Long-run productivity growth, credit booms, and financial crises*

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Abstract

While financial crises tend to be preceded by credit booms, most credit booms do not end up in crises. Crises typically occur when there is also a persistent slowdown in productivity growth. I develop a model in which risk of crisis emerges endogenously during boom because of increased fragility of the banking sector. Banks raise financing from households to invest in long-term projects, but their ability to do so is limited by moral hazard. Demandable deposits create discipline by exposing misbehaving banks to runs, and thus help them increase external financing. Normally, banks finance themselves with a mix of equity and deposits that maximizes discipline, but ensures that they always remain solvent. When growth prospects become sufficiently strong, however, worsening moral hazard induces banks to rely exclusively on deposit financing, which enables a boom in credit, asset prices, and investment. If the anticipated growth fails to materialise, though, the excessive deposit financing leads to a systemic banking crisis. I also study policy implications of the model.

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I. Introduction

It is well-documented that major financial crises are typically preceded by booms in credit and asset prices[1] and are followed by protracted periods of slow growth.[2] Existing literature often studies booms as the result of financial liberalisation, excessive risk taking, or over-optimistic expectations,[3] while slow recoveries are attributed to ensuing credit crunches and deleveraging during crises.[4] These mechanisms are undoubtedly important, but there are several empirical observations linking financial cycles to the real economy which they cannot account for. Firstly, starts of credit booms are often associated with accelerated trend growth rate of real productivity, and, importantly, most credit booms do not end up in crises. When they do, however, financial crises tend to follow, rather than lead, persistent slowdowns in productivity growth (Gorton and Ordoñez, 2019; Dell'Ariccia et al., 2012; Paul, 2020).[5] This suggests that slow economic growth cannot be attributed solely to crises, and, in fact, it is deteriorating economic prospects that could be among the factors that trigger crises in the first place. Strikingly, Cao and L'Huillier (2018) document that the three largest economic disasters in the developed world, – The Great Depression, The Japanese Slump, and The Great Recession, – were all preceded by periods of major technological innovations and rapid productivity growth which ran out of steam before the crises. The evidence thus suggests that the ingredients for a typical financial crisis include deteriorating macroeconomic fundamentals, but also a preceding period of economic prosperity. This leads to an important question which I study theoretically in this paper: why do booms make the economy susceptible to the risk of financial crises?

To address it, I develop a model in which the key mechanism is a build-up of financial fragility in the banking sector during periods of booming productivity growth, when expected returns on banks' long-term investments are high. Building on the seminal work of Diamond and Rajan (2000, 2001b), part of banks' external financing comes in the form of short-term demandable deposits. Deposits discipline banks against trying to squeeze their external investors by exposing misbehaving banks to runs, and thus allow them to increase financing. Normally, banks effectively mix deposits and equity

[1]See Reinhart and Reinhart (2010); Mendoza and Terrones (2008, 2014); Schularick and Taylor (2012); Reinhart and Reinhart (2010); Krishnamurthy and Muir (2017).

[2]See Cerra and Saxena (2008); Reinhart and Reinhart (2010); Reinhart and Rogoff (2009, 2014); Krishnamurthy and Muir (2017); Queralto (2019).

[3]For example, different strands of literature emphasized either moral hazard due to implicit government guarantees (Farhi and Tirole, 2012; Chari and Kehoe, 2016), overoptimism (Bordalo et al., 2018), or pecuniary externalities operating through borrowing constraints (see e.g. Lorenzoni (2008)).

[4]See, for example, Queralto (2019); Anzoategui et al. (2019); Bianchi et al. (2019); Guerron-quintana and Jinnai (2014); Garcia-Macia (2017); Ennis and Keister (2003).

[5]For the Great Recession, Fernald (2014); Cette et al. (2016); Cao and L'Huillier (2018) provide evidence that productivity has slowed *well before* the onset of the Financial Crisis. An updated version of Kahn and Rich (2007) gives a similar conclusion – see Appendix A for details.

financing to maximize discipline, yet to avoid the risks of destructive runs. Crucially, however, bankers' moral hazard becomes worse when long-run productivity growth prospects are strong, prompting them to rely heavily on deposits, since their ability to raise financing through other means deteriorates. Deposit financing enables a boom in credit, asset prices, and investment. If future aggregate growth prospects deteriorate prematurely, however, the value of banks' assets falls, rendering them insolvent, and instigating systemic bank runs. A long period of slow subsequent growth is then not just the result of the crisis, but also its cause.

More specifically, banks in the model have access to productive long-term projects that require capital investments. The long-run payoff of banks' projects is uncertain, and can be either high or low, depending on the aggregate state of productivity. Capital is supplied by households, who cannot use it as productively as banks. Banks purchase capital on a competitive market, using own funds and also financing they raise from households.

Crucially, while banks would prefer to finance their uncertain long-term investments with outside equity or similar flexible state-contingent instruments, their ability to issue equity is constrained by moral hazard and limited commitment. Specifically, banks can take actions that irreversibly reduce the ability of external investors to collect repayments from them in the future.[6] But since equity investors cannot commit to act against their best collective interest, they cannot credibly threaten to punish and liquidate opportunistic banks that try to squeeze them down to the liquidation value of assets.

Banks can, however, increase their financing by issuing deposits that are demandable at any time and feature a sequential service (aka first-come first-served) property, as in Diamond and Rajan (2001b). This creates a built-in collective action problem among depositors: when faced with a prospect of lower repayments than promised, each individual depositor finds it optimal to run and demand full repayment, hoping to be among the first in line. Deposits thus act as a disciplining device, since depositors will run and liquidate bank's assets whenever the bank is unable to repay them in full, even if it is not in their best collective interest. Foreseeing this, the bank will have strong incentives to maintain high pledgeability of future returns.

In normal times, when low productivity growth is a fairly likely outcome, banks are careful: they limit the level of deposits to what they can repay in both high and low productivity states, and issue an incentive-compatible amount of risky outside equity against the high state. As the probability of the high state increases, however, the ability of safe banks to issue outside equity deteriorates, because banks have a greater incentive to squeeze the equity investors' share of the high state returns. Therefore,

[6] This is meant to capture that banks can create obscure and opaque corporate structure, reduce transparency about nature of their investments, maintain weak accounting standards etc.

when the high productivity state becomes sufficiently likely, banks find it optimal to follow a risky strategy and finance themselves exclusively with deposits which they will be unable to repay if the low aggregate state materialises. This allows banks to increase the total amount of financing in a boom, and leads to higher equilibrium asset prices and investment. On the dark side, however, this introduces financial fragility, and there is a systemic banking crisis in the low productivity state.

I consider implications of the model for welfare and government policy. In contrast to much of the post-Great Recession focus on macroprudential regulation, the model presented here cautions against relying solely on ex-ante preventive policies like leverage restrictions. While a strict macroprudential limit on banks' depositary liabilities can eliminate crises, it also limits investment at times of high productivity growth, precisely when it is the most desirable, and thus reduces welfare. Ex-post government bailouts, on the other hand, can save the banking sector from a collapse and improve welfare *in a crisis*. However, anticipation of unrestrained bailouts can completely destroy market discipline of deposits, leading to an inefficient level of investment and hurting welfare. Ex-post interventions are thus only desirable if the government can commit to help banks in case of a systemic banking crisis driven by worsening fundamentals, but not to interfere when the market carries out discipline against opportunistic banks.

Of course, even well-targeted ex-post bailouts deal with symptoms rather than the underlying problem: inability of banks to credibly pledge future returns to investors. This motivates the question: should the banks be monitored during booms to mitigate agency problems and enforce repayments to outside investors? Under simple assumptions about costs and benefits of supervision, I find that the regulator will indeed sometimes supervise banks, increasing their financing and eliminating crises, thus improving welfare. However, the regulator may optimally choose to withdraw and let banks rely on discipline provided by deposits when the confidence in high productivity growth is particularly strong. This potentially sheds light on why, for example, regulation and supervision of the financial sector in the US appear particularly lax in the years preceding the 2008 Financial Crisis.

II. Literature Review

This paper builds on Diamond and Rajan (2001b) who, in a similar vein to the seminal paper of Calomiris and Kahn (1991), strive to explain banks' reliance on short-term demandable deposits that expose them to runs. In these papers, demandable deposits with the first-come first-served feature align incentives and preclude banks from acting against depositors interests. Similarly to the present work, Diamond and Rajan (2000) also analyse optimal bank capital structure under uncertainty. The contribution of my paper is incorporation of this mechanism in the context of a simple macroeconomic model with aggregate uncertainty. I then demonstrate how systemic fragility of the banking sector increases in order to facilitate financing of investments during periods of strong economic growth, thus explaining why financial crises tend to follow credit booms.

The underlying idea that productivity underpins credit booms and financial crises can be traced back to at least Fisher (1933). Closely related recent studies include Gorton and Ordoñez (2019), L'Huillier et al. (2020), Boissay et al. (2016). While in these models crises are certain and perfectly predictable during booms, in my model crises are low probability events, consistent with evidence on agents' expectations.[7]

My paper also contributes to the literature on bank runs. Following Thakor (2018), the literature can be loosely divided into "illiquidity" and "insolvency" camps, although the line between the two issues is thin in practice. According to the first camp, rooted in the seminal work of Diamond and Dybvig (1983), runs are panic-based phenomena, and are essentially coordination failures in a world with multiple equilibria. The present paper belongs to the second camp, which seeks to explain bank runs as driven by the insolvency risk of banks due to weak economic fundamentals, consistent with a number of empirical findings.[8] One prominent example of this literature is Allen and Gale (1998), who build a model in which partial bank runs are an efficient way to improve aggregate risk sharing between early and late consumers. In a series of recent notable papers by Gertler and Kiyotaki (2015); Gertler et al. (2019a); Martin et al. (2014), while bank runs are still mostly panic-based, run equilibria are only possible when the fundamentals are sufficiently weak. In contrast to the present paper, however, the above papers do not account for why banking crises tend to follow credit booms, or why banks finance themselves with deposits or repos.

Gertler et al. (2019b) develop a model in which banking panics are preceded by credit booms, but not all credit booms are "bad", i.e. result in crises. While this is similar to my mechanism, I differ from them in that runnable deposits constitute part of banks' optimal capital structure in my model, and deposit financing endogenously rises in booms. The advantage of this is that banks cannot eliminate the problem by making suspension of convertibility (temporary ban on withdrawals) in case of a run part of the deposit contract.

Starting with Aguiar and Gopinath (2007), there has been a growing literature on

[7]See also Cao and L'Huillier (2018), who similarly relate major economic booms and slumps to low frequency variations in the trend productivity growth. They abstract from financial crises altogether, however, and instead focus on consumption behaviour over the medium run in a permanent income framework with learning about permanent productivity shocks.

[8]For example, Calomiris and Gorton (1991) document that banking crises are not random events, but are accounted for by bad macroeconomic news and high insolvency risk of banks; Calomiris and Mason (2003) show that most bank failures during the Great Depression can be well explained by fundamentals, leaving only limited role to panics; Thakor (2018) surveys empirical evidence and concludes that the 2008 Financial Crisis was likely an insolvency risk crisis, rather than an illiquidity crisis.

small open emerging economies that associates Sudden Stops with changes in trend productivity growth in these countries due to frequent policy regime changes, e.g. Flemming et al. (2019), Seoane and Yurdagul (2019), and Akıncı and Chahrour (2018). These models feature pecuniary externalities due to occasionally binding collateral constraints, and show that trend, rather than transitory shocks, produce realistic Sudden Stops dynamics, and can account for both preceding credit booms and slow recoveries. In this paper I leave out the pecuniary externalities and financial accelerator effect that are central to these papers, and specifically focus on bank runs and insolvency crises.[9]

III. The Model

III.A. The framework

There are three periods: $t \in \{0,1,2\}$. I shall also refer to period 2 as the 'long run'. There are two types of agents in the economy: households and bankers. There are two types of goods: consumption good, which is the numeraire, and physical capital. Capital is used to produce consumption good, as described below, but cannot be consumed itself. Lastly, all agents are risk-neutral, and, for clarity, I assume that there is no discounting and everyone consumes in period 2.

In period 0, banks can invest in projects that mature and pay off in the long run, i.e. period 2. Banks are scalable, and perfectly diversify away any idiosyncratic projects' risks. Each project requires investment of one unit of physical capital in period 0, which bankers need to purchase on a competitive market. For simplicity, I assume that all capital is owned by households in period 0, and the aggregate supply of capital is fixed and normalised to 1. We will later relax the assumption of fixed capital stock and allow for variable aggregate investment.

There is undiversifiable aggregate uncertainty about the long-run productivity that pertains to all banks' projects. Specifically, there are two possible aggregate productivity states $s \in \{H, L\}$, with respective ex-ante probabilities π and $1-\pi$. In the high productivity state H, the average return per project is R^H in period 2, whereas in the low productivity state L it is R^L, with $R^L < R^H$. The state is realised in period 1 and is observed by all agents. However, it takes time until period 2 to formally verify the aggregate state, and thus contracts cannot be state-contingent in period 1.

Projects are bank-specific, and other banks or households cannot run them after

[9]There has been a large post-crisis literature on the role of BGG/KM-like financial accelerator effect during the financial crisis. Gertler and Karadi (2011) build a macro model where the banking sector is subject to balance sheet constraints and thus the classic financial accelerator. Brunnermeier and Sannikov (2014); Mendoza (2010); He and Krishnamurthy (2019) emphasize asymmetries and nonlinearities of models with financial frictions away from steady state. Lorenzoni (2008); Stein (2012) theoretically study the ex ante overborrowing and inefficiency associated with pecuniary externalities interacting with borrowing constraints.

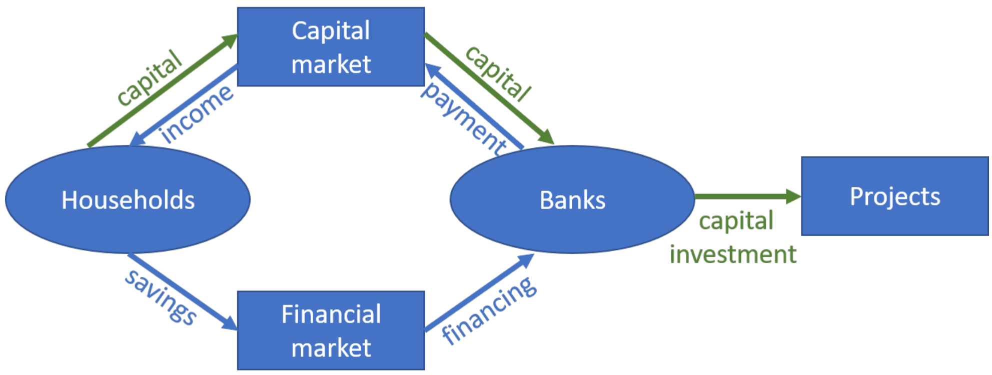


FIGURE 1: Flow of resources in period 0

the investment is made in period 0.[10] This reflects the idea that banks are relationship lenders who possess superior information about their borrowers, although in this model I assume for simplicity that banks manage their projects directly.[11]

Banks can, however, liquidate their projects for Λ per project in period 1 before they mature. To be specific, if liquidated, a project's capital is extracted in full and sold on a competitive and liquid secondary capital market back to the households, who employ it in a traditional sector that yields Λ per unit of capital. Liquidation is always less profitable than leaving capital with the bank and letting the project mature: $\Lambda < R^L$.[12]

Each bank starts with a positive endowment of consumption good, which we will call net worth.[13] Banks finance their capital purchases with their net worth and financing they obtain from households. In what follows, we assume that aggregate net worth of the banking sector N is sufficiently scarce such that banks need to raise additional financing from households. Households, on the other hand, are never constrained in their ability to provide financing to banks in period 0, or purchase banking sector's capital in case of liquidation in period 1.[14] Financial market is competitive, and banks' investors break-even in expectation. Figure 1 illustrates the flow of resources in period 0.

[10]This assumption of extreme project illiquidity ensures that no banks bet on buying projects cheaply off distressed counterparties in a crisis, and considerably simplifies the analysis.

[11]The setup can also be interpreted as one in which there are entrepreneurs who run the projects, but (a) entrepreneurs are penniless and need to raise external financing; (b) households are unable to finance the entrepreneurs directly due to some unmodelled agency problems, whereas banks have the expertise to resolve them; (c) entrepreneurs compete for bank funding, so that all project returns go to banks.

[12]The assumption that the liquidation value does not depend on the state is not critical for the results, but simplifies the exposition.

[13]The results would be similar if, instead, we assumed that banks start with a stock of physical capital and liabilities to households.

[14]This, of course, will be always true if households have sufficiently large endowments of consumption good. This would also be the case, however, even if households start with zero endowments if we assume that all transactions happen instantaneously. In that case, household sector effectively ends up lending capital to banks in exchange of promises of future payments (or, conversely, accepting physical capital in lieu of repayments when banks liquidate projects).

III.B. The first best

It is instructive to describe the first-best outcome in this model. Absent agency problems we shall introduce below, it is never desirable to liquidate banks' projects in period 1. Any financing banks raise from households, therefore, takes the form of long-term, state-contingent liabilities that are repaid in period 2 when projects mature.

Consider a bank with net worth n. If the bank raises additional b, it can start $\frac{n+b}{Q}$ projects. Since bank's investors break-even in expectation, the expected value of future repayments is just b, and the bank's expected return is:

$$\frac{n+b}{Q}\mathbb{E}[R^s]-b,$$

where $\mathbb{E}[R^s]=\pi R^H+(1-\pi)R^L$ is the expected return on banks' projects. Clearly, as long as $Q\neq\mathbb{E}[R^s]$, banks are either willing to expand borrowing to infinity, or are not willing to invest into projects at all, neither of which can be the equilibrium. The first-best equilibrium thus requires $Q^*=\mathbb{E}[R^s]$. There is no capital invested in the traditional sector. Intermediation is costless and efficient, as banks earn zero expected profits.

IV. Agency problems and financial contracts: equity vs. deposits

In this section we outline the agency problems that banks suffer from, and explore the instruments that they can use to raise financing from households. As we shall see, banks financed by well-coordinated equity investors are never inefficiently liquidated. However, ability of banks to finance their capital investments using only equity is limited. This is because, after the investments are made, bankers can reduce ability of outsiders to collect repayments out of future returns, and equity investors cannot commit to punish misbehaving banks. As in Diamond and Rajan (2001b), banks can overcome this by issuing demand deposits, which effectively commit depositors to run and liquidate banks that cannot repay them in full, even when liquidation is not in their best collective interest. While deposits bring about the needed discipline, they can also lead to socially undesirable bank failures.

IV.A. Financial frictions

The first best described in the previous section may be unattainable in equilibrium due to the following financial frictions. Banks suffer from limited pledgeability of future returns: at most fraction $\theta\in(0,1)$ of banks' returns is collectable by external claimholders in period 2. What is worse, after the investments in period 0 are made, banks can also take actions that further irreversibly reduce the ability of investors to collect from them in the future. Formally, a bank can set $\tilde{\theta}\in[0,\theta]$, such that at most fraction $\tilde{\theta}$ of its projects' output can be collected by external claimants in period 2. This is meant to capture the ability of banks to create obscure and opaque corporate structures, reducing transparency about nature of their investments, maintaining weak accounting standards etc. Bank's choice of $\tilde{\theta}$ is observable by its investors in period 1, but not verifiable and cannot be included in a contract. Bankers cannot commit to maintain high $\tilde{\theta}$ if it is not in their best interest. In addition, there is also limited commitment on behalf of households, precluding banks from being able to purchase insurance against the aggregate state.

Financial contracts can give investors control rights to liquidate banks' assets. I assume it is always possible to force banks to liquidate projects and pay proceeds to the investors in period 1, irrespective of $\tilde{\theta}$. Without the liquidation rights, investors would not be able to get any repayments at all, since banks would always set $\tilde{\theta} = 0$; banks thus would not obtain any financing from the households in the first place. To keep the model interesting, I assume $\theta R^L > \Lambda$, so even in the low state investors may receive more than the liquidation value of assets if bank maintains high $\tilde{\theta}$.

IV.B. Equity financing: well-coordinated investors

One financing option banks have is to issue long-term state-contingent liabilities, which, for concreteness, we will call (outside) equity. The general equity contract we consider specifies control rights to liquidate assets in period 1 as well as promised state-contingent payouts in period 2; if investors are not repaid in full in period 2, they are entitled to everything that can be recovered from the bank.[15] Crucially, equity investors are assumed to be well-coordinated and to always act as one to maximize their collective payoff. Whenever there is a conflict of interest between individual investors, they are always able to efficiently negotiate among themselves. The distribution of claims among equity investors is therefore irrelevant, and we can treat them as one representative financier.

Equity investors cannot commit ex ante to act against their best interest ex post. They will thus never liquidate assets of a bank if they stand to gain more from letting it continue running until period 2, even if the bank is not able to repay the promised amount in full. This lenience is a double-edged sword. While it assures that equity-financed banks will never get liquidated while they generate value for their investors, it also allows banks to squeeze their investors by reducing their ability to collect from them in the future. As a consequence, the ability of banks to finance themselves with equity is limited:

[15]While this contract looks more like state-contingent long-term debt rather than equity, the results are the same if instead we consider a more traditional but restrictive equity contact that entitles investors to a fixed share of bank's returns in period 2.

Lemma 1. *The amount of financing that a bank can raise by only issuing equity is at most a fraction $\frac{\Lambda}{R^L}$ of the expected returns on its assets.*

This result follows because investors anticipate that the bank can always set $\tilde{\theta} = \Lambda/R^L < \theta$ after selling equity, without risking liquidation. As investors can still collect Λ per project in period 2 even if the low state materialises, they will never liquidate.[16]

IV.C. Deposits: creating collective action problem among investors

The central problem with equity is that coordinated investors cannot make credible threats to punish and liquidate banks that try to squeeze them, since this is not in their best interest ex post. In the seminal paper, Diamond and Rajan (2001b) suggest that the use of 'harder' claims like demandable deposit contracts disciplines the banks against trying to be opportunistic. Their idea is that deposit contracts that promise repayments on demand (forcing banks to liquidate assets in period 1, if necessary), and feature sequential service (aka first come, first served property), can break the coordination between investors and make it impossible for the banks to reduce their liabilities on deposits. This is because there is a built-in collective action problem among depositors: whenever a bank is unable to repay all of them in full, each individual depositor has an incentive to run on the bank hoping to be among the first in line and be made whole, rather than accept lower repayment. An attempt to squeeze depositors will thus trigger a run in which all depositors try to withdraw, even when it is in their best collective interest to agree to lower payments.[17] To put differently, deposits commit creditors to punish and liquidate opportunistic banks ex ante, even if they would not choose to do so ex post. Foreseeing this, banks that are funded by deposits to a sufficiently high extent will have stronger incentives to maintain high pledgeability of their future returns, allowing them to borrow more.

I assume that deposit contracts with sequential service constraint are available to agents in the economy, and it is the only mechanism capable of creating a collective action problem among investors. Because the state cannot be verified until period 2, however, face value of deposits in period 1 cannot be made state-contingent. In fact, I assume without loss of generality that banks issue only simple deposits that have fixed face value across both periods and states; banks can then issue equity against the states in which they are able to repay more than the face value of deposits.[18] Lastly, by

[16] The bank may have incentives to set $\tilde{\theta}$ even lower, thus risking liquidation in the low state and further limiting financing available ex ante.

[17] For the detailed formal development of this argument, see section III.D, and also the proof of Lemma 2 in the Appendix of Diamond and Rajan (2001b).

[18] Firstly, it would be suboptimal for a bank to issue deposits that promise lower payments in period 2 than in period 1 in some states, since depositors would then always run in period 1 in those states. Secondly, while it is in principle possible to issue state-contingent deposits that pay more in period 2 than period 1 in some states, it does not make a difference to total financing that bank is able to raise.

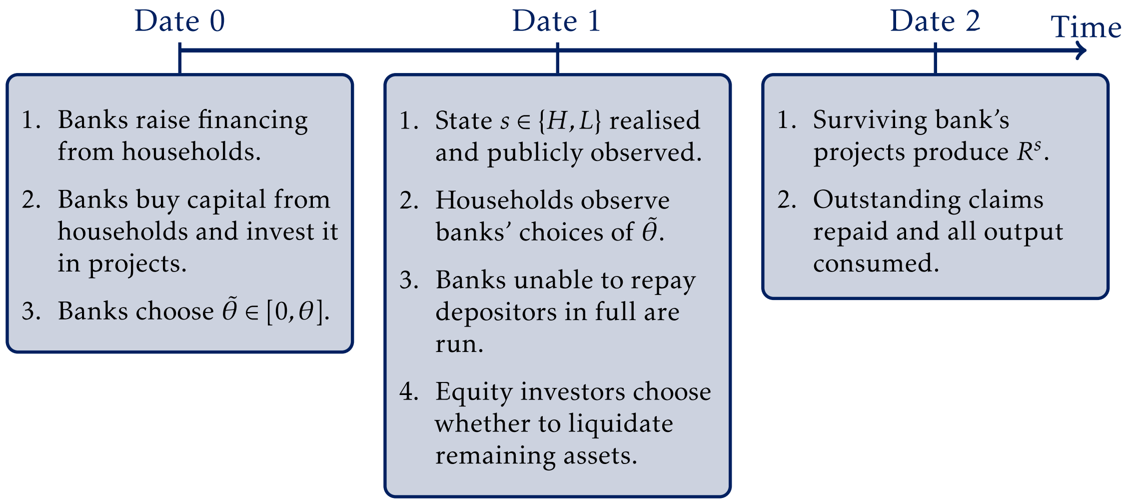


Figure 2: Timeline

virtue of their instant demandability, deposits are always senior to equity: assuming depositors can run and liquidate assets quicker than equity investors in period 1, equity always gets only the residual value, if any, after all depositors are served.[19]

Crucially, deposit funding also has a dark side: a bank may be inefficiently run and liquidated even when it does not try to extract rents from its creditors, if the pledgeable value of its assets falls below the value of its depositary liabilities due to unfavourable economic conditions. In that case it would be desirable for depositors to agree to lower repayments, but deposit contracts are explicitly designed to prevent that from happening. I assume, however, that banks cannot fall prey to classic panic bank runs as in Diamond and Dybvig (1983), and fundamentally solvent banks are always able to obtain financing in period 1.

Figure 2 summarizes the timing of events. Let us now turn to how banks combine equity and deposit financing in equilibrium.

V. Banks' choice of financing, equilibrium, and financial crises

In this section we first consider an individual profit maximizing bank that takes market price of capital as given. I show that when the probability of the high productivity state is relatively low, the bank is safe: it can raise the maximum feasible amount of external financing and maximize its payoff by relying on a mix of outside equity and deposits that it can always repay. However, when the high productivity state becomes more likely, the ability of a bank with safe level of deposits to issue outside equity declines

Since a prospect of reduction in future repayments would not trigger a run as long as depositors get at least as much as the current face value of their deposits, they cannot commit not to negotiate period 2 repayments that are in excess of the face value of deposits in period 1. But then they are not different from equity investors with respect to those excess repayments.

[19]This is because in period 1 equity investors will always agree to a necessary reduction in their period 2 claims to forestall a run by depositors.

due to moral hazard. At some point the bank finds it optimal to leverage itself up with deposits beyond what it can repay in the low state, i.e. become risky. This improves discipline and allows the bank to pledge more high-state returns to external investors, but comes at the cost of making run inevitable in the low state. Second, I show that the model has a unique equilibrium. Similarly to the case of individual bank, when probability of the high state is sufficiently high, and the aggregate net worth of the banking sector is scarce, all banks choose risky strategy in equilibrium. This facilitates boom in asset prices and aggregate investment, but results in a systemic financial crisis if the low state materializes.

V.A. Banker's problem

Throughout this subsection we suppose that $Q < \mathbb{E}[R^s] \equiv \pi R^H + (1-\pi)R^L$, so banks are financially constrained, earn positive expected profits, and want to expand. This will indeed be the case in equilibrium when aggregate net worth of the banking sector is sufficiently scarce and the probability of the high state π is sufficiently high. The less interesting case $Q = \mathbb{E}[R^s]$ arises only when banks' financing constraints do not bind in equilibrium and the first best outcome is achieved.

Let b be the total amount of financing that a bank with net worth n raises, and so $m \equiv \frac{n+b}{Q}$ be the number of projects the bank starts. Let d and e^s be the face values of bank's deposits and equity in state s, respectively. Without loss of generality, we can assume that e^s is an incentive-compatible amount that bank actually pays out to equity investors in state s. In state s in period 1, investors would liquidate the bank if $m\tilde{\theta}R^s < \max\{d, m\Lambda\}$, i.e. either if the pledgeable value of bank's assets is not enough to repay its depositors in full, or is below the liquidation value of the assets.[20]

Depending on its capital structure, the bank can be either *safe* or *risky*. Bank is safe if it is solvent and avoids liquidation of its assets in both high and low productivity states. A risky bank, on the other hand, gets liquidated by its investors if the low state materialises. Intuitively, whether a bank is risky boils down to how much it relies on deposits as the disciplining device. Bank will choose to be safe or risky depending on which one yields higher expected profit. We can then look at these two strategies separately, and compare the resulting payoffs.

[20] Of course, it always makes sense for a financially constrained bank to give investors all control rights in period 1 in this model.

V.A.1 Safe strategy

Taking as given that it is optimal for the bank to be safe, the bank's maximization problem can be written as:

$$\max \quad v = \pi\left[mR^H - d - e^H\right] + (1-\pi)\left[mR^L - d - e^L\right] \tag{1}$$

$$\text{s.t.} \quad m = \frac{n+b}{Q} \tag{2}$$

$$b = d + \pi e^H + (1-\pi)e^L \tag{3}$$

$$d + e^s \leq m\theta R^s,\ s \in \{L,H\} \tag{4}$$

$$d + e^L \leq \max\{d, m\Lambda\} \tag{5}$$

$$d + e^H \leq \frac{R^H}{R^L}\max\{d, m\Lambda\} \tag{6}$$

$$v \geq \pi\left(mR^H - \max\{d, m\Lambda\}\right) \tag{7}$$

Constraint (3) is the break-even condition for bank's investors; (4) restricts liabilities of a safe bank to what it can feasibly pay out in each state; (5) and (6) place the limits on the maximum repayments in the low and high states respectively that the bank cannot reduce simply by lowering $\tilde{\theta}$ to $\frac{\max\{d,m\Lambda\}}{mR^L}$, and still avoiding liquidation in both states; lastly (7) is the incentive compatibility constraint that ensures that the safe bank does not benefit in expectation from squeezing equity investors out completely in the high state by setting $\tilde{\theta} = \frac{\max\{d,m\Lambda\}}{mR^H}$, and accepting the risk of failure in the low state.

Since $Q < \pi R^H + (1-\pi)R^L$, the bank will strive to raise as much external financing as possible, i.e. V is maximized when b is maximized. Analysis of the constraints reveals that this is achieved when $e^L = 0$ and $d = m\theta R^L$, i.e. bank operates with the highest possible safe level of deposits, and issues equity only against the high state. This is intuitive, because deposits provide discipline, and therefore relax constraints (5)-(7). The solution to the safe bank's profit maximization problem then depends on whether it is constraints (6) or (7) that is binding, which in turn depends on the probability of the high state π:

Lemma 2. *A safe bank always operates with $e^L = 0$ and $d = m\theta R^L$ to maximise discipline. Let*

$$\dot{\pi} \equiv \frac{(1-\theta)R^L}{\theta(R^H - R^L) + (1-\theta)R^L} \in (0,1). \tag{8}$$

- *When $\pi \leq \dot{\pi}$, constraints (6) binds, constraint (7) is slack, and the bank is able to pledge the maximum fraction θ of expected future returns to external investors. It raises $b_s/m_s = \theta\mathbb{E}[R^s]$ per project, supervises $m_s = \frac{n}{Q-\theta\mathbb{E}[R^s]}$ projects, and its expected payoff is $v_s = m_s(1-\theta)\left(\pi R^H + (1-\pi)R^L\right)$.*

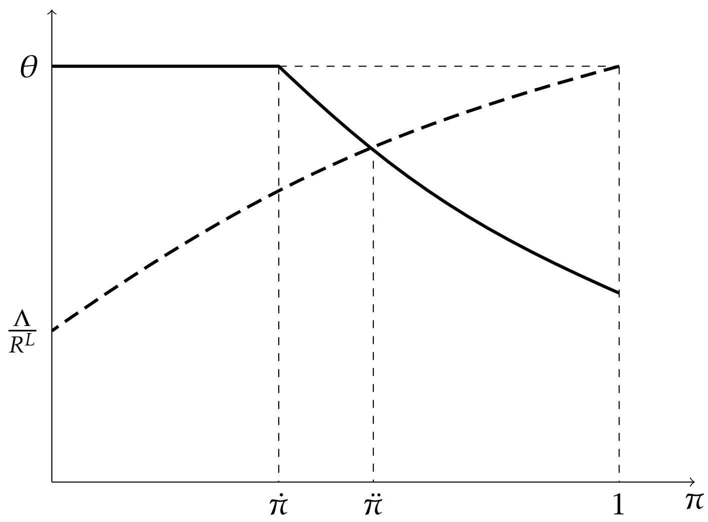


Figure 3: Fraction of expected projects' value that safe (solid line) and risky (dashed line) banks can pledge to external investors

- *When $\pi > \dot{\pi}$, constraint* (7) *binds, and the bank can only raise $b_s/m_s = \pi\theta R^L + (1-\pi)R^L$ per project externally. The bank runs*

$$m_s = \frac{n}{Q - \pi\theta R^L - (1-\pi)R^L} \tag{9}$$

projects, and earns the expected payoff

$$v_s = m_s\pi\left(R^H - \theta R^L\right). \tag{10}$$

Corollary 1. *Ability of a safe bank to finance its projects externally falls as the high state becomes more likely.*

The intuition for the result is simple. As the high state becomes more likely, the banker's moral hazard becomes worse. He has stronger incentive to squeeze equity investors and get higher share of the pie in the high state, so the amount of outside equity the bank can issue falls. The ability of a safe bank to use deposits to reduce this moral hazard is limited by the fact that it must be able to repay depositors in full in all states. The solid line in Figure 3 illustrates the fraction of expected returns pledgeable by a safe bank as a function of π.

V.A.2 Risky strategy

This brings us to the second, risky, strategy that the bank may pursue when the high state is sufficiently likely: accept that it will fail in the low state, but raise more financing against the high state using deposits and start more projects. Taking as given that the bank has $d > m\theta R^L$ and fails in the low state, its problem becomes:

$$\begin{aligned} \max \quad & v = \pi\left(mR^H - d\right) && (11) \\ \text{s.t.} \quad & m = \frac{n+b}{Q} \\ & b = \pi d + (1-\pi)m\Lambda && (12) \\ & d \leq m\theta R^H && (13) \end{aligned}$$

Constraint (12) is the break-even condition of bank's financiers, who liquidate the bank and keep the proceeds in the low state; (13) limits deposit liabilities of a risky bank to what it can feasibly repay in the high state. Risky bank issues no outside equity and $e^H = 0$, since otherwise it could squeeze equity investors out by setting $\tilde{\theta} = \frac{d}{mR^H}$, while still avoiding run and liquidation in the high state.

Combining (11) and (12), it is easy to see that for the risky strategy to earn positive profit, and thus for the bank to even consider it over the safe one, we must have $Q < \pi R^H + (1-\pi)\Lambda$, i.e. capital price should not exceed the value of the projects given liquidation in the L state. When that's the case, the bank's payoff is again maximized when external financing b is maximized. This is achieved when the bank issued maximum amount of deposits, $d = m\theta R^H$, since that way the bank commits to repay the maximum pledgeable fraction θ of returns in the high state.

Lemma 3. *The solution to the risky bank's problem is achieved when constraint* (13) *binds and the bank promises maximum pledgeable fraction of returns in the high state to depositors. This allows the bank to raise external financing* $b_r/m_r = \pi\theta R^H + (1-\pi)\Lambda$ *per project, supervise*

$$m_r = \frac{n}{Q - \pi\theta R^H - (1-\pi)\Lambda} \tag{14}$$

projects, and earn the expected payoff

$$v_r = m_r \pi (1-\theta) R^H. \tag{15}$$

The risky strategy allows the bank to raise more external financing against the high state, so as the high state becomes more likely, the ability of a risky bank to finance itself externally improves. The dashed line on Figure 3 shows the amount of external financing that a risky bank can raise as a fraction of the first-best expected value of its projects, $\mathbb{E}[R^s]$. As π approaches 1, this fraction approaches maximum feasible value θ.

V.A.3 Safe or risky?

So when will the bank adopt a high, risky level of deposits?

LEMMA 4. *The necessary conditions for a bank to consider risky strategy are $Q < \pi R^H + (1 - \pi)\Lambda$ and $\pi > \ddot{\pi}$, where*

$$\ddot{\pi} \equiv \frac{R^L - \Lambda}{\theta(R^H - R^L) + R^L - \Lambda} \in (\dot{\pi}, 1). \tag{16}$$

Then, the bank strictly prefers risky strategy to safe strategy iff $Q < \bar{Q}$, where:

$$\bar{Q}(\pi) \equiv \pi R^H + (1 - \pi)\Lambda - \frac{(1 - \pi)(1 - \theta)(R^L - \Lambda)R^H}{\theta(R^H - R^L)}, \tag{17}$$

i.e., ceteris paribus, (a) π is sufficiently high; (b) Q is sufficiently low.

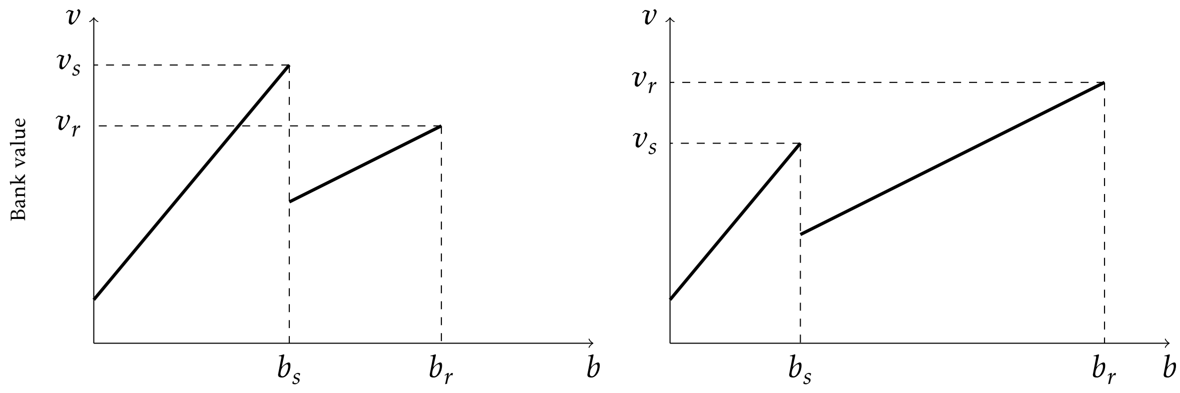
When $\pi < \ddot{\pi}$, the bank can obtain more external financing following the safe strategy, hence there is no benefit at all of increasing leverage and becoming risky. When $\pi > \ddot{\pi}$, the bank trades off the ability to rise more financing and intermediate more projects offered by the risky strategy vs. losses due bank run and liquidation in the low state. Figure 4 depicts the bank's expected value as a function of its reliance on external financing, holding the market price of capital fixed. It increases linearly up until b_s, at which point it drops discontinuously: to raise more external financing than b_s, the bank must lever itself up with deposits beyond what it can repay in the low state, causing a bank run and liquidation in the L state. The value then continues to increase linearly in b up until b_r, although now with a lower slope reflecting lower value of each project. The bank's problem reduces to simply choosing between the two peaks: v_s (playing it conservatively) and v_r (betting on the high growth, but suffering a run if it slows down), whichever yields a higher value. Comparing (15) and (10), the second claim in the lemma follows.[21] More likely high productivity state and cheaper capital make the risky strategy more appealing, the latter because additional financing bank is able to obtain translates into more additional projects when Q is low.

V.B. Equilibrium and Financial Crises

Equilibrium requires that financial and capital markets clear in period 0. The key equilibrating variable is the price of capital Q: demand for capital from banks that take Q as given must equal supply of capital by households. At the same time, banks' demand for capital depends on the amount of external financing they obtain, which, as we have seen, also depends on Q.

We say that there is a risk of financial crisis if all or a substantial fraction of banks choose risky strategy in period 0, and are run and liquidated in the L state. The central

[21] Here I make use of the fact that in equilibrium we will necessarily have $Q > \pi\theta R^H + (1 - \pi)\Lambda$ and $Q > \pi\theta R^L + (1 - \pi)R^L$, otherwise banks could make infinite profits and would demand infinite amount of capital.



(a) Bank chooses safe strategy (b) Bank chooses risky strategy

FIGURE 4: Bank's value as a function of external financing

result of this paper, formally established in the proposition below, is that such risk emerges in equilibrium during booms, when the probability of a high productivity state is high.

PROPOSITION 1. *There is an essentially unique equilibrium in this economy (with respect to aggregate outcomes),*[22] *which depends on the probability of the high state* π. *Suppose* $N < (1-\theta)R^H$, *i.e. the aggregate net worth of the banking sector is sufficiently scarce. Then there are thresholds*

$$\underline{\pi} = \frac{N\frac{\theta(R^H-R^L)}{R^H-\theta R^L} + R^L - \Lambda}{\theta(R^H-R^L)+R^L-\Lambda} \quad \text{and} \quad \overline{\pi} = \frac{N\frac{\theta(R^H-R^L)}{(1-\theta)R^H} + R^L - \Lambda}{\theta(R^H-R^L)+R^L-\Lambda},$$

with $\ddot{\pi} < \underline{\pi} < \overline{\pi} < 1$, *such that:*

a. *If* $\pi \geq \overline{\pi}$, *there is a unique equilibrium in which all banks are financed with risky level of deposits. This facilitates credit and asset price boom in period 0: banks borrow* $\pi\theta R^H + (1-\pi)\Lambda$ *per project, and drive the equilibrium price of capital to*

$$Q^* = N + \pi\theta R^H + (1-\pi)\Lambda. \tag{18}$$

There is a systemic financial crisis in which all banks fail if the low state materialises.

b. *If* $\pi \in (\underline{\pi}, \overline{\pi})$, *in equilibrium fraction* ζ^* *of banks (measured by net worth)*[23] *end up choosing risky level of deposits, where*

$$\zeta^* = \frac{(1-\theta)R^H}{N\theta(R^H-R^L)}[Q^* - \pi\theta R^L - (1-\pi)R^L - N],$$

[22] While there may be multiple equilibria in (b) and (c), essential uniqueness here means that they are always equivalent in terms of aggregate outcomes, e.g. the amount of credit, price of capital, and fraction of banks that end up being risky.

[23] Here we require a technical assumption that banks are atomistic, such that such split is always possible for any $\zeta \in (0,1)$.

while the remaining banks are safe. Equilibrium price of capital is $\bar{Q}$ *given in* (17). *Fraction* ζ^* *of banks that fail if low state materialises increases in the ex-ante probability of high state:* $\zeta^{*\prime}_{\pi} > 0$.

c. *If* $\pi \leq \underline{\pi}$*, all banks are safe, and never fail in equilibrium.*

The condition $N < (1-\theta)R^H$ is a plausible one – assuming otherwise would imply that the banking sector has enough own resources to be able to bid up capital prices to the full value of the investment projects even when the high state is certain, and thus can never earn positive profits. But it is unlikely that bankers would have accumulated that much net worth during normal times when the probability of high state is low.

It is not difficult to imagine the effect of an asset prices boom on aggregate investment. In Appendix B I formally extend the above result to the case with variable aggregate capital. To summarise our findings, during booms in productivity, worsening moral hazard induces banks to rely exclusively on deposits, facilitating a boom in asset prices and aggregate investment. If the anticipated growth fails to materialise, however, excessive deposit financing leads to a systemic financial crisis.

VI. Welfare and policy implications

In this section I discuss policy implications of the theory presented above. We'll see that ex-ante leverage restrictions and ex-post bailouts hurt welfare by stifling investment and destroying discipline, respectively. However, regulatory supervision of banks that enhances their transparency and governance can sometimes eliminate crises and improve welfare.

VI.A. Ex-ante leverage restrictions

While financial crises in the model are destructive and undesirable ex post, equilibria with crises are ex-ante constrained efficient: unlike many models with financial accelerator effects, here are no pecuniary externalities that agents do not take into account. Even though growing reliance of banks on deposit-like short-term financing introduces the risk of financial disaster, it also allows to increase financing of capital investment when it is most valuable: during booms with strong prospects of high future returns.

It is easy to see that sufficiently hard restrictions on ability of banks to leverage with deposits can always preclude financial crises in the present setting. However, this will not be Pareto improving: restricted leverage also means lower capital prices, and necessarily lower welfare of households, who supply capital. Interestingly, in some cases leverage restrictions may lead to higher profits of the banking sector, since they effectively limit the competition between banks on the capital market, and allow them to enjoy higher returns per project. Nevertheless, there is a net loss to the society in the form of missed investment opportunities.

This point is quite general, and would remain an important consideration in more realistic settings that incorporate additional social costs of bank failures which may not be fully internalised by financial market participants, e.g. unemployment. Even if these additional costs tilt the balance in favour of using leverage restrictions to preclude possible financial crises, policy makers must understand that such policies are not free to use.

VI.B. Cleaning-up ex post: government bailouts

Unlike the models in which financial crises stem from panics and illiquidity, notably Diamond and Dybvig (1983), in the present model banking crisis is not a result of agents' failure to coordinate on a 'good' equilibrium. Once growth opportunities deteriorate during a boom, banks are run by depositors because they become fundamentally insolvent, in the sense that their liabilities on deposits exceed what they can possibly repay.

Despite this, saving banks in a crisis is, in principle, desirable *ex post*, since liquidation of banking assets destroys wealth for both households and banks. In practice, government rescue could take many forms: costly government guarantees of problematic banks' debt; lending to troubled banks at below-market interest rates; or simply injecting equity into banks. Arguably, most of these tools were used in the US during the 2008 Financial Crisis.[24]

However, recommending unrestrained government support to failing banking sector would be ill advised. The theory suggests that fragile capital structure is a market solution to bank discipline problem, and, similarly to large existing literature on moral hazard emanating from implicit government guarantees,[25] expectations of government rescue could completely destroy ex-ante incentives. If creditors expect that the government will use taxpayers' money to bail out troubled banks, they will have no reasons to care about bankers' conduct and incentives, leading to an overheated credit market, inflated asset prices, and high rent extraction by bankers. Incentives of banks to maintain high pledgeability of returns would be lost, and aggregate investment could be severely distorted.

Government bailouts would thus only be desirable ex ante if they are carried out

[24]Despite the fact that Lehman Brothers was allowed to fail because the Fed deemed it fundamentally insolvent at the time, one can argue that other insolvent banks were effectively bailed out. Notwithstanding popular claims that the US government has made money on assisting troubled banks, this is not true if one takes into account the fair economic value of government's assistance: Lucas (2019) estimates the direct cost of bailouts to the US government to be in excess of £500bn, or 3.5% of GDP.

[25]Some of the prominent papers on the topic, among others, are Chari and Kehoe (2016); Farhi and Tirole (2012).

in a way that preserves market discipline. This requires that the government must be able to commit to bail out banks only in a genuine crisis driven by a significant decline in expected economic growth, but let fail any bank that tries to extract rents from its financiers or taxpayers.[26] How to generate such a commitment remains an important question actively discussed in academic literature and policy circles. In essence, this is an institutional design problem of giving proper incentives to the regulator responsible for bailouts. I conjecture that the optimal design would at least require that the regulator (i) is well informed about the aggregate state of the economy, and (ii) is more reluctant to assist banks than a benevolent social planner would be. The latter would ensure that the regulator does not intervene unless there are significant benefits to the society from doing so, and could be achieved by making bailouts legally difficult and politically costly to the regulator.

VI.C. Addressing financial frictions directly

The fundamental problem described in the paper is inability of banks to credibly pledge future returns to external financiers. Financing with rigid, demandable deposit-like instruments during booms, and the resulting financial crises are thus just the symptoms of the underlying cause.

One implication of the theory is the empirically valid prediction that banking crises are more likely to erupt in developing countries that are characterised by weak financial institutions and governance problems, while, at the same time, having less stable political regimes and more volatile economic trends. The second implication is that the best remedy against financial crises is a developed and transparent financial sector with sufficient intermediation capacity to allow it to refrain from fragile short-term financing – a point also forcefully stressed in Diamond and Rajan (2001a).

We can also ask a more immediate question: should the government monitor banks during booms to mitigate agency problems and enforce repayments to outside investors? The answer, of course, depends on the feasibility and costs of monitoring. Formally, suppose that, by tightly supervising banks, the regulator can eliminate moral hazard completely and ensure that a fraction θ of banks' returns gets repaid. However, active regulator's interference in banks' business also reduces future returns by a fraction $1-\chi$, such that banks' projects only generate χR^s in state s. Let us assume that the regulator is household-friendly, i.e. its sole objective is to maximize the welfare of household, and places zero weight on bankers' profits. Since households supply capital, and always break-even in expectation on the financial market, household welfare maximization is tantamount to maximizing capital price, and thus the amount of financing that banks can sustain. Then one can show that:

[26] Of course, if such commitment is in place, no bank attempts to do so in equilibrium.

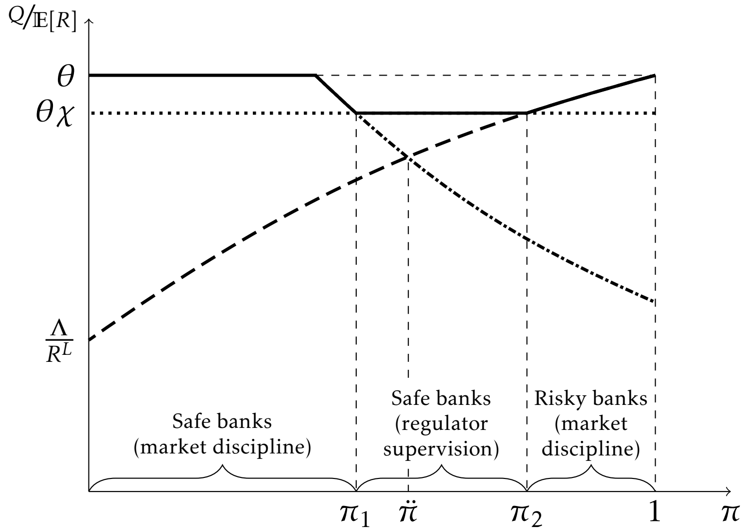


Figure 5: Capital price as a fraction of its first best level: market discipline vs regulatory supervision

Proposition 2. *If the cost of supervision $1-\chi$ is sufficiently low, specifically*

$$\chi > \frac{\max\left\{\underline{\pi}R^L + \frac{1-\underline{\pi}}{\theta}R^L, N + \underline{\pi}\theta R^L + (1-\underline{\pi})R^L\right\}}{\underline{\pi}R^H + (1-\underline{\pi})R^L}, \tag{19}$$

there exist π_1, π_2, with $\pi_1 < \underline{\pi} < \pi_2 < 1$, such that banks are supervised iff $\pi \in (\pi_1, \pi_2)$.

However, there is no supervision otherwise, and the equilibrium features potential financial crisis when $\pi > \pi_2$.

The main message is that the regulator will indeed actively supervise banks, sometimes eliminating the possibility of a financial crisis, when the probability of the high state is moderately high. The regulator, however, will choose to leave the market to its own devices once the high productivity state becomes very likely. Intuitively, when the probability of the low state becomes small, expected benefit of preventing a crisis falls; regulatory supervision thus becomes more costly than deposits in forcing repayments from banks in the high state. This potentially sheds some light on why, for example, regulation and supervision of financial sector in the US appears particularly lax in the years preceding the 2008 Financial Crisis: on the back of strong confidence in the high productivity growth, the regulators might had been afraid to do more harm than good by interfering.

We can graphically illustrate the proposition in a special case $N \to 0$ (banking sector has negligibly low aggregate net worth), which is particularly easy to plot. When banks have very low net worth, the ability to raise external financing becomes their crucial concern in equilibrium, and banks are willing to become risky the moment it allows them to better finance themselves, i.e. when $\pi > \ddot{\pi}$. Figure 5 plots the price of capital Q as a fraction of its first-best level, $\mathbb{E}R = \pi R^H + (1-\pi)R^L$, assuming that either (i) regulator actively supervises banks (dotted line), (ii) all banks rely on market discipline and choose the safe strategy (dash-dotted line), or (iii) all banks rely on market discipline and choose the risky strategy (dashed line). The latter two lines are effectively the same as in Figure 3, because equilibrium capital price now equals financing that banks can raise per project. In equilibrium, and with optimal supervision, the price of capital is the highest of the three, highlighted by the solid line on the plot. Supervision can achieve greater repayment from banks than market discipline when $\pi \in [\pi_1, \pi_2]$, and it eliminates financial crises when $\pi \in (\ddot{\pi}, \pi_2]$. However, the regulator prefers to let banks finance themselves with risky level of deposits when $\pi > \pi_2$.

VII. Concluding remarks

This paper presents a model in which financial crises result from build-ups of bank leverage and financial fragility during periods of rational optimism, when banks expect high returns on their long-term investments that ultimately do not materialise. The key mechanism is an increasing reliance of banks on deposit financing, which helps them overcome agency problems and increase funding, but also exposes them to runs. The model is consistent with empirical evidence that credit booms and financial crises appear to be preceded by swings in the long-run productivity trends.

Ex-ante leverage restrictions can eliminate crises, but may hurt welfare, because they stifle investment at the time when it is most valuable. Unrestrained ex-post bailouts destroy ex-ante incentives and lead to inefficient levels of investment. They are therefore desirable only if the government can commit to interfere only when banks require help because of deteriorating fundamentals, but otherwise allow them to fail. How to engender such a commitment is a fascinating direction for future research.

Regulatory supervision of banks that enhances their accountability to investors can sometimes eliminate crises and improve welfare. However, it may still be optimal for the regulator to back away and let banks rely solely on market discipline during times when the confidence in high productivity growth is very strong. More generally, the theory presented here emphasizes that a transparent financial sector with strong corporate governance may not only enable superior allocation of resources, but also improves financial stability.

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APPENDICES

Appendix A. Productivity, Booms, and the 2008 Crisis

There is ample empirical evidence of low-frequency variation in the long-run growth rate of productivity. For example, Kahn and Rich (2007) show that a Markov switching model in which labour productivity growth can be either high or low, with a small

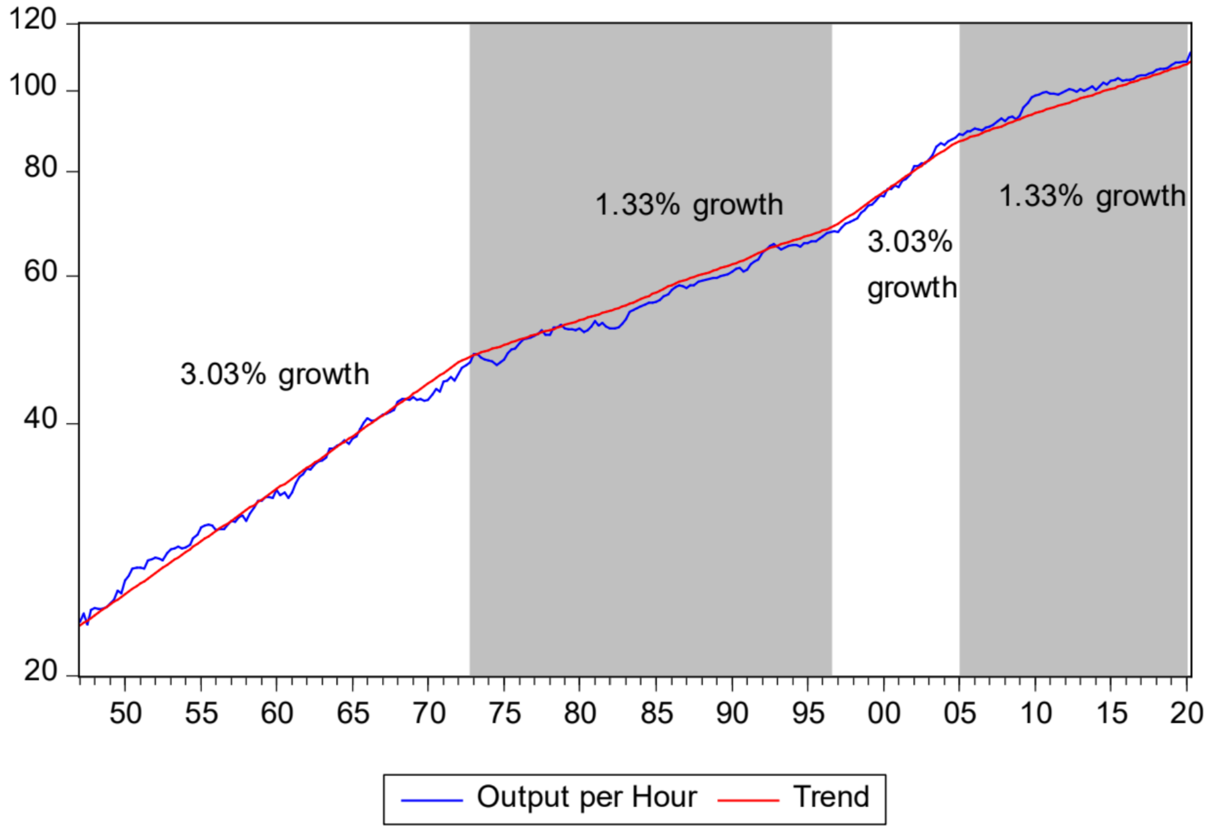

FIGURE A.1: US labour productivity growth trends (log scale) from Kahn and Rich model

probability of transition between the states, fits the postwar US data surprisingly well.[27] Moreover, accelerations in average productivity growth appear to be associated with starts of credit booms; and, while financial crises often follow credit booms, many credit booms do not, in fact, end up in crises (Gorton and Ordoñez, 2019; Dell'Ariccia et al., 2012). Crises, however, typically follow after several years of slow productivity growth (Gorton and Ordoñez, 2019; Paul, 2020). Evidence thus appears to suggest that, paraphrasing Schularick and Taylor (2012), crises are productivity booms gone wrong: they follow booms in which accelerated productivity growth ultimately disappoints.

The Great Recession is a case in point. It is well documented that there has been a marked acceleration in the US productivity growth in the mid 1990s after more than 25 years of sluggish growth, widely attributed to information and communication technologies.[28] Figure A.1, taken from the up-to-date version of Kahn and Rich (2007), demonstrates a shift to the high-growth regime around 1997. The gradual recognition of the New Economy prompted many people, including professional economists, to express confidence in high rate of growth for the decades to come.[29]. Figure A.2 shows

[27]See also Edge et al. (2007); Benati (2007), and references therein.

[28]See Benati (2007); Kahn and Rich (2007); Fernald (2014). In addition, Fernald (2014) demonstrates that although capital deepening played a role, high growth of labour productivity in the late 1990s- early 2000s was driven primarily by TFP.

[29]Among many others were: De Long (2003); Cummins and Violante (2002); Jorgenson et al. (2004);

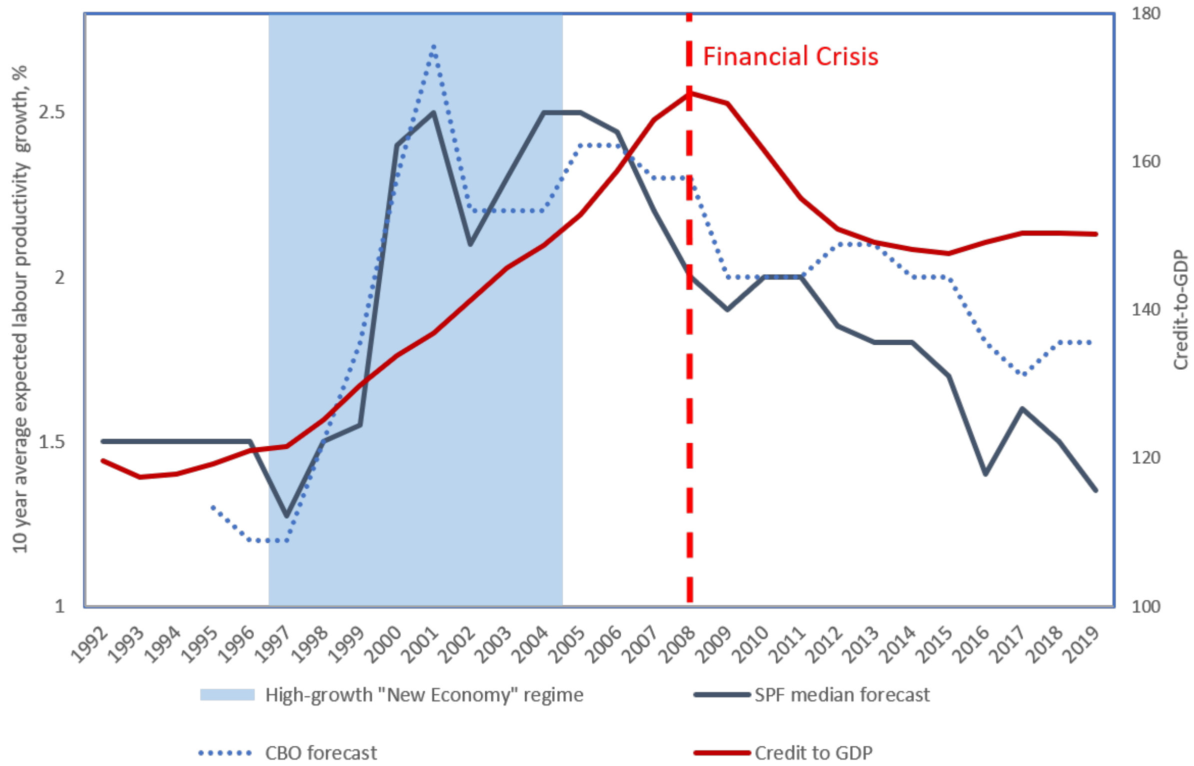

Figure A.2: The New Economy, long-run productivity growth expectations, and credit

that medium professional forecasts of 10-year average productivity growth nearly doubled in the 3 years 1997-2000, and were hardly affected by the dot-com bust. At the time, they were not necessarily unreasonable: since shifts in trend are infrequent and difficult to predict, the best forecast following an acceleration of productivity may well be to expect that the economy will experience a prolonged period of high growth. The figure also shows that this period was marked by a large credit boom in the US. As is evident from the figures, however, the trend productivity growth has slowed down again around the beginning of 2005. The evidence that productivity has slowed *well before* rather than as a result of the Great Depression is also presented in Fernald (2014); Cette et al. (2016); Cao and L'Huillier (2018). Long-term forecasts began to decline, and the Financial Crisis broke out three years later.

Appendix B. Capital investment

In this appendix we relax the assumption that the stock of capital is fixed. This introduces realistic deadweight losses from restricting banks' leverage through aggregate investment.

Suppose that capital is produced by households using only their labour as input.

Stiroh and Botsch (2007); Gordon (2003).

Each household runs a competitive capital producing firm and solves:

$$\max_{k_i} Qk_i - \gamma_i \frac{k_i^2}{2}, \tag{A.1}$$

where k_i is the amount of capital produced, and the quadratic term represents the disutility of labour required to produce k_i units of capital. First-order condition is

$$k_i(Q) = \frac{Q}{\gamma_i}, \tag{A.2}$$

which, aggregated over all households, yields the aggregate supply of capital:

$$K^S(Q) = \int_{i \in \mathcal{H}} \frac{Q}{\gamma_i} \, \mathrm{d}F_h(i) = \frac{Q}{\gamma}. \tag{A.3}$$

The following proposition, similarly to Proposition 1 in the paper, establishes that there is a unique equilibrium that features potential financial crisis if aggregate banks' net worth is relatively scarce, and the probability of a high productivity state is sufficiently high:

Proposition A.1. *There is an essentially unique equilibrium,*[30] *which is parameter-dependent. Suppose the aggregate net worth of the banking sector is sufficiently scarce, namely* $N < \frac{1-\theta}{\gamma} {R^H}^2$. *Then there exist thresholds* $\underline{\pi}, \overline{\pi}$, *with* $\ddot{\pi} < \underline{\pi} < \overline{\pi} < 1$, *such that:*

- *If* $\pi \geq \overline{\pi}$, *all banks choose risky strategy and there is a financial crisis if the low state materialises.*
- *If* $\pi \in (\underline{\pi}, \overline{\pi})$, *there is a mixed strategy equilibrium in which some banks are safe, and some are risky.*
- *If* $\pi \leq \underline{\pi}$, *all banks choose safe strategy, and never fail in equilibrium.*

$N < \frac{1-\theta}{\gamma} {R^H}^2$ is again a plausible restriction that the banking sector does not have enough own resources to be able to bid up the price of capital to the first-best level even when the high state becomes certain. The central results therefore remain unchanged when we allow variable capital, although it is more challenging to obtain closed-form solutions for probability thresholds, capital prices, and investment. However, it is straightforward to characterize the equilibrium in the limiting case where $N \to 0$, i.e. the banking sector is close to penniless in the aggregate, and raises most of its financing externally. In that case, price of unit of capital approaches the amount of external financing that banks can raise per project, and we have the following:

[30] With respect to aggregate outcomes.

Corollary A.1. *As $N \to 0$, both thresholds $\underline{\pi}, \overline{\pi} \to \ddot{\pi}$, and the equilibrium capital price*

$$Q^* \to \begin{cases} \theta\left(\pi R^H + (1-\pi)R^L\right) & \text{if } \pi \le \dot{\pi} \\ \pi\,\theta R^L + (1-\pi)R^L & \text{if } \pi \in (\dot{\pi}, \underline{\pi}] \\ \pi\theta R^H + (1-\pi)\Lambda & \text{if } \pi \ge \overline{\pi}, \end{cases} \tag{A.4}$$

where the last case corresponds to the equilibrium with a possible financial crisis. The equilibrium capital investment is $K^* = Q^*/\gamma$.

When banks have very low net worth, the ability to raise external financing becomes a crucial concern in equilibrium, and banks are willing to become risky the moment it allows them to better finance themselves, as reflected in $\overline{\pi}$ falling to $\ddot{\pi}$.

Because risky banks are able to raise more financing, increasing the demand for capital, we also have:

Corollary A.2. *In equilibrium with financial crisis, the capital prices and aggregate investment are higher compared to a case in which all banks restrict their leverage to avoid a financial crisis in the L state.*

Appendix C. Proofs

Proof of Proposition 1. It is straightforward to verify that $\ddot{\pi} < \underline{\pi} < \overline{\pi} < 1$ when $N \in (0, (1-\theta)R^H)$. Let us prove each part of the proposition consecutively.

a. First, we show this is indeed an equilibrium. If all banks choose risky strategy and maximum level of deposits they can repay only in the high state, the aggregate demand for capital is:

$$K^D(Q) = \frac{N}{Q - \pi\theta R^H - (1-\pi)\Lambda}.$$

which follows from aggregating (14). Together with fixed capital supply $K^S = 1$, this immediately implies the equilibrium price of capital in (18). Banks are indeed behaving optimally iff $Q^* \le \bar{Q}$ by Lemma 4, which, with a little bit of algebra, can be shown to hold iff $\pi \ge \overline{\pi}$, as required.

To prove uniqueness, suppose there is a different equilibrium, in which fraction $\zeta < 1$ of banks, measured by net worth, are risky, and the rest $1-\zeta$ are safe. Aggregate demand for capital is given by

$$K^D = \frac{\zeta N}{Q - \pi\theta R^H - (1-\pi)\Lambda} + \frac{(1-\zeta)N}{Q - \pi\theta R^L - (1-\pi)R^L}. \tag{A.5}$$

Combined with equilibrium condition $K^D = K^S \equiv 1$, it is straightforward to show that equilibrating price Q is an increasing function of ζ. So in this other equilibrium price of capital is below Q^* found in (18), and thus also below $\bar{Q}$. But then all banks would strictly prefer risky strategy by Lemma 4, a contradiction.

b. To show that it is indeed an equilibrium outcome, first note that because equilibrium price is $\bar{Q}$, individual banks are indifferent between safe and risky strategy. Combining (17) with aggregate demand in (A.5) and market clearing condition, it is straightforward to show that $\bar{Q}$ is indeed the equilibrating price when exactly fraction ζ^* of banks (measured by net worth) choose risky level of deposits.

   There are multiple equilibria, since there are numerous strategy profiles, pure and mixed, that result in fraction ζ^* of banks choosing risky level of deposits. The equilibrium aggregate outcome described in the proposition, however, is unique. There is no equilibrium in which more than fraction ζ^* of banks chose risky level of deposits, since that would lead to more financing and higher capital price in period 0, but then all banks would strictly prefer to be safe. Similarly, there is no equilibrium in which less than fraction ζ^* of banks end up choosing risky strategy, because that would imply lower capital price and all banks preferring risky strategy.

c. When $\pi \leq \underline{\pi}$, there is no equilibrium in which any of the banks end up being risky. Firstly, when $\pi \leq \ddot{\pi}$, all banks are safe by Lemma 4. Secondly, if such an equilibrium where to exist when $\pi \in (\ddot{\pi}, \underline{\pi}]$, the demand for capital would be given, again, by (A.5). But then it is straightforward to verify that equilibrating capital price would always exceed $\bar{Q}$ whenever $\zeta > 0$. But then all banks would strictly prefer being safe, a contradiction.

Q.E.D.

Proof of Proposition 2. We are going to proceed with the proof as follows. First, we derive the condition (19), which the condition under which the regulator implements supervision policy when the probability of high state is $\underline{\pi}$. Second, we demonstrate that if the condition (19) is satisfied, there exist π_1, π_2, with $\pi_1 < \underline{\pi} < \pi_2 < 1$, such that banks are supervised iff $\pi \in (\pi_1, \pi_2)$. Lastly, we show that it is never optimal for the regulator to supervise banks if it is not optimal to do so when $\pi = \underline{\pi}$, i.e. (19) does not hold.

Without bank supervision, the equilibrium price of capital is

$$Q^*(\pi) = \begin{cases} \min\left\{N + \theta[\pi R^H + (1-\pi)R^L], \pi R^H + (1-\pi)R^L\right\} & \text{if } \pi \leq \dot{\pi} \\ \min\left\{N + \pi\theta R^L + (1-\pi)R^L, \pi R^H + (1-\pi)R^L\right\} & \text{if } \pi \in (\dot{\pi}, \underline{\pi}] \\ \bar{Q}(\pi) & \text{if } \pi \in (\underline{\pi}, \overline{\pi}) \\ N + \pi\theta R^H + (1-\pi)\Lambda & \text{if } \pi > \overline{\pi}, \end{cases} \tag{A.6}$$

where the last two cases are already given in Proposition 1. The first two follow from either: (1) aggregating capital demand in Lemma 2 and combining it with market clearing condition, under the assumption that banks are constrained and exhaust their financing capacity, or (2) the maximum price that unconstrained banks would pay for capital, $\mathbb{E}[R^S] = \pi R^H + (1-\pi)R^L$, whichever is *smaller*. It is straightforward to verify that $Q^*(\pi)$ is continuous on $[0,1]$.

When policy is implemented, the price of capital is simply

$$Q_p(\pi) = \min\left\{N + \theta\chi[\pi R^H + (1-\pi)R^L], \chi[\pi R^H + (1-\pi)R^L]\right\}. \tag{A.7}$$

The first term in the min operator again follows from the capital market clearing condition assuming banks are constrained and exhaust their financing capacity. The second term caps the equilibrating price at the maximum level that unconstrained banks would pay for capital when the policy is implemented, $\chi\mathbb{E}[R^S]$. $Q_p(\pi)$ is an increasing and continuous function on $[0,1]$.

At $\pi = \underline{\pi}$, banks are constrained and so $Q^*(\underline{\pi}) = N + \underline{\pi}\theta R^L + (1-\underline{\pi})R^L$. The household-friendly regulator will find it optimal to supervise banks if and only if $Q_p(\underline{\pi}) > Q^*(\underline{\pi})$, from which the condition (19) follows.

Suppose the condition (19) is satisfied, and $Q_p(\underline{\pi}) > Q^*(\underline{\pi})$. Then there is $\pi_1 \in (\dot{\pi}, \underline{\pi})$ s.t. $Q_p(\underline{\pi}) > Q^*(\pi)$ when $\pi \in (\pi_1, \underline{\pi}]$, but $Q_p(\underline{\pi}) \leq Q^*(\pi)$ when $\pi \leq \pi_1$. This follows by recognizing that $Q^*(\pi) > Q_p(\pi)$ when $\pi \leq \dot{\pi}$ or when banks are unconstrained and $Q^* = \mathbb{E}[R^s]$. Therefore, we can only have $Q_p(\pi) > Q^*(\pi)$ in the region where $Q^*(\pi) = N + \pi\theta R^L + (1-\pi)R^L$, which is a decreasing function of π, and so must intersect $Q_p(\pi)$ at a single point, π_1.

There is also $\pi_2 \in (\underline{\pi}, 1)$ s.t. $Q_p(\underline{\pi}) > Q^*(\pi)$ when $\pi \in [\underline{\pi}, \pi_2)$, but $Q_p(\underline{\pi}) \leq Q^*(\pi)$ when $\pi \geq \pi_2$. This follows because, firstly, $Q_p(\pi)$ must cross $Q^*(\pi)$ at least once, since it is easy to verify that $Q^*(1) > Q_p(1)$. Secondly, once $Q_p \leq Q^*$ at some $\hat{\pi} > \underline{\pi}$, then $Q_p(\pi) \leq Q^*(\pi)\ \forall \pi \in [\hat{\pi}, 1]$. Let us now show the latter.

First, it is straightforward to see that if $Q_p \leq Q^*$ at some $\hat{\pi} \in [\underline{\pi}, \overline{\pi}]$, then $Q_p(\pi) \leq Q^*(\pi)\ \forall \pi \in [\hat{\pi}, \overline{\pi}]$. This is because on the interval $[\underline{\pi}, \overline{\pi}]$, $\bar{Q}(\pi)$ is a linear function with a slope greater than $R^H - \Lambda$, and so always greater than the slope of $Q_p(\pi)$, which is at most $\chi(R^H - R^L)$. Next, we also have that if $Q_p \leq Q^*$ at $\hat{\pi} \in [\overline{\pi}, 1]$, then $Q_p(\pi) \leq Q^*(\pi)\ \forall \pi \in$

$[\overline{\pi}, 1]$. This is straightforward to see if, when supervised, banks are constrained in equilibrium at $\hat{\pi}$ and so $Q_p(\pi) = N + \theta\chi[\pi R^H + (1-\pi)R^L]$ on $[\hat{\pi}, 1]$, which again has lower slope than that of Q^*. If, when supervised, banks are unconstrained at $\hat{\pi}$, then $Q_p(\hat{\pi}) = \chi[\hat{\pi}R^H + (1-\hat{\pi})R^L]$. With a bit of algebra, we can verify, however, that $Q_p(\hat{\pi}) \leq Q^*(\hat{\pi})$ at this point also implies that $N + \theta\chi[\hat{\pi}R^H + (1-\hat{\pi})R^L] < Q^*(\hat{\pi})$.[31] This, in turn, implies that Q_p cannot possibly exceed Q^* as π increases.

Taken together, the above implies that the regulator supervises banks iff $\pi \in (\pi_1, \pi_2)$ when (19) holds.

The above considerations about the behaviour of the functions $Q^*(\pi)$ and $Q_p(\pi)$ also lead us to conclude that there is no π at which the regulator would find it optimal to supervise banks when the condition (19) is not satisfied. As $Q_p \leq Q^*$ at $\underline{\pi}$, it must be the case that $Q_p \leq Q^*$ when $\pi < \underline{\pi}$, since even in the region where banks are constrained and $Q^*(\pi) = N + \pi\theta R^L + (1-\pi)R^L$, $Q^*(\pi)$ increases and $Q_p(\pi)$ falls when π decreases below $\underline{\pi}$. Similarly, $Q_p \leq Q^*$ at $\underline{\pi}$ implies that $Q_p(\pi) \leq Q^*(\pi)\ \forall \pi > \underline{\pi}$. *Q.E.D.*

[31] Using $Q_p(\hat{\pi}) \leq Q^*(\hat{\pi})$, it follows that $N + \theta\chi[\hat{\pi}R^H + (1-\hat{\pi})R^L] < Q^*(\hat{\pi})$ whenever $\theta N < (1-\theta)[\hat{\pi}\theta R^H + (1-\hat{\pi})\Lambda]$. The right-hand-side of the last inequality increases in $\hat{\pi}$. This inequality holds, however, even when $\hat{\pi} = \overline{\pi}$, which can be verified by substituting in $\overline{\pi}$ from Proposition 1 and rearranging.