta_2),\delta_1)>\frac{(\theta+\Delta_I)\,I_1+\Delta_I\delta_1}{\Delta_I\,(R-\delta_2)}. \tag{A.15}$$

Let

$$H(x,\delta_1,\delta_2):=p_1(x,\delta_1)-\frac{(x+\Delta_I)\,I_1+\Delta_I\delta_1}{\Delta_I\,(R-\delta_2)} \tag{A.16}$$

(Note: Recall that $p_1(x,\delta_1)$ does not depend directly on δ_2.)

From the proof of Proposition 1, $H(\theta,0,0)<0$ for $\theta\in[\theta_0^*,\mu+\sigma]$ and $H(\theta_0^*,0,0)=0$. The assumption in also implies that $H(\mu+\sigma,\delta_1,\delta_2)<0$ for all $\delta_1\geq 0$ and $\delta_2\geq 0$.

I- Consider $\delta_1=0$ and $\delta_2>0$. Then,

$$0\geq H(x,0,0)>H(x,0,\delta_2) \text{ for all } x\in[\theta_0^*,\mu+\sigma]. \tag{A.17}$$

Therefore, there is no possible equilibrium $\theta^*(0,\delta_2)\geq\theta_0^*$ and hence, issuing only equity at $t=0$ is strictly better than issuing (some) long-term debt with no short-term debt.

II- Consider now $\delta_1>0$ and $\delta_2>0$. Assume first that $\Delta_I\geq\sigma$. From Lemma A.1,

$$p_1(x,0)\geq p_1(x,\delta_1) \text{ for all } x\in[\theta_0^*,\mu+\sigma], \tag{A.18}$$

and hence

$$0 \geq H(x,0,0) > H(x,\delta_1,0) > H(x,\delta_1,\delta_2) \text{ for all } x \in [\theta_0^*, \mu+\sigma] \tag{A.19}$$

Therefore, there is no possible equilibrium $\theta^*(\delta_1, \delta_2) \geq \theta_0^*$ and therefore, issuing only equity at $t = 0$ is strictly better than issuing (some) short-term debt or short-term debt in combination with long-term debt.

III- Finally, consider again $\delta_1 > 0$ and $\delta_2 > 0$, but now assume that $\sigma > \Delta_I$ From the assumption in Eq. 1,

$$0 > H(\mu+\sigma, \delta_1, 0). \tag{A.20}$$

and from Lemma A.1, $p_1(x, \delta_1)$, and hence, $H(x, \delta_1, 0)$ is convex in x. Therefore, for $\delta_1 > 0$ and $\delta_2 = 0$, there exists a unique equilibrium $\theta^*(\delta_1, 0) \in [\mu-\sigma, \mu+\sigma):$ (i) if $H(\mu-\sigma, \delta_1, 0) \leq 0$ then $\theta^*(\delta_1, 0) = \mu - \sigma$ (no investment at $t = 1$); and (ii) if $H(\mu-\sigma, \delta_1, 0) > 0$ then $\theta^*(\delta_1, 0) \in (\mu-\sigma, \mu+\sigma)$ and is uniquely characterized by $H(\theta^*(\delta_1, 0), \delta_1, 0) = 0$. In either case,

$$H(x, \delta_1, 0) \leq 0 \text{ for all } x \in [\theta^*(\delta_1, 0), \mu+\sigma], \tag{A.21}$$

which implies that

$$0 \geq H(x, \delta_1, 0) > H(x, \delta_1, \delta_2) \text{ for all } x \in [\theta^*(\delta_1, 0), \mu+\sigma]. \tag{A.22}$$

Therefore, there is no possible equilibrium $\theta^*(\delta_1, \delta_2) > \theta^*(\delta_1, 0)$ with $\delta_2 > 0$. Specifically, if $\theta^*(\delta_1, 0) = \mu - \sigma$ (case (i)), $\theta^*(\delta_1, \delta_2) = \mu - \sigma < \theta_0^*$, where the inequality follows from Proposition 1, so issuing long-term debt in combination with short-term debt reduces investment with respect to all-equity financing; alternatively, if $\theta^*(\delta_1, 0) > \mu - \sigma$ (case (ii)), any possible equilibrium has $\theta^*(\delta_1, \delta_2) < \theta^*(\delta_1, 0)$, so issuing long-term debt in combination with short-term debt reduces investment. **QED**

Proof of Proposition 3

(i) Assume that first that $\frac{\Delta_I R}{I_1} > 1 + \frac{\Delta_I(\delta_1/I_1)}{\mu-\sigma+\Delta_I}$. From Eq. 4, type $\theta = \mu - \sigma$ invests when

$$p_1(\hat{\theta}, \delta_1) > \frac{(\mu - \sigma + \Delta_I)\, I_1 + \Delta_I \delta_1}{\Delta_I R}$$

Since $p_1(\mu - \sigma, 0) = \mu - \sigma + \Delta_I$, for a given $\delta_1 \geq 0$, low type invests even if no other firm invests ($\theta^* = \mu - \sigma$) when

$$\mu - \sigma + \Delta_I > \frac{(\mu - \sigma + \Delta_I)\, I_1 + \Delta_I \delta_1}{\Delta_I R} \tag{A.23}$$

which is the condition in Proposition 3.

The assumption Eq. 1 implies that for any given $\delta_1 \geq 0$, high-type banks do not invest even if all other firms invests:

$$p_1(\mu + \sigma, \delta_1) = \mu + \Delta_I < \frac{(\mu + \sigma + \Delta_I)\, I_1}{\Delta_I R} < \frac{(\mu + \sigma + \Delta_I)\, I_1 + \Delta_I \delta_1}{\Delta_I R} \tag{A.24}$$

Therefore, there is at least one $\theta^* \in (\mu - \sigma, \mu + \sigma)$ such that Eq. 4 is satisfied with equality:

$$p_1(\theta^*, \delta_1) = \frac{(\theta^* + \Delta_I)\, I_1 + \Delta_I \delta_1}{\Delta_I R}. \tag{A.25}$$

Next, we prove uniqueness and stability. Recall that

$$H(x, \delta_1, 0) = p_1(x, \delta_1) - \frac{(x + \Delta_I)\, I_1 + \Delta_I \delta_1}{\Delta_I R}. \tag{A.26}$$

$H(x, \delta_1, 0) = 0$ is a quadratic function on x (see Eq. A.4) and therefore it has at most two solutions. Since $H(\mu - \sigma, \delta_1, 0) > 0$ and $H(\mu + \sigma, \delta_1, 0) < 0$, then there is a unique solution in $x \in (\mu - \sigma, \mu + \sigma)$. Furthermore, let θ^* be the unique solution in $\theta^* \in (\mu - \sigma, \mu + \sigma)$. Then $H(x, \delta_1) > 0$ for all $x \in [\mu - \sigma, \theta^*)$ and $H(x, \delta_1, 0) < 0$ for all $x \in (\theta^*, \mu + \sigma]$, that is, the unique equilibrium is stable.

(ii) Assume now that $\frac{\Delta_I R}{I_1} \leq 1 + \frac{\Delta_I(\delta_1/I_1)}{\mu-\sigma+\Delta_I}$. Then,

$$p_1(\mu-\sigma,\delta_1) = \mu-\sigma+\Delta_I < \frac{(\mu-\sigma+\Delta_I)\, I_1 + \Delta_I\delta_1}{\Delta_I R} \tag{A.27}$$

This implies that there is a corner equilibrium in which banks do not invest at $t=1$, i.e., $\theta^* = \mu - \sigma$. **QED**

Proof of Proposition 4

(A) Assume first that $\sigma \leq \Delta_I$. From Lemma A.1, $p_1(x,0) \geq p_1(x,\delta_1)$ for all $x \in [\theta_0^*, \mu+\sigma]$, and hence,

$$0 \geq H(x,0,0) > H(x,\delta_1,0) \text{ for all } x \in [\theta_0^*, \mu+\sigma], \tag{A.28}$$

whre $H(x,\delta_1,\delta_2)$ is defined in the proof of Proposition 2. Therefore, there is no possible equilibrium $\theta^*(\delta_1,0) \geq \theta_0^*$ and hence, issuing only equity at $t=0$ is strictly better than issuing any combination of short-term debt and equity.

(B) Assume now that $\sigma > \Delta_I$. From the proof of Lemma A.1, $p_1(x,\delta_1)$ is convex in x and hence, so is $H(x,\delta_1,0)$. From the assumption in Eq. 1 $H(\mu+\sigma,\delta_1,0) < 0$. Consider an optimal debt $\delta_1^* > 0$ such that $H(\mu+\sigma,\delta_1^*,0) \leq 0$, then $H(x,\delta_1^*,0) < 0$ for all $x \in (\mu-\sigma,\mu+\sigma]$, and hence for $\theta^*(\delta_1^*,0) = \mu-\sigma < \theta_0^*$, where the inequality follows from the proof of Proposition 2 (see case II in the proof). Therefore, issuing all equity would be better than issuing short-term debt δ_1^*, and hence $\delta_1^* > 0$. Consequently, if $\delta_1^* > 0$, it must be the case that $H(\mu-\sigma,\delta_1,0) > 0$ and hence that

$$\mu-\sigma < \theta^*(\delta_1,0) < \mu+\sigma. \tag{A.29}$$

From the proof of Lemma A.1, $p_1(x,\delta_1)$ is increasing and strictly concave in δ_1, and hence so is $H(x,\delta_1,0)$. Therefore, for any $\delta_1 > 0$ such that $H(\mu-\sigma,\delta_1,0) > 0$, there is a unique threshold $\theta^*(\delta_1) := \theta^*(\delta_1,0) \in (\mu-\sigma,\mu+\sigma)$ such that $H(\theta^*(\delta_1),\delta_1) = 0$, where $H(\theta^*(\delta_1),\delta_1) :=$

$H(\theta^*(\delta_1), \delta_1, 0)$.

Denote by $H_{\delta_1}(x, \delta_1)$ and $H_x(x, \delta_1)$ are the partial derivatives with respect to δ_1 and x of $H(x, \delta_1)$

Claim I: There is a $\theta^T \in (\mu - \sigma, \mu + \sigma)$ such that $H_{\delta_1}(\theta_0^*, \delta_1)|_{\delta_1=0} > 0$ if and only is $\theta_0^* < \theta^T$.

Proof. From the proof of Lemma A.1

$$H_{\delta_1}(x, \delta_1) = \frac{\partial p_1(x, \delta_1)}{\partial \delta_1} - \frac{1}{R} = \frac{(\sigma - \Delta_I)(\mu + \sigma - x)(x - \mu + \sigma)I_1}{8\sigma^2 \left(\delta_1 + \frac{\theta - \mu + \sigma}{2\sigma} I_1\right)^2} - \frac{1}{R} \tag{A.30}$$

Evaluating $H_{\delta_1}(x, \delta_1)$ at $x = \theta_0^*$ and $\delta_1 = 0$:

$$H_{\delta_1}(\theta_0^*, \delta_1)|_{\delta_1=0} = \frac{\mu + \sigma - \theta_0^*}{\theta_0^* - \mu + \sigma} \frac{\sigma - \Delta_I}{I_1} - \frac{1}{R} \tag{A.31}$$

which is positive if and only if

$$\theta_0^* < \theta^T := \frac{\mu - \sigma + \frac{R}{I_1}(\sigma - \Delta_I)(\mu + \sigma)}{1 + \frac{R}{I_1}(\sigma - \Delta_I)} \tag{A.32}$$

where $\theta^T \in (\mu - \sigma, \mu + \sigma)$. ■

Claim II: If $\theta_0^* \geq \theta^T$ then $\delta_1^* = 0$

Proof. In any equilibrium with $\delta_1^* > 0$, $\theta^*(\delta_1^*) \geq \theta_0^*$ as the bank can always continue with threshold θ_0^* for $\delta_1 = 0$. Then

$$H(\theta^*(\delta_1^*), \delta_1^*) = \int_0^{\delta_1^*} H_{\delta_1}(\theta_0^*, \delta_1) d\delta_1 + \int_{\theta_0^*}^{\theta^*(\delta_1^*)} H_x(x, \delta_1^*) dx \tag{A.33}$$

where $H_{\delta_1}(x, \delta_1)$ and $H_x(x, \delta_1)$ are the partial derivatives with respect to δ_1 and x of $H_x(x, \delta_1)$.

Consider first the case that $H_x(x, \delta_1^*)|_{x=\theta^*(\delta_1^*)} \leq 0$. Then since $H_{xx}(x, \delta_1) > 0$, then $H_x(x, \delta_1^*) \leq 0$ for all $x \in [\theta_0^*, \theta^*(\delta_1^*)]$, and hence $\int_{\theta_0^*}^{\theta^*(\delta_1^*)} H_x(x, \delta_1^*) dx < 0$. Note also that $\int_0^{\delta_1^*} H_{\delta_1}(\theta_0^*, \delta_1) d\delta_1 < 0$ since (i) $H_{\delta_1\delta_1}(x, \delta_1) < 0$ (see Lemma A.1) and (ii) for $\theta_0^* > \theta^T$,

$H_{\delta_1}(\theta_0^*, \delta_1)|_{\delta_1=0} \leq 0$. Therefore, if $H_x(x, \delta_1^*)|_{x=\theta^*(\delta_1^*)} \leq 0$, then, for all $\delta_1^* > 0$ and $\theta^*(\delta_1^*) \geq \theta_0^*$, $H(\theta^*(\delta_1^*), \delta_1^*) < 0$.

Consider now the case that $H_x(x, \delta_1^*)|_{x=\theta^*(\delta_1^*)} > 0$. Then since $H_{xx}(x, \delta_1^*) > 0$, $H_x(x, \delta_1^*) > 0$ for all $x \in [\theta^*(\delta_1^*), \mu + \sigma]$. This implies that, for all, for all $\delta_1^* > 0$ such that $\theta^*(\delta_1^*) \geq \theta_0^*$, $H(\theta^*((\delta_1^*)), \delta_1) \leq H(\mu + \sigma, \delta_1) < 0$, where the second inequality follows from the assumption in Eq. 1.

Since in both cases, for all $\delta_1^* > 0$ such that $\theta^*(\delta_1^*) \geq \theta_0^*$, $H(\theta^*((\delta_1^*)), \delta_1) < 0$, there is no which implies that there is no equilibrium with $\delta_1^* > 0$ such that $\theta^*(\delta_1^*) \geq \theta$. [Recall that any equilibrium $\theta^*(\delta_1^*) \in (\mu + \delta, \mu + \delta)$ satisfies $H(\theta^*((\delta_1^*)), \delta_1) = 0$.] ■

Claim III: If $\theta_0^* < \theta^T$ there is a $\widetilde{\delta}_1 > 0$ such that $\theta^*(\widetilde{\delta}_1) > \theta_0^*$.

Proof. If $\theta_0^* < \theta^T$, from **Claim I** $H_{\delta_1}(\theta_0^*, \delta_1)|_{\delta_1=0} > 0$, and hence, there is some $\widetilde{\delta}_1 > 0$ such that $H(\theta_0^*, \widetilde{\delta}_1) > 0$. From the assumption in Eq. 1, $H(\mu+\sigma, \widetilde{\delta}_1) < 0$, and since $H_{\delta_1\delta_1}(x, \delta_1) < 0$ (Lemma A.1), there is a unique $H(\theta^*(\widetilde{\delta}_1), \widetilde{\delta}_1) = 0$. Therefore, it is not optimal for the firm to issue all equity at $t = 0$. ■

Claim IV: If $\theta_0^* < \theta^T$ there is a unique $\delta_1^* > 0$ such that $\theta^*(\delta_1^*) = \max_{\delta_1} \theta^*(\delta_1) > \theta_0^*$.

Proof. From Lemma A.1 $H_{xx}(x, \delta_1) > 0$ and $H_{\delta_1\delta_1}(x, \delta_1) < 0$. From the assumption in Eq. 1 $H(\mu + \sigma, \delta_1) < 0$ for all $\delta_1 \geq 0$, and there is $d > 0$ such that $H(\mu - \sigma, \delta_1) < 0 \iff \delta_1 > d$. Continuity, implies that for every $\delta_1 \in [0, d]$, there exists at least one $x \in [\mu - \sigma, \mu + \sigma]$ such that $H(x, \delta_1) = 0$. We next show uniqueness of this root. Fix $\delta_1 \in [0, d]$. Since $H_{xx}(x, \delta_1) > 0$, $H(\mu - \sigma, \delta_1) \geq 0$, $H(\mu + \sigma, \delta_1) < 0$, there exists a unique $\theta^*(\delta_1) \in [\mu - \sigma, \mu + \sigma)$ such that $H(\theta^*(\delta_1), \delta_1) = 0$.

Moreover, if $\delta_1 > d$, then $H(\mu - \sigma, \delta_1) < 0$ and $H(\mu + \sigma, y) < 0$. From $H_{xx}(x, \delta_1) > 0$, it follows that $H(x, \delta_1) < 0$ for all $x \in [\mu - \sigma, \mu + \sigma]$, so that $\theta^*(\delta_1) = \mu - \sigma < \theta_0^*$, so it strictly better to have $\delta_1 - 0$ than $\delta_1 > d$.

Because $\theta^*(\delta_1)$ is uniquely defined on the compact interval $[0, d]$, a maximizer, δ_1^*, exists. We now prove uniqueness.

Suppose by contradiction that there exist two distinct maximizers $\delta_1^I < \delta_1^{II}$ in $[0, d]$ such that

$$\theta^*(\delta_1^I) = \theta^*(\delta_1^{II}) = \underline{\theta}. \tag{A.34}$$

Then $H(\underline{\theta}, \delta_1^I) = H(\underline{\theta}, \delta_1^{II}) = 0$. Fix $x = \underline{\theta}$. Since $H_{\delta_1\delta_1} < 0$ (the function is strictly concave), for every $\delta_1^m \in (\delta_1, \delta_2)$, $H(\underline{\theta}, \delta_1^m) > 0$. On the other hand, $H(\mu + \sigma, \delta_1^m) < 0$. Hence, by continuity in x, the unique root of $\theta^m(\delta_1^m)$ such that $H(\theta^m(\delta_1^m), \delta_1^m) = 0$, and this root must lie strictly to the right of $\underline{\theta}$, that is, $\theta^m(\delta_1^m) > \underline{\theta}$. But this contradicts the assumption that δ_1^I and δ_1^I are maximizers. Therefore the maximizer, δ_1^*, is unique.

Finally, from **Claim III**, there is $\widetilde{\delta}_1 > 0$ such that $\theta_0^* < \theta^*(\widetilde{\delta}_1) \leq \theta^*(\delta_1^*)$, where the second inequality follows from δ_1^* being the unique maximizer. ■

This completes the proof. **QED**

Proof of Proposition 5

i) First, an increase in σ or a decrease in Δ_I increases

$$\theta^T = \frac{\mu - \sigma + \frac{R}{I_1}(\sigma - \Delta_I)(\mu + \sigma)}{1 + \frac{R}{I_1}(\sigma - \Delta_I)} = \frac{-2\sigma}{1 + \frac{R}{I_1}(\sigma - \Delta_I)} + \mu + \sigma \tag{A.35}$$

Therefore: $\frac{d\theta^T}{d\Delta_I} < 0$ and

$$\frac{d\theta^T}{d\sigma} = \frac{-2}{1 + \frac{R}{I_1}(\sigma - \Delta_I)} + \frac{2\sigma\frac{R}{I_1}}{\left(1 + \frac{R}{I_1}(\sigma - \Delta_I)\right)^2} + 1 = \frac{2\left(\frac{\Delta_I R}{I_1} - 1\right)}{\left(1 + \frac{R}{I_1}(\sigma - \Delta_I)\right)^2} + 1 > 0 \tag{A.36}$$

Second, an increase in σ or a decrease in Δ_I decreases θ_0^*:

$$\theta_0^* = \frac{\Delta_I - \frac{I_1}{R} + \frac{\mu - \sigma}{2}}{\frac{I_1}{\Delta_I R} - \frac{1}{2}} \Longrightarrow \frac{d\theta_0^*}{\Delta_I} > 0 \text{ and } \frac{d\theta_0^*}{d\sigma} < 0 \tag{A.37}$$

Note: Recall that $\frac{\Delta_I R}{I_1} < 2$ so that high types do not invest.

ii) An increase in Δ_I keeping constant $r := \frac{\Delta_I R}{I_1}$ constant (aka a decrease in $\frac{R}{I_1}$ keeping constant r), increases θ_0^* and decreases θ^T:

$$\theta^T = \frac{-2\sigma}{1 + \frac{r}{\Delta_I}(\sigma - \Delta_I)} + (\mu + \sigma) \tag{A.38}$$

$$\theta_0^* = \frac{\Delta_I - \frac{\Delta_I}{r} + \frac{\mu - \sigma}{2}}{\frac{1}{r} - \frac{1}{2}} \tag{A.39}$$

and hence,

$$\left.\frac{d\theta^T}{d\Delta_I}\right|_{\frac{\Delta_I R}{I} = r} < 0 \tag{A.40}$$

$$\left.\frac{d\theta_0^*}{d\Delta_I}\right|_{\frac{\Delta_I R}{I} = r} = \frac{1 - \frac{1}{r}}{\frac{1}{r} - \frac{1}{2}} > 0 \tag{A.41}$$

since $1 < r < 2$.

iii) θ^T increases with μ at a rate of 1 and θ_0^* increases in μ at a rate greater than 1, therefore, and increase in μ makes short-term debt less likely to be optimal.

$$\frac{d\theta^T}{d\mu} = 1 \quad ; \quad \frac{d\theta_0^*}{d\mu} = \frac{\frac{1}{2}}{\frac{I_1}{\Delta_I R} - \frac{1}{2}} > 1 \Leftrightarrow \frac{I_1}{\Delta_I R} < 1 \tag{A.42}$$

Proof of Proposition 6

Take any investment threshold θ^* and let $\theta_I \in (\mu - \sigma, \mu + \sigma)$

$$\mathbb{E}[\theta | \theta < \theta_I] = \frac{\theta_I + \mu - \sigma}{2} \tag{A.43}$$

$$\mathbb{E}[\theta | \theta > \theta_I] = \frac{\theta_I + \mu + \sigma}{2} \tag{A.44}$$

$$\mathbb{E}[\theta + \Delta_I | \theta_I < \theta < \theta^*] = \Delta_I + \frac{\theta_I + \theta^*}{2} \tag{A.45}$$

Note that $\mathbb{E}[\theta+\Delta_I|\theta_I<\theta<\theta^*]>\mathbb{E}[\theta|\theta<\theta_I]$ and that $\mathbb{E}[\theta+\Delta_I|\theta_I<\theta<\theta^*]>\mathbb{E}[\theta|\theta>\theta^*]$ if

$$\Delta_I+\frac{\theta_I+\theta^*}{2} > \frac{\theta^*+\mu+\sigma}{2}\Rightarrow \tag{A.46}$$

$$\Delta_I > \frac{\mu+\sigma-\theta_I}{2} \tag{A.47}$$

which is satisfied for θ_I large enough. The equilibrium price $p_1(\theta^*,\delta_1)$ function is a weighted average of $\mathbb{E}[\theta|\theta<\theta_I]$, $\mathbb{E}[\theta|\theta>\theta^*]$ and $\mathbb{E}[\theta+\Delta_I|\theta_I<\theta<\theta^*]$ with the weight shifting away from $\mathbb{E}[\theta+\Delta_I|\theta_I<\theta<\theta^*]$ as δ_1 increases. Therefore, for some $\widetilde{\theta}<\mu+\sigma$, if $\theta_I>\widetilde{\theta}$, the price

$$p_1(\theta^*,\delta_1)=\frac{\left\{\begin{array}{c}\Pr(\theta_I<\theta<\theta^*)\mathbb{E}[\theta+\Delta_I|\theta_I<\theta<\theta^*](\delta_1+I_1)+\\ +\left[\mathbb{E}[\theta|\theta>\theta^*]\Pr(\theta>\theta^*)+\mathbb{E}[\theta|\theta<\theta_I]\Pr(\theta>\theta^*)\right]\delta_1\end{array}\right\}}{\Pr(\theta_I<\theta<\theta^*)(\delta_1+I_1)+\left[\Pr(\theta>\theta^*)+\Pr(\theta>\theta^*)\right]\delta_1} \tag{A.48}$$

is decreasing in δ_1, i.e., $\frac{\partial p_1(\theta^*,\delta_1)}{\partial\delta_1}<0$, and hence, setting $\delta_1=0$ maximizes investment at $t=1$ and is optimal.**QED**

Proof of Proposition 7

First we show that short-term informed debtholders of type θ^* (the marginal type that invests) do not roll over their debt. If $\delta_2=0$, from Eq. 3, for a given price p_1, type θ bank invests when

$$(\theta+\Delta_I)\left(R-\frac{\delta_1+I_1}{p_1}\right)>\theta\left(R-\frac{\delta_1}{p_1}\right). \tag{A.49}$$

that is, θ^* is such that

$$p_1=\frac{(\theta^*+\Delta_I)\,I_1+\Delta_I\delta_1}{\Delta_I R}. \tag{A.50}$$

The value of a type θ^* claim that promises to pay one unit at $t=2$ is $\theta^*+\Delta_I$ for financing to be feasible it has to be the case that $\delta_1+I_1<p_1R$, and hence, since $p_1\le 1$, that $\delta_1+I_1<R$. From Eq. A.50,

$$p_1=(\theta^*+\Delta_I)+\frac{(\theta^*+\Delta_I)\,(I_1-\Delta_I R)+\Delta_I\delta_1}{\Delta_I R} \tag{A.51}$$

and therefore $p_1 < \theta^* + \Delta_I$ if $(\theta^* + \Delta_I)(I_1 - \Delta_I R) + \Delta_I \delta_1 < 0$:

$$(\theta^* + \Delta_I)(I_1 - \Delta_I R) + \Delta_I \delta_1 < (\theta^* + \Delta_I)(I_1 - R + \delta_1) < 0 \tag{A.52}$$

where the last inequality follows from $\delta_1 + I_1 < R$. Therefore, $p_1 < \theta^* + \Delta_I$. This proves that informed debtholders of type θ^* do not roll over their debt.

Let $\theta^{**} := \max\{\theta^*, p_1\}$ then the price paid by new investors at $t = 1$ is: (Note that $\sigma > \Delta_I$, implies that $\mathbb{E}[\theta|\theta > \theta^*] > \mathbb{E}[\theta + \Delta_I|\theta \leq \theta^*]$, and hence, $p_1 < \theta^* + \Delta_I$ implies that $p_1 < \mu + \sigma$.)

$$\begin{aligned}
p_1(\theta^*, \delta_1, \alpha_I) &= \frac{\left\{\begin{array}{c} \alpha_l \delta_1 \int_{\theta^{**}}^{\mu+\sigma} \frac{\theta}{2\sigma} d\theta + (\alpha_l + \alpha_I)\,\delta_1 \int_{\theta^*}^{\theta^{**}} \frac{\theta}{2\sigma} d\theta + \\ + (\alpha_l \delta_1 + I) \int_{p_1-\Delta_I}^{\theta^*} \frac{\theta+\Delta_I}{2\sigma} d\theta \\ + (\alpha_l + \alpha_I)\delta + I) \int_{\mu-\sigma}^{p_1-\Delta_I} \frac{\theta+\Delta_I}{2\sigma} d\theta \end{array}\right\}}{\alpha_l \delta_1 + \frac{\theta^*-\mu+\sigma}{2\sigma} I + \left(\frac{\theta^{**}-\theta^*}{2\sigma} + \frac{p_1-\Delta_I-\mu+\sigma}{2\sigma}\right) \alpha_I \delta_1} && \text{(A.53)} \\
&= \frac{\left\{\begin{array}{c} \alpha_l \delta_1 \left(\mu + \frac{(\theta^*-\mu+\sigma)\Delta_I}{2\sigma}\right) + \frac{\theta^*-\mu+\sigma}{2\sigma} I \left(\frac{\theta^*+\mu-\sigma}{2} + \Delta_I\right) + \\ + \left(\begin{array}{c} \frac{\theta^{**}-\theta^*}{2\sigma}\left(\frac{\theta^{**}+\theta^*}{2}\right) \\ + \frac{p_1-\Delta_I-\mu+\sigma}{2\sigma}\left(\frac{p_1-\Delta_I+\mu-\sigma}{2} + \Delta_i\right) \end{array}\right) \alpha_I \delta_1 \end{array}\right\}}{\alpha_l \delta_1 + \frac{\theta^*-\mu+\sigma}{2\sigma} I + \left(\frac{\theta^{**}-\theta^*}{2\sigma} + \frac{p_1-\Delta_I-\mu+\sigma}{2\sigma}\right) \alpha_I \delta_1} && \text{(A.54)} \\
&= \frac{\left\{\begin{array}{c} \left[\begin{array}{c} \alpha_l \left(\mu + \frac{(\theta^*-\mu+\sigma)\Delta_I}{2\sigma}\right) + \\ + \alpha_I \left(\frac{\theta^{**}-\theta^*}{2\sigma}\left(\frac{\theta^{**}+\theta^*}{2}\right) + \frac{p_1-\Delta_I-\mu+\sigma}{2\sigma}\left(\frac{p_1-\Delta_I+\mu-\sigma}{2} + \Delta_I\right)\right) \end{array}\right] \delta_1 + \\ + \frac{\theta^*-\mu+\sigma}{2\sigma} I \left(\frac{\theta^*+\mu-\sigma}{2} + \Delta_I\right) \end{array}\right\}}{\left[\alpha_l + \alpha_I \left(\frac{\theta^{**}-\theta^*}{2\sigma} + \frac{p_1-\Delta_I-\mu+\sigma}{2\sigma}\right)\right] \delta_1 + \frac{\theta^*-\mu+\sigma}{2\sigma} I} && \text{(A.55)}
\end{aligned}$$

Let $\alpha_I = 1$:

$$p_1(\theta^*, \delta_1, 1) = \frac{Q_{Inf}\left(\frac{\frac{\theta^{**}-\theta^*}{2\sigma}}{Q_{Inf}} \frac{\theta^{**}+\theta^*}{2} + \frac{\frac{\theta^{**}-\theta^*}{2\sigma} - Q_{Inf}}{Q_{Inf}} \left(\frac{p_1-\Delta_I+\mu-\sigma}{2} + \Delta_I\right)\right) + Q_{Inv}\left(\frac{\theta^*+\mu-\sigma}{2} + \Delta_I\right)}{Q_{Inf} + Q_{Inv}} \tag{A.56}$$

where to above to save on notation

$$Q_{Inv} \;:\; = \frac{\theta^* - \mu + \sigma}{2\sigma} I \tag{A.57}$$

$$Q_{Inf} \;:\; \frac{\theta^{**} - \theta^*}{2\sigma} + \frac{p_1 - \Delta_I - \mu + \sigma}{2\sigma} \tag{A.58}$$

Note that since for $\theta \in (\theta^*, \theta^{**})$, $p_1 < \theta$ (these are types just above θ^* that do not roll over their debt) which implies that

$$\frac{\theta^{**} + \theta^*}{2} < p_1. \tag{A.59}$$

Furthermore, for $\theta \in (\mu - \sigma, p_1 - \Delta_s)$, $p_1 < \theta + \Delta_I$ (these are types that invest but do not roll over their debt) which implies that $\frac{p_1 - \Delta_I + \mu - \sigma}{2} + \Delta_I < p_1$. This implies that

$$\frac{\theta^* + \mu - \sigma}{2} + \Delta_I > \left\{ \begin{array}{c} \frac{\frac{\theta^{**} - \theta^*}{2\sigma}}{Q_{Inf}} \frac{\theta^{**} + \theta^*}{2} \\ + \frac{\frac{\theta^{**} - \theta^*}{2\sigma} - Q_{Inf}}{Q_{Inf}} \left(\frac{p_1 - \Delta_I + \mu - \sigma}{2} + \Delta_I \right) \end{array} \right\} \tag{A.60}$$

and hence that, $p_1(\theta^*, 0, 1) > p_1(\theta^*, \delta_1, 1)$. By continuity, there is an $\alpha_I^* < 1$ such that for all $\alpha_I > \alpha_I^*$, $p_1(\theta^*, 0, \alpha_I) > p_1(\theta^*, \delta_1, \alpha_I^*)$, Finally, $\sigma > \Delta_I$ implies that $p_1(\theta^*, 0, 0) < p_1(\theta^*, \delta_1, 0)$ which in turn, implies that $\alpha_I^* > 0$. Finally, for all $\alpha_I > \alpha_I^*$, $p_1(\theta^*, 0, \alpha_I) > p_1(\theta^*, \delta_1, \alpha_I^*)$, and since,

$$p_1 = \frac{(\theta^* + \Delta_I) I_1 + \Delta_I \delta_1}{\Delta_I R} \tag{A.61}$$

choosing $\delta_1 = 0$, maximizes θ^*, that is, maximizes investment at $t = 1$, and hence, it is optimal. **QED**

Proof of Proposition 8

The assumption in Eq. 1 implies that the highest type, $\theta = 2\mu$, does not invest at $t = 1$ even if every other bank does, that is, when $\hat{\theta}^{n\delta} = 2\mu$. Furthermore, for $\theta = 0$, condition Eq. 19 becomes

$$0 < \Delta_I \left(R - \frac{I_1}{p_1^{n\delta}(\hat{\theta}^{n\delta})} \right), \tag{A.62}$$

which is satisfied because $p_1^{n\delta}(\hat{\theta}^{n\delta}) \geq \Delta_I$ and $\Delta_I R - I_1 > 0$. Therefore, the lowest type always invests. It follows that any equilibrium threshold must be interior $\theta^{n\delta} \in (0, 2\mu)$ and, by continuity, that there must be at least one such equilibrium. Any interior equilibrium in $(0, 2\mu)$ satisfies the following equilibrium condition

$$\theta^{n\delta} R = (\theta^{n\delta} + \Delta_I)\left(R - \frac{I_1}{p_1^{n\delta}(\theta^{n\delta})}\right), \tag{A.63}$$

where

$$p_1^{n\delta}(\hat{\theta}^{n\delta}) = \Delta_I + \frac{\hat{\theta}^{n\delta}}{2}. \tag{A.64}$$

Using Eq. A.64, Eq. A.63 can be written as:

$$\frac{\theta^{n\delta} + \Delta_I}{\frac{\theta^{n\delta}}{2} + \Delta_I} = \frac{\Delta_I R}{I_1} \tag{A.65}$$

For $\theta^{n\delta} = 2\mu$, from Eq. 1, the left-hand-side in Eq. A.65 is greater than $(\Delta_I R)/I_1$, while for $\theta^{n\delta} = 0$ is smaller. Since left-hand-side in Eq. A.65 is strictly increasing in $\theta^{n\delta}$ there is a unique $\theta^{n\delta}$ satisfying the equilibrium condition in Eq. A.65. **QED**

Proof of Proposition 10

Existence: The investment incentive condition in Eq. 24 becomes:

$$(\theta + \Delta_I)\left(R - \frac{I_1}{p_r} - \frac{I_1}{p_1^{\delta}(\theta^{\delta})}\right) > \theta\left(R - \frac{I_1}{p_r}\right), \tag{A.66}$$

where

$$p_1^{\delta}(\hat{\theta}^{\delta}) = \frac{(1-q_l)\frac{\hat{\theta}^{\delta}}{2\mu}\left(\Delta_I + \frac{\hat{\theta}^{\delta}}{2}\right) + q_l \mu}{(1-q_l)\frac{\hat{\theta}^{\delta}}{2\mu} + q_l} \tag{A.67}$$

Using $p_r = \mu$, Eq. A.66 can be written as:

$$\frac{\theta + \Delta_I}{p_1^\delta(\hat{\theta}^\delta)} + \frac{\Delta_I}{\mu} > \frac{\Delta_I R}{I_1} \tag{A.68}$$

The assumption in Eq. 1 and $(\mu/2)\,R > I_1$ imply that

$$\frac{2\mu + \Delta_I}{p_1^\delta(2\mu)} + \frac{\Delta_I}{\mu} < \frac{\Delta_I R}{I_1} < \frac{\Delta_I}{p_1^\delta(0)} + \frac{\Delta_I}{\mu} \tag{A.69}$$

so that the highest type is not willing to invest even if every other type invests (if $\theta^\delta = \hat{\theta}^\delta = 2\mu$), and the lowest type strictly prefers to invest even if no other type invests (if $\theta^\delta = \hat{\theta}^\delta = 0$). Therefore, any θ^δ equilibrium must satisfy

$$\frac{\theta^\delta + \Delta_I}{p_1^\delta(\theta^\delta)} + \frac{\Delta_I}{\mu} = \frac{\Delta_I R}{I_1} \tag{A.70}$$

and by continuity there is at least one equilibrium $\theta^\delta \in (0, 2\mu)$.

Uniqueness: Let $u := \frac{\theta^\delta}{2\mu} \in [0,1]$ and $d := \frac{\Delta_I}{\mu} \in (0,1)$ then Eq. A.70 can be written as

$$F(u) := d + \frac{(2u + d)\,((1 - q_l)u + q_l)}{(1 - q_l)u(d + u) + q_l} = \frac{\Delta_I R}{I_1} \tag{A.71}$$

We next show that F is strictly increasing on $(0,1)$:

$$F'(u) = \frac{N(u)}{((1 - q_l)u(d + u) + q_l)^2}, \tag{A.72}$$

where

$$N(u) := au^2 + bu + c, \tag{A.73}$$

with

$$a := (1 - q_l)\,[d - q_l(d + 2)]\,, \tag{A.74}$$

$$b := 2q_l(1 - q_l)(2 - d), \tag{A.75}$$

$$c := q_l\left[(1-q_l)d(1-d)+2q_l\right]. \tag{A.76}$$

Since $d \in (0,1)$ and $q_l \in (0,1)$, we have $b > 0$ and $c > 0$. Therefore, if $a \geq 0$, then all coefficients of N are positive, so $N(u) > 0$ for all $u \in (0,1)$. Suppose instead that $a < 0$. Then N is a concave quadratic, so its minimum on $[0,1]$ is attained at one of the endpoints. We have $N(0) = c > 0$. Moreover,

$$N(1) = a+b+c = d+(2-d)q_l - d(d+2)q_l(1-q_l). \tag{A.77}$$

Using $q_l(1-q_l) \leq \frac{1}{4}$, we obtain

$$N(1) \geq d - \frac{d(d+2)}{4} + (2-d)q_l = \frac{d(2-d)}{4} + (2-d)q_l > 0. \tag{A.78}$$

Hence $N(u) > 0$ on $(0,1)$ also in this case. Therefore, so F is strictly increasing on $(0,1)$, which proves uniqueness. **QED**

Proof of Proposition 11

From Eq. 1,

$$1 < \frac{\Delta_I R}{I_1} < \frac{2\mu+\Delta_I}{\mu+\Delta_I} \tag{A.79}$$

Let $r := \frac{\mu}{\Delta_I} > 2$, $K := \frac{\Delta_I R}{I_1}$, $K^{\max} := \frac{2\mu+\Delta_I}{\mu+\Delta_I}$ and

$$\phi(K) := \theta^{n\delta}(K) - 2\mu(1-q_\ell)u(K) \qquad \text{for } K \in (1, K^{\max}), \tag{A.80}$$

where, from Proposition 8

$$\theta^{n\delta}(K) = \frac{\Delta_I(K-1)}{1-K/2}, \tag{A.81}$$

and, from the proof of Proposition 10,

$$u(K) := \frac{\theta^{\delta}(K)}{2\mu} \in (0,1) \tag{A.82}$$

is the unique solution of $F(u) = K$ (see Eq. A.71)

We next prove that there exists a unique $T \in (1, K^{\max})$ such that $\phi(K) < 0 \iff K < T$.

Step 1: *We rewrite the inequality $\phi(K) < 0$ in terms of $u(K)$:*

$$\frac{\Delta_I(K-1)}{1-K/2} < 2\mu(1-q_\ell)u \iff K < \frac{\Delta_I + 2\mu(1-q_\ell)u}{(\Delta_I + \mu(1-q_\ell)u)} \tag{A.83}$$

where we made used that $K < 2$ on $(1, K^{\max})$, so $1 - K/2 > 0$. Therefore, $\phi(K) < 0 \iff K < G(u)$, where

$$G(u) := \frac{\Delta_I + 2\mu(1-q_\ell)u}{\Delta_I + \mu(1-q_\ell)u}. \tag{A.84}$$

Since $F(u) = K$, we get $\phi(K) < 0 \iff F(u) < G(u)$. Define $\Psi(u) := G(u) - F(u)$, so that $\phi(K) < 0 \iff \Psi(u(K)) > 0$.

Step 2: *Next, we show that Ψ has a unique zero $u_T \in (0,1)$, with $\Psi(u) > 0 \iff u < u_T$.* After dividing by Δ_I so that $r := \frac{\mu}{\Delta_I} > 2$, one may write

$$F(u) = \frac{1}{r+u} + \frac{(2ru+1)\left((1-q_\ell)u + q_\ell\right)}{(1-q_\ell)u(1+ru) + q_\ell r} \tag{A.85}$$

$$G(u) = \frac{1 + 2r(1-q_l)\,u}{1 + r(1-q_l)u}. \tag{A.86}$$

A direct simplification gives $\Psi(u) = \frac{P(u)}{Q(u)}$, where $Q(u) > 0$ on $[0,1]$, and

$$P(u) = a_3u^3 + a_2u^2 + a_1u + a_0 \tag{A.87}$$

with $a_3 = r(q_\ell - 1)(q_\ell r + q_\ell + r) < 0$; $a_2 = -r\left(q_\ell(1-q_\ell)(2r^2 - r) + 2\right) < 0$; and $a_0 = q_\ell r(r-2) > 0$. Thus, in descending powers of u, the coefficient pattern of P is $(-, -, \pm, +)$, which has exactly one sign change. By Descartes' rule of signs, P has exactly one positive real root. Next, we show that this unique positive root lies in $(0,1)$. At $u = 0$, $\Psi(0) = G(0) - F(0) = 1 - 2/r > 0$, because $r > 2$. At $u = 1$,

$$G(1) = \frac{1 + 2r(1-q_l)}{1 + r(1-q_l)} < \frac{1+2r}{1+r} = K^{\max}, \tag{A.88}$$

since $q_l < 1$. On the other hand, Eq. 1 gives $F(1) > K^{\max}$. Hence $\Psi(1) = G(1) - F(1) < 0$. Therefore Ψ has a zero in $(0, 1)$. Since it has exactly one positive zero, this zero is unique; denote it by $u_T \in (0, 1)$. Because $\Psi(0) > 0$ and $\Psi(1) < 0$, its sign is $\Psi(u) > 0 \iff u < u_T$ and $\Psi(u) < 0 \iff u > u_T$. Therefore.

$$\phi(K) < 0 \iff u(K) < u_T, \qquad \phi(K) > 0 \iff u(K) > u_T. \tag{A.89}$$

From the proof of Proposition 10, $u(K)$ is determined by the equilibrium condition $F(u) = K$, and $F'(u) > 0$ in $u \in (0, 1)$. Therefore, $u(K)$ is continuous and strictly increasing in K.

Step 3: Finally, we define the threshold T.

From the proof of Proposition 10, $u(K)$ is determined by the equilibrium condition $F(u) = K$, and $F'(u) > 0$ in $u \in (0, 1)$. Therefore, $u(K)$ is strictly increasing in K. Therefore, $\phi(1) < 0$ and $\phi(K^{\max}) > 0$, by continuity, it follows that $u(K) < u_T^*$ for K near 1, while $u(K) > u_T$ for K near $K^{\max}$, there exists a unique $T \in (1, K^{\max})$ such that $u(T) = u_T$. Moreover, $u(K) < u_T \iff K < T$. Since $\phi(K) < 0 \iff u(K) < u_T$, we conclude that $\phi(K) < 0 \iff K < T$. Recalling the definition of $\phi(K)$, this proves the proposition:

$$\theta^{n\delta}(K) < \theta^{\delta}(K)(1 - q_\ell) \iff K < T. \tag{A.90}$$

QED