

# DOES SIZE MATTER? BAILOUTS WITH LARGE AND SMALL BANKS\*

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## Abstract

This paper studies how large and small banks make funding decisions in an equilibrium model in which the government provides system-wide bailouts to the financial sector. We show that bank size, purely on strategic grounds, is a key determinant of banks' leverage choices, even when bailout policies treat large and small banks symmetrically. Large banks always take on more leverage than small banks because they internalize that their decisions directly affect the government's optimal bailout policy. In equilibrium, each small bank also chooses strictly higher borrowing when large banks are present, since banks' leverage choices are strategic complements. Overall, the presence of large banks increases aggregate leverage and the size of bailouts. The optimal ex-ante regulation features size-dependent policies that disproportionately restrict the leverage choices of large banks. A quantitative assessment shows that our model is consistent with differences in the behavior of large and small U.S. banks. An increase from 50% to 80% in the share of assets held by the 5 largest banks is associated with a 25% increase in leverage ratios (from 10 to 12.5). Under the optimal policy, large banks face a Too-Big-To-Fail tax on their borrowing of 0.5%.

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*A surprising number of pundits seem to think that if one could only break up the big banks, governments would be far more resilient to bailouts, and the whole “moral hazard” problem would be muted. That logic is dubious, given how many similar crises have hit widely differing systems over the centuries. A systemic crisis that simultaneously hits a large number of medium-sized banks would put just as much pressure on governments to bail out the system as would a crisis that hits a couple of large banks.*

Kenneth Rogoff. All for One Tax and One Tax for All? Project Syndicate, 04/29/2010

## 1 Introduction

The differential treatment of large financial institutions has drawn substantial interest in recent financial regulatory discussions. In particular, several regulatory measures put in place after the 2008 financial crisis have singled out large banks as subjects of increased regulatory scrutiny. At the same time, the US banking industry has become increasingly concentrated, as illustrated in Figure 1. The total number of US banks has dropped from 14,000 in the 1970’s to less than 6,000 as of today, while the top 10 bank holding companies now control more than 50% of total bank assets. These developments suggest that concerns about too-big-to-fail banks are now more important than ever before.

Even though the too-big-to-fail question has been a perennial subject of heated public debates – see, for instance, the forceful exposition of Stern and Feldman (2004) – the number of formal contributions to this topic remains small. In this paper, we formally study the effects of bank size on bank’s funding decisions in an environment with systemic bailouts. From a positive perspective, we seek to understand whether the current levels of bank concentration have consequences for aggregate banking stability. From a normative perspective, we seek to understand whether regulators need to directly address bank concentration *per se*, or whether size-independent regulations that apply to all banks are sufficient. We address both sets of questions theoretically and provide a quantitative illustration of the mechanisms at play.

A simple example illustrates the underlying mechanism behind our results. Is the government’s decision problem different when it contemplates a bailout of 10 banks of size one versus a bailout of one bank of size 10? If we assume that the losses associated with bank failure are proportional to bank size, the naive answer to this question, from an ex-post perspective, is no. This can be called the too-many-to-fail critique to the too-big-to-fail problem, or the “clones” property of bailouts – see our opening quotation and the quotations reproduced in the Appendix for different formulations of this logic. The problem with this argument is that large banks are aware that their individual choices directly affect the likelihood and size of a bailout, while small banks are individually unable to modify bailout policy responses. Therefore, anticipating the

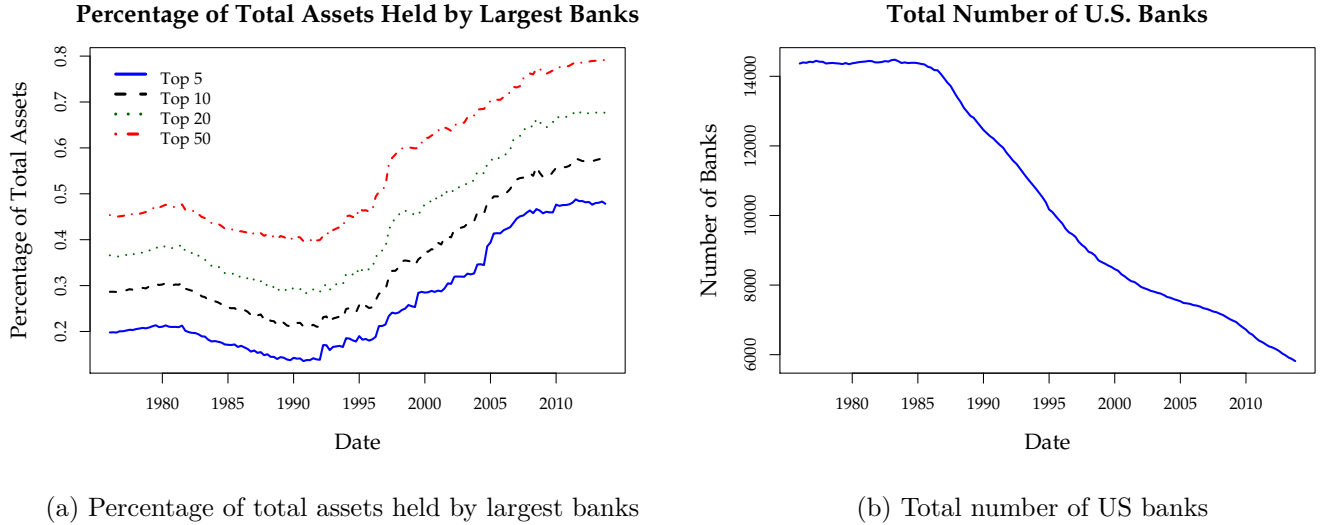


Figure 1: Measures of bank concentration

**Note:** Figure 1a shows the share of total assets held by the 5, 10, 20, and 50 largest US banks in terms of assets from 1976Q1 until 2013Q4. Figure 1b shows the total number of US banks each year over the same period. Note that the secular increase in concentration reaches back further. The US economy had more than 25,000 banks in the 1920's; see, e.g., Davison and Ramirez (2014). Both figures are based on US Call Reports data, as distributed by Drechsler, Savov and Schnabl (2016, 2017). See also Janicki and Prescott (2006) and Fernholz and Koch (2016), who study the dynamics of the distribution of bank's assets and document the sustained increase in concentration in the US banking sector over the last decades. Bank concentration in other countries is even higher than in the US – see Figure 2 of Laeven, Ratnovski and Tong (2014).

government's policy response and internalizing the effect of their size, large banks decide to be more aggressive at an ex-ante stage, increasing their leverage in equilibrium and, consequently, the likelihood of a bailout. Moreover, this effect is amplified by strategic spillovers to small banks. Aggressive leverage by large banks increases the implicit bailout subsidy for the banking sector as a whole. Small banks, encouraged by this shield, respond by increasing their leverage beyond what they would optimally choose in the absence of large banks.

In our model, banks optimally choose their leverage trading off bankruptcy costs associated with default with costs of equity issuance, as in the canonical trade-off theory of capital structure.<sup>1</sup> Ex-post, to avoid bankruptcy costs, the government may find it optimal to bail

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<sup>1</sup>Our results remain valid under alternative theories of bank capital structure, as long as a meaningful trade-off between bank equity and debt finance remains. Our results arise from market participants anticipating system-wide bailouts, not from the specifics of the private costs and benefits of leverage.

out banks but, as in Farhi and Tirole (2012), it has to implement system-wide bailout policies.<sup>2</sup> To highlight the strategic role of bank size, we make two conservative assumptions. First, banks have constant returns to scale, so that they are ex-ante identical with the exception of their size. Second, the government decides its bailout policy considering all banks equally, that is, the government’s objective is simply to minimize aggregate welfare losses, regardless of whether large or small institutions generate these losses. These assumptions guarantee that a too-many-to-fail scenario, in which multiple small banks fail, can provide as strong a motivation for a bailout as the failure of a single large institution of equal size.

Our first result shows that a large bank takes on more leverage than a small bank, purely on strategic grounds. Relative to a small bank, a large bank internalizes that its actions directly affect the size of the government’s optimal bailout, which generates an additional incentive to take on debt. Our second result establishes that small banks take on more leverage when a large bank is present. This arises because bank’s borrowing choices are strategic complements. Intuitively, when choosing their capital structure ex-ante, banks anticipate that, ex-post, the size of any bailout increases with aggregate leverage. When other banks increase their leverage, each individual bank rationally anticipates larger bailouts, which provide an effective shield against bankruptcy costs and increase the marginal value of increasing its own leverage. Thus, leverage choices become strategic complements, introducing a coordination motive among banks.<sup>3</sup> Because large banks have an additional incentive to take on more leverage, their presence makes small banks more willing to borrow. This strategic interaction generates amplification: large banks take on yet more leverage in response to small banks’ choices, small banks respond with a further round of increased borrowing, and so forth, until convergence. These effects arise even though bank managers do not directly exploit government bailouts. Instead, the incentive to take leverage is driven by managers’ interaction with competitive capital markets, which value bank debt more generously when expected bailouts are larger.

When combined, our results about the behavior of large and small banks imply that system-

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<sup>2</sup>Farhi and Tirole (2012) show that even when richer targeted instruments are available, as long as the government does not perfectly observe the performance of each individual bank, the optimal policy is partially non-targeted, generating strategic complementarities. In a related environment, Bianchi (2016) shows that systemic and broad-based bailouts dominate idiosyncratic and targeted bailouts. Kelly, Lustig and Van Nieuwerburgh (2016) provide direct empirical evidence consistent with market participants that expect system-wide bailouts to occur.

<sup>3</sup>As in Farhi and Tirole (2012), this coordination motive opens the door to multiple equilibria. Our main results do not rely on uniqueness of equilibrium. Using tools from monotone comparative statics (e.g. Milgrom and Shannon, 1994), we can characterize the differential roles of large and small banks regardless of which equilibrium is selected. In our quantitative assessment, however, we find a unique equilibrium for a wide range of reasonable parameter values.

wide leverage is higher in an economy in which large banks are present. Our results predict that all banks, large and small, take more leverage and default more frequently, also implying the the government relies on bailouts more frequently than when banks are small. We show that an increase in bank size is associated with a leverage multiplier that increases the quantitative significance of this mechanism.

After establishing the positive predictions of bank size for the behavior of banks, we characterize the optimal ex-ante bank regulation. First, we show that when the government implements a constrained efficient outcome, all banks, large and small, choose the same level of leverage. This result implies that the optimal ex-ante regulation in terms of quantities, which can be implemented through binding capital requirements, is identical for large and small banks. Subsequently, we show that the optimal regulation can be equivalently implemented with size-dependent Pigouvian taxes. Large banks are charged a supplement tax on borrowing, which counteracts their incentive to increase leverage so as to maximize government subsidies. Our normative results provides a formal rationale to regulate large banks differently from small banks, simply because of their size. Our results further imply that there is a natural complementarity between financial regulation and policies that directly control industry structure (i.e., antitrust policy, merger regulation, etc.).

Although stylized, our model can be directly calibrated. To quantitatively assess the mechanisms studied in the paper, we illustrate the predictions of our model when selecting parameters consistent with US data over the period 1976Q1 to 2014Q4. We find that our model is able to rationalize the differences in leverage between large and small banks observed in reality.

We use the quantitative results of the model as a laboratory to study the effects of industry concentration. We find an increasing and convex relation between the leverage choices of large and small banks and the degree of industry concentration. We show that moderate increases in industry concentration starting from the status quo, in which the Top 5 largest banks hold roughly half of total bank assets, are associated with substantial increases in leverage by large and small banks. In particular, an increase from 50% to 80% in the share of assets held by the 5 largest banks is associated with a 25% increase in leverage ratios (from 10 to 12.5).

Finally, with the goal of guiding policymakers on the size of optimal corrective policies, we also compute the associated Too-Big-To-Fail taxes implied by the optimal policy. Under the optimal ex-ante policy, large banks face a Too-Big-To-Fail tax of 0.5% in terms of debt to assets for the current levels of concentration, over and above the Pigouvian levy that is charged to small banks. This optimal Too-Big-To-Fail tax increases up to roughly 1% if the share of assets held by the 5 largest banks reaches 80%.

**Related Literature** This paper is most closely related to the growing literature that studies the implications of bank bailouts, and other system-wide government interventions in financial crises. The core idea underlying both earlier and most recent contributions, including those of Holmstrom and Tirole (1998), Freixas (1999), Schneider and Tornell (2004), Acharya and Yorulmazer (2007), Diamond and Rajan (2011), Farhi and Tirole (2012), Bianchi (2016), Keister (2016), Nosal and Ordoñez (2016), Chari and Kehoe (2016), Bianchi and Mendoza (2017), and Gourinchas and Martin (2017) is that the lack of government’s commitment regarding ex-post optimal policies modifies the ex-ante behavior of banks, a phenomenon that is often described as moral hazard.

The strategic problem faced by banks in our model is most closely related to that in Farhi and Tirole (2012), who identify the strategic complementarity caused by systemic, non-targeted bailouts. They refer to this behavior as collective moral hazard. While our results build on theirs, we focus on size asymmetries, while they exclusively study an environment with symmetric (small) agents. Bianchi (2016) shows that non-targeted and systemic bailouts are preferred to targeted ones, since the latter exacerbate banks’ ex-ante responses (moral hazard), and provides a full-fledged macroeconomic calibration. Our results clearly highlight the importance of size asymmetries in a similar environment.

Only a few papers refer to size asymmetries in the context of bank bailouts. Freixas (1999) rationalizes the presence of too-big-to-fail policies, through which a regulator responds more strongly to the actions of large banks, if the costs associated with bank failure are increasing in bank size. Acharya and Yorulmazer (2007) formalize the too-many-to-fail argument, showing that multiple failures by small banks can generate an identical bailout response as the failure of a single large bank. By design, our environment captures the too-many-to-fail effect. In their extension with asymmetric banks, the behavior of large banks does not affect the optimal bailout policy at the margin, which is crucial for our results. Nosal and Ordoñez (2016) show that uncertainty about the ex-post bailout policy can mitigate the ex-ante effects of lack of commitment, reducing the strength of strategic complementarities and consequently reducing the incentives of banks to take on excessive risk. They show that this effect is weakest for large banks. The thorough reviews of Freixas and Rochet (2008) and Gorton and Winton (2003) do not discuss the effect of bank size on banks’ funding decisions.

In general, this paper belongs to the large literature that studies strategic complementarities and coordination games. In these environments, when complementarities are sufficiently strong, there exists the possibility of multiple equilibria, as emphasized by Cooper and John (1988) and Angeletos and Lian (2016). Our main results remain valid regardless of whether there is a unique equilibrium: we exploit monotone comparative statics tools to make claims that hold in

*any* equilibrium. Within that line of work, purely from a strategic viewpoint, our results are most closely related to the work by Corsetti et al. (2004), who study the effect of a large speculator in a canonical currency attack global game framework. They provide conditions under which the presence of a large agent makes coordination easier. Despite the many modeling differences between their paper and ours — their model features a binary action game with dispersed information — our paper, as theirs, solves a model with strategic complementarities with agents of different sizes.<sup>4</sup> Also related is the work by Sakovics and Steiner (2012), who show that policy interventions, in coordination games among small agents, ought to be targeted towards players whose choices have a large impact on others’ incentives. Similarly, it is optimal in our model to target macroprudential taxes at large banks, whose leverage choices generate large spillovers to other banks.

Within the sizable quantitative literature, the work of Cuciniello and Signoretto (2015) – see also Corbae (2015) – studies the effects of banks size in the context the the model of Corbae and Derasmo (2010), who provide a detailed quantitative analysis of banking dynamics in a strategic environment. Our quantitative results abstract from several of the features emphasized in this line work to highlight the effects of system-wide guarantees.

Finally, within the small but growing empirical literature that seeks to directly quantify the effects of bank size and government guarantees, the work of Kelly, Lustig and Van Nieuwerburgh (2016) is most relevant. By comparing the price of out-of-the-money put options on individual banks with the price of identical options on a bank index, they present evidence consistent with market participants who expect substantial collective government guarantees, which is the starting point of our theory.

**Outline** Section 2 describes the environment and Section 2.1 characterizes the equilibrium, introducing our main positive results. Section 3 conducts the normative analysis and Section 4 describes the implication of our results for policymaking. Section 5 provides a quantitative illustration of our results and Section 6 concludes. The Appendix contains all proofs and technical derivations.

## 2 Environment

Our model provides a parsimonious framework to study banks’ borrowing decisions in the presence of government bailouts and heterogeneity in banks’ size. We first describe the economic environment and then discuss our modeling assumptions in a series of remarks.

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<sup>4</sup>Recent work by Kacperczyk, Nosal and Sundaresan (2017) studies the effect of large players in a model of financial market trading and information acquisition.





A contentious issue is whether the costs of equity are private or social costs. We do not take a stand in this debate and allow for either case. We therefore assume that  $\bar{\psi}(u + t^i - b^i)$  dollars are reimbursed to financiers as a lump sum if the bank does not default, where  $0 \leq \bar{\psi} \leq \psi$ . The boundary case  $\psi = \bar{\psi}$  corresponds to purely private costs, for example arising from tax considerations, while  $\psi < \bar{\psi}$  implies that the private costs of bank equity issuance are also social costs.

Notice that returns, as well as the costs of distress and equity issuance, exhibit constant returns and are independent of bank size. This allows us to define all bank-level (lower-case) variables *per unit of capital*. For example, a large bank that manages a point mass  $\mu(i) > 0$  share of capital issues debt with face value  $\mu(i)b^i$ , earns a return  $\mu(i)u$  and receives  $\mu(i)t^i$  from the government. A subset  $S$  of small banks collectively issue debt with face value  $\int_S b^i d\mu$ , earn returns  $u\mu(S)$  and receive transfers  $\int_S t^i d\mu$ . We can express aggregates of bank level variables  $a^i$  as the Lebesgue integral  $\int_0^1 a^i d\mu$ .<sup>7</sup>

**Government policy** The existence of deadweight losses associated with bank failure provides a rationale for a benevolent government to bail out banks at date 1. Formally, we allow the government to transfer funds to banks under the following three assumptions.

First, we assume that government transfers cannot be conditioned on bank characteristics. This assumption captures the fact that many bank support policies are provided to the banking system as a whole, and cannot be perfectly targeted to distressed banks, as established in [Farhi and Tirole \(2012\)](#). Second, we assume that the government must decide on the level of the bailout transfer with imperfect information about the realization of the aggregate state. Formally, the government chooses a transfer  $t(s)$  contingent on a signal  $s$  about the realization of aggregate returns  $u$ . Hence, each bank  $i$  receives a transfer  $t^i = t(s)$  per unit of capital. This assumption captures that bailout policies are often determined under uncertainty about fundamentals. From a formal standpoint, it guarantees that the problem solved by banks is smooth. Finally, we assume that government transfers are associated with a net deadweight loss of  $\kappa(t)$  dollars, where  $\kappa(t)$  is a weakly increasing and convex function that satisfies  $\lim_{t \rightarrow \infty} \kappa(t) = \infty$ . This deadweight loss of intervention can be literally interpreted as a fiscal distortion.<sup>8</sup> This assumption limits the size of the optimal transfer chosen by the government.

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<sup>7</sup>The Lebesgue notation is convenient since we can include large and small banks in one integral. For an illustration, suppose there is one large bank  $i = 0$  with point mass  $\mu(i) = \lambda$ , and all  $i > 0$  form a continuum of identical small banks with mass  $1 - \lambda$ . Then the aggregate of a variable  $a^i$  is  $\int_0^1 a^i d\mu = \lambda a^0 + (1 - \lambda) \int_{i>0} a^i di$ , where the second term is the standard (Riemann) integral over small banks.

<sup>8</sup>A broader interpretation of  $\kappa(t)$  not only captures the slack of the fiscal capacity of the government, but it can also capture the “type” of the government: hawkish vs. dovish, as in [Diamond and Rajan \(2012\)](#), among others.

Asset returns and government signals are drawn according to a joint distribution  $F(u, s)$ . We write  $F_u(u|s)$  for the conditional distribution of asset values, with density  $f_u(u|s)$ , and  $G(s)$  for the marginal distribution of signals, with density  $g(s)$ .

We impose a mild regularity condition that prevents the conditional c.d.f.  $F_u(u|s)$  from changing too quickly. Formally, we assume that the conditional density of asset returns satisfies the following condition for all marginal default states  $u = b^i - t$ :

$$\frac{d \log f_u(u|s)}{d \log u} = \frac{u f'_u(u|s)}{f_u(u|s)} > -1, \quad \forall s. \quad (1)$$

Intuitively, enough noise is necessary to preserve the smoothness of the capital structure problem faced by banks. As we show in the Appendix, when signals are normally distributed, a high enough variance for the signal  $s$  is a sufficient condition for Equation (1) to hold over the relevant region.

**Equilibrium definition** An equilibrium is defined as a set of bank capital structure decisions  $b^i$  and default decisions, prices for bank debt  $q^i$  and equity  $e^i$ , and a government bailout policy  $t(s)$ , such that (i) banks maximize their market value net of issuance costs, given the behavior of other banks and the government, (ii) financiers break even when purchasing debt or equity, and (iii) the government maximizes ex-post welfare at date 1 given their signal.

## Remarks on the environment

Our assumptions are geared towards studying an environment in which banks have endogenous funding and default choices and government policies arise endogenously from a well-defined government’s objective. Some of the assumptions deserve further discussion.

**Remark 1: Differences between large and small banks.** By design, in this paper, the differences between large and small banks are strategic rather than technological. Banks’ technology features constant returns to scale and government bailouts are not targeted at large banks. This allows us to speak to the “too many to fail” argument. In this paper, whether a single large bank or many small banks are in distress is irrelevant *ex-post*.<sup>9</sup>

Moreover, in the context of our paper, identical technologies are a conservative assumption. Indeed, we argue that the presence of large banks renders the financial system riskier. If policy-

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<sup>9</sup>This assumption is in line with recently developed empirical metrics of systemic risk, such as CoVaR (Adrian and Brunnermeier, 2016). CoVaR is defined so that many small banks generate the same measure of ex-post distress as one large bank, holding constant their asset exposures and leverage. Adrian and Brunnermeier (2016) further show that bank size predicts high contributions to CoVaR in the US data. This is consistent with the equilibrium prediction of our model, since larger banks choose higher leverage and contribute more to systemic risk.

makers provided implicit guarantees to large banks but not to small ones – as would occur, for example, if we allowed the marginal cost of default  $(1 - \phi)$  to be bank specific and increasing in bank size – this effect would be strengthened. Similarly, all banks in our setup choose their leverage simultaneously, so that large banks have no timing advantage. This assumption removes herding and signaling effects in the presence of large banks, which would also strengthen our conclusions. Our key point is, therefore, that policy bias or timing advantages are not necessary for large banks to be important: size matters purely for strategic reasons.

We focus on the role of size as the single dimension of heterogeneity across banks. Banks may differ on their degree of interconnectedness in the form of network centrality, their exposure to or realization of idiosyncratic shocks, or in richer dimensions regarding liquidity risk or maturity mismatch. While these are important factors, they are unlikely to change our main results, since ex-post government responses continue to induce strategic complementarities even when there is additional heterogeneity. *Ceteris paribus*, the presence of large banks then continues to lead to increased risk taking.

***Remark 2: Systemic bailouts and noisy signals.*** Bailouts in our model are systemic and not targeted, which is consistent with the evidence in Kelly, Lustig and Van Nieuwerburgh (2016). This assumption is relevant in the sense that it generates strategic complementarities among banks. Targeted transfers can be introduced to the model, and our results go through as long as some strategic complementarities remain, which occurs in a wide class of settings. In particular, while we focus on monetary transfers for concreteness, the interpretation of ex-post government intervention can be broader, and strategic complementarities arise naturally if the government could intervene by lowering interest rates below their otherwise optimal level (a policy often referred to as the “Greenspan put”) or by conducting asset purchase and lending programs such as TARP or TALF. Even if targeted instruments were available, Farhi and Tirole (2012) have shown that strategic complementarities remain as long as the government does not perfectly observe the performance of each individual bank.

Finally, even if we allowed transfers to be targeted *ex-post*, it is not obvious that policy is anticipated perfectly *ex-ante*. If a large bank A fails and the government decides to conduct a targeted bailout, it can either provide a subsidy directly to bank A or a subsidy to bank B in order to purchase A’s assets. The various proposals tabled before the failures of Lehman Brothers and Bear Stearns in 2008 are a case in point. If it is unclear which exact policy option the government will pursue *ex-post*, strategic complementarities will remain *ex-ante*. Indeed, ex-ante ambiguity may be an optimal arrangement: Nosal and Ordoñez (2016), for example, argue that constructive ambiguity is valuable when governments conduct bailouts but lack commitment. This point further motivates our assumption that bailouts are noisy; the

government does not know the exact realization of the common shock when choosing its policy at date 1. As well as generating constructive ambiguity, this assumption provides smoothness in the bank’s optimization problem, which facilitates the exposition.

***Remark 3: Banks’ capital structure and institutional setting.*** Although we have adopted a classic trade-off theory formulation, in which bankers have a meaningful source of outside equity, to determine bank funding choices, alternative assumptions that generate a well-defined capital structure decision do not modify the insights of the paper. For example, the trade-off between bank debt and equity could be driven by concerns about moral hazard among shareholders, a desire to create “money-like” and information-sensitive claims (Gorton and Pennacchi, 1990; Stein, 2012; DeAngelo and Stulz, 2015), or concerns about bank runs and market discipline as in Diamond and Rajan (2001). Our results merely rely on the presence of strategic complementarities, which arise from the non-targeted bailout, with heterogeneity in bank sizes.

Furthermore, the financial institutions in our model need not be interpreted as traditional banks. Indeed, they could represent any segment of the financial sector and the “shadow banking” system, as long as widespread defaults cause social costs and induces the government to provide support. This observation also motivates our choice to abstract from (insured or uninsured) demand deposit contracts and focus on leverage choices more generally. More generally, the results of this paper can be adapted to other sectors of the economy in which government bailouts occur.

Finally, note that bank managers in our model act as a veil and are solely motivated by the maximization of bank value, or equivalently, by the desire to reduce banks’ cost of funds. Therefore, our results do not assume that bank managers are ill-intentioned or that they directly have to form expectations of bailout probabilities and government policy, it is sufficient if market participants do so.

## 2.1 Equilibrium characterization

We characterize the equilibrium of the model backwards in multiple steps. First, we characterize the ex-post optimal government policy. Next, we determine banks’ default decisions at date 1 and their date 0 market value for a given government policy. Finally, we study banks’ ex-ante funding decisions at date 0.

## Ex-post optimal bailout policy

At date 1, the government observes the signal  $s$  of asset values and chooses transfers  $t$  to maximize expected social welfare. Given banks' borrowing choices  $\mathbf{b} = (b^i)_{i=0}^1$ , a choice of transfer  $t$ , and a signal  $s$ , we let  $W_1(\mathbf{b}, t|s)$  denote expected social welfare from the perspective of date 1.

In our model, date 1 welfare corresponds to the sum of aggregate resources:

$$\begin{aligned} W_1(\mathbf{b}, t|s) &= \mathbb{E}[u|s] - \kappa(t) \\ &\quad - (1 - \phi) \int \Pr[\mathcal{D}^i|s] \mathbb{E}[u|\mathcal{D}^i, s] d\mu \\ &\quad - (\psi - \bar{\psi}) \int \Pr[\mathcal{N}^i|s] \mathbb{E}[t + u - b^i|\mathcal{N}^i, s] d\mu. \end{aligned} \quad (2)$$

The interpretation of Equation (2) is intuitive. The first line captures the present value of banks' assets and deadweight costs of taxation. The second and third lines respectively measure the deadweight costs of bank failure and equity issuance. Note that the latter accounts for the possibility that the costs of equity are partly or exclusively private costs when  $\bar{\psi} > 0$ .

Hence, the government's optimal bailout policy after observing the signal  $s$  is to maximize expected welfare. It corresponds to

$$t(\mathbf{b}|s) = \arg \max_{t \geq 0} W_1(\mathbf{b}, t|s). \quad (3)$$

The optimal bailout policy  $t(\mathbf{b}|s)$  is characterized by the following first-order condition:

$$(1 - \phi) \int f_u(b^i - t|s) (b^i - t) d\mu \leq \kappa'(t) + (\psi - \bar{\psi}) \int \Pr[\mathcal{N}^i|s] d\mu, \quad (4)$$

which is satisfied with equality when the optimal  $t$  is strictly positive. Intuitively, the left-hand side in Equation (4) measures the marginal benefit of transfers, which equals the marginal reduction in default costs. The right-hand side measures the marginal cost of the bailout which consists of two terms. First, the government incurs the direct marginal cost of taxation  $\kappa'(t)$ . Second, an indirect cost arises when a bailout is conducted but the bank remains solvent. In this case, the bailout constitutes a transfer to shareholders, who derive a lower marginal utility from this transfer due to the social costs  $(\psi - \bar{\psi})$  of equity.<sup>10</sup> This second term only matters whenever bank  $i$  is solvent, which occurs with conditional probability  $\Pr[\mathcal{N}^i|s]$ . In the empirically relevant region where public news  $s$  are bad, this probability is low, and therefore bailouts are driven largely by the trade-off between the benefit of preventing bank failure and the cost of taxation.

The government's optimal response illustrates the key difference between small and large banks. A small bank's choice  $b^i$  has no impact on the integral in (4), and therefore no impact on

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<sup>10</sup>This indirect cost is absent if we assume that the costs of equity issuance are sunk at date 0. Assuming that these costs are paid ex-post clarifies the exposition, but does not materially affect our qualitative results.

ex-post optimal transfers. But if bank  $j$  is large – with point mass  $\mu(j)$  – and the government chooses a strictly positive transfer,  $t(\mathbf{b}|s) > 0$ , after receiving a signal  $s$ , a marginal change in the large bank borrowing position  $b^j$  increases the optimal transfer, since

$$\frac{\partial t(\mathbf{b}|s)}{\partial b^j} \stackrel{\text{sign}}{=} \left[ f'_u(b^j - t|s)(b^j - t) + f_u(b^j - t|s) + \frac{\psi - \bar{\psi}}{1 - \phi} f_u(b^j - t|s) \right] \Big|_{u=b^j - t(\mathbf{b}|s)} > 0, \quad (5)$$

where the inequality is implied by our regularity condition. The formal derivation of (5) is in the Appendix, but the economics are clear. If a large bank takes more leverage, all else equal, the failure of this bank becomes more likely after adverse realizations of the public signal  $s$ . Therefore, to reduce the deadweight losses associated with bank failure, the government decides in favor of a larger bailout.

### Banks' default decision and date 0 market value

At date 1, given a realization of banks' aggregate return  $u$  and after the government chooses a bailout policy  $t(\mathbf{b}|s)$ , a bank  $i$  defaults on its debt whenever  $u + t(\mathbf{b}|s) < b^i$ , and repays otherwise. As expected, holding  $u$  and  $t(\mathbf{b}|s)$  constant, the likelihood of default increases with the level of bank borrowing  $b^i$ .

Formally, the payoff to debtholders corresponds to

$$\begin{cases} b^i, & \text{if } u + t(\mathbf{b}|s) \geq b^i \\ \phi u + t(\mathbf{b}|s), & \text{if } u + t(\mathbf{b}|s) < b^i, \end{cases} \quad (6)$$

while the payoff to shareholders corresponds to

$$\begin{cases} (1 - \psi)(u + t(\mathbf{b}|s) - b^i), & \text{if } u + t(\mathbf{b}|s) \geq b^i \\ 0, & \text{if } u + t(\mathbf{b}|s) < b^i. \end{cases} \quad (7)$$

In equilibrium, because financiers are risk-neutral, the market value of bonds  $q^i b^i$  is determined by the expected payoff to debtholders, while the market value of bank shares  $e^i$  is determined by the expected payoff to shareholders.

Therefore, taking expectations at date 0, the market value of a bank given a level of borrowing  $b^i$  and a set of possible transfers  $t(\mathbf{b}|s)$  for each signal realization  $s$ , corresponds to

$$\begin{aligned} V(b^i, t(\mathbf{b}|s)) &\equiv q^i b^i + e^i \\ &= \mathbb{E}[u + t(\mathbf{b}|s)] - (1 - \phi) \Pr[\mathcal{D}^i] \mathbb{E}[u | \mathcal{D}^i] - \psi \Pr[\mathcal{N}^i] \mathbb{E}[u + t(\mathbf{b}|s) - b^i | \mathcal{N}^i], \end{aligned} \quad (8)$$

where  $\mathcal{D}^i = \{t(\mathbf{b}|s) + u < b^i\}$  denotes the event of default and  $\mathcal{N}^i = \{t(\mathbf{b}|s) + u \geq b^i\}$  denotes the complementary non-default region. Note that expectations and probabilities in Equation (8)

account for the realizations of the return  $u$  and signal  $s$  received by the government. The value function  $V(b^i, t(\mathbf{b}|s))$  is therefore defined in terms of *all* possible realizations of these variables and of the corresponding government policy  $t(\mathbf{b}|s)$ . A detailed derivation of this function is in the Appendix. Equation (8) highlights that banks' leverage decisions are driven by competitive market forces. Bank managers do not directly benefit from government bailouts, and their objective function simply corresponds to their firm's market value at date 0. Nevertheless, markets generate implicit incentives to capture government bailouts, because the implicit subsidy is accounted for in security prices.

Equation (8), which effectively corresponds to the banks' objective function, further clarifies our previous remark on the difference between large and small banks. From a technological perspective, both large and small banks face an identical optimization problem. Large banks are different only in a strategic sense; unlike small banks, they expect their leverage choices to directly impact bailout policies  $t(\mathbf{b}|s)$  in future states of the world. Equation (8) also highlights that banks' decisions are determined through classic tradeoff theory: only its second element, which corresponds to costs of distress, and its third element, which corresponds to the costs of equity issuance, are affected directly by the choice of  $b^i$  for a given value of  $t(\mathbf{b}|s)$ .

### Banks' leverage choices

We now turn to banks' incentives when choosing their borrowing level  $b^i$  at date 0. Bank  $i$ 's problem is

$$\max_{b^i \geq 0} V(b^i, t(\mathbf{b}|s)), \text{ subject to (3)}. \quad (9)$$

The bank takes as given others' choices  $(b^j)_{j \neq i}$ , and realizes that the government will respond to the collective choice  $\mathbf{b}$  according to Equation (3). Then, it chooses its leverage  $b^i$  to maximize the joint value of debt and equity.

The first order condition for a small bank  $i$ , which takes the government policy  $t(\mathbf{b}|s)$  as given, is

$$\frac{\partial V(b^i, t(\mathbf{b}|s))}{\partial b^i} = \psi \Pr[\mathcal{N}^i] - (1 - \phi) \int_{\partial D^i} u dF = 0. \quad (10)$$

where  $\partial D^i = \{u, s | b^i = t(\mathbf{b}|s) + u\}$  is the boundary of the default region.<sup>11</sup> This expression is familiar from the canonical trade-off theory of capital structure. The first term captures the

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<sup>11</sup>Technically, the second term is defined as a "line integral", along a one-dimensional curve (i.e., along  $\partial D^i$ ) in a two-dimensional space (i.e., in the space of signals  $s$  and asset returns  $u$ ). In terms of Riemann integrals, this line integral is defined as

$$\int_{\partial D^i} J(u, s) dF(u, s) = \int_S J(b^i - t(\mathbf{b}|s), s) f(b^i - t(\mathbf{b}|s), s)$$



deadweight costs of equity issuance, which encourage higher leverage and arise whenever the bank is in the solvent region  $\mathcal{N}^i$ . The second term measures the deadweight costs of default, which discourage higher leverage.

In addition to these terms, large banks internalize the indirect effect of its leverage on the optimal bailout  $t(\mathbf{b}|s)$ , as characterized in Equation (5). Therefore, the first-order condition for a large bank  $j$  is to set the *total* derivative of its value function equal to zero:

$$\begin{aligned} \frac{dV(b^j, t(\mathbf{b}|s))}{db^j} &= \frac{\partial V(b^j, t(\mathbf{b}|s))}{\partial b^j} \\ &+ \mathbb{E} \left[ \frac{\partial t(\mathbf{b}|s)}{\partial b^j} (1 - \psi \mathbf{1}(\mathcal{N}^j)) \right] + (1 - \phi) \int \frac{\partial t(\mathbf{b}|s)}{\partial b^j} u dF = 0, \end{aligned} \quad (11)$$

where  $\mathbf{1}(\mathcal{N}^j)$  denotes an indicator function for the non-default states of bank  $j$ . Comparing (10) and (11), it follows that *ceteris paribus*, a large bank has strictly greater incentives to take leverage than a small bank, measured by the two terms on the second line of (11). First, increasing leverage strictly increases the expected government transfer  $\mathbb{E}[t(\mathbf{b}|s)]$ . To the extent that transfers are eventually distributed to shareholders, these benefits are adjusted for the deadweight costs of equity. Second, by increasing transfers, an increase in leverage  $b^j$  shifts the default boundary, reducing the bankruptcy region and consequently the deadweight losses associated with bankruptcy.

We next consider the impact of a large bank's leverage on small banks' payoffs and incentives. We show that, all else constant, small banks have greater market value, and a higher marginal incentive to borrow, when large banks borrow more.

**Lemma 1. (Effect of large bank leverage on small banks' incentives)** *Suppose that in some states a positive bailout is optimal, that is,  $t(\mathbf{b}|s) > 0$  for some  $s$ . Then for a small bank  $i$  with borrowing level  $b^i$ , denoting by  $b^j$  the leverage choice of a large bank, we have*

$$\frac{dV(b^i, t(\mathbf{b}|s))}{db^j} > 0 \quad (12)$$

$$\frac{d^2V(b^i, t(\mathbf{b}|s))}{db^i db^j} > 0. \quad (13)$$

Lemma 1 shows that both the *value* of a small bank and its *marginal benefit* from leveraging up are increasing in the leverage choices of the large bank. The first result is intuitive. If a large bank takes more leverage, the government's optimal bailout policy is more generous. Financiers are now willing to pay more for claims on a small bank at date 0, because they expect to benefit from a higher bailout at date 1. Thus, other things equal, the market value of a small bank increases, which explains Equation (12)

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for any function  $J(u, s)$ , where  $\mathcal{S}$  denotes the support of signals.



The second result in Equation (13) shows that banks' payoffs are supermodular in each others' borrowing choices. The economic implication of supermodularity is that banks' leverage decisions become *strategic complements* in the sense of Bulow, Geanakoplos and Klemperer (1985) and Cooper and John (1988). Higher leverage for large banks strengthens the strategic incentives for small banks to increase leverage. Intuitively, small banks perceive that they are shielded by the large banks.

To understand this point, recall that a small bank's appetite for borrowing is driven by the trade-off between the costs of equity issuance and the costs of default. When a large bank levers up, bailouts are larger and, consequently, small banks remain solvent more frequently. This has two effects. First, the costs of equity issuance, which hit shareholders when the bank is solvent, become more salient, and the marginal benefit of issuing debt rises. Second, since default becomes less likely, the marginal costs of default fall, and borrowing becomes yet more attractive. Both effects increase small banks' appetite for borrowing. Moreover, the same logic applies if  $b^j$  in Equation (13) is interpreted as the borrowing among the whole sector of small banks, or at least among a subset of small banks with positive mass.

In summary, our model simultaneously allows for moral hazard in the classical sense, since large banks have incentives to take leverage in order to exploit government subsidies, and for collective moral hazard in the sense of Farhi and Tirole (2012), since small banks have a bigger appetite for leverage when their peers are also leveraging up.

These observations lead to the two main positive results of this paper, which are stated in Propositions 1 and 2. We note that two technical challenges arise in characterizing equilibria. First, large banks' objective functions are not necessarily concave. Second, the strategic complementarity in leverage choices opens the door to multiple equilibria. Since we wish to keep the model general, we do not restrict the primitives to guarantee concavity or uniqueness.<sup>12</sup> Without such restrictions, it is not possible to derive comparative statics by totally differentiating the relevant first-order conditions. Instead, our proofs rely on a modified version of the results on monotone comparative statics in Milgrom and Shannon (1994), which require only supermodularity of payoffs.

**Proposition 1. (Large banks borrow more)** *Large banks borrow strictly more than small banks in any equilibrium.*

This result follows from observing that large banks are subject to moral hazard in the classical sense. Large banks internalize that their leverage decisions directly affect the size of bailouts  $t$  and, therefore, that they can increase the market prices of their debt and equity at date 0 by

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<sup>12</sup>In Section 5, we show numerically that both concavity and uniqueness of equilibrium are satisfied for a range of empirically plausible parameters.

borrowing more and boosting their implicit government subsidy. Small banks, by contrast, are not subject to classical moral hazard because bailouts depend exclusively on aggregate conditions, and small banks rationally consider their impact on aggregates to be infinitesimal. Therefore, large banks choose to borrow strictly more than small ones.

Figure 3 provides a simple graphical illustration of equilibrium when there are large and small banks. Consider an economy where there is a single large bank with point mass  $\lambda$  and a complementary mass  $1 - \lambda$  of small banks. In this case, each small bank takes as given the borrowing choices  $b^L$  of the large bank and the choices  $b^S$  of its small peers, and its best response is to set

$$b^i = \arg \max_b V(b, t(b^S, b^L | s)) \equiv \tilde{B}^S(b^S, b^L).$$

Given a borrowing level  $b^L$  for large banks, the equilibrium choice of the sector of small banks is found by solving the fixed point problem  $b^S = \tilde{B}^S(b^S, b^L)$ . Figure 3b shows this for two different levels  $b_0^L$  and  $b_1^L$ . This induces the best response of the small bank sector as a whole, shown as the red (solid) curve  $B^S(b^L)$  in Figure 3a. The large bank, by contrast internalizes its impact on transfers and selects

$$b^L = \arg \max_b V(b, t(b^S, b | s)) \equiv B^L(b^S),$$

shown as the blue (dotted) curve in Figure 3a. The economy is in equilibrium if small banks and large banks are responding optimally to each others' choices, that is, where the best response curves intersect. Proposition 1 establishes that, regardless of parameters, any equilibrium will be below the 45-degree line where the large bank chooses more leverage  $b^L > b^S$  than small ones.

Strategic complementarities also imply that large banks' appetite for leverage spills over to small banks. Indeed, the mere presence of large banks induces small banks to leverage up more aggressively.

**Proposition 2. (When large banks are present, small banks take more leverage)** *Let  $b_0$  be the smallest borrowing level which occurs in a symmetric equilibrium with only small banks. In any equilibrium with large banks, each small bank chooses strictly higher borrowing  $b^i > b_0$ .*

Proposition 2 is an instance of collective moral hazard, and follows naturally from Lemma 1. Consider a hypothetical market where all banks are small and choose to borrow  $b_0$  in equilibrium, and suppose that a subset of these banks merge to form a large bank. As shown in Proposition 1, the large bank has an independent incentive to increase their leverage to  $b > b_0$ . Because banks leverage decisions are strategic complements, the marginal benefit of borrowing increases for the remaining small banks, and they follow suit by choosing  $b^i > b_0$ .

We can combine our positive results in the following Corollary, which follows directly from both Propositions.

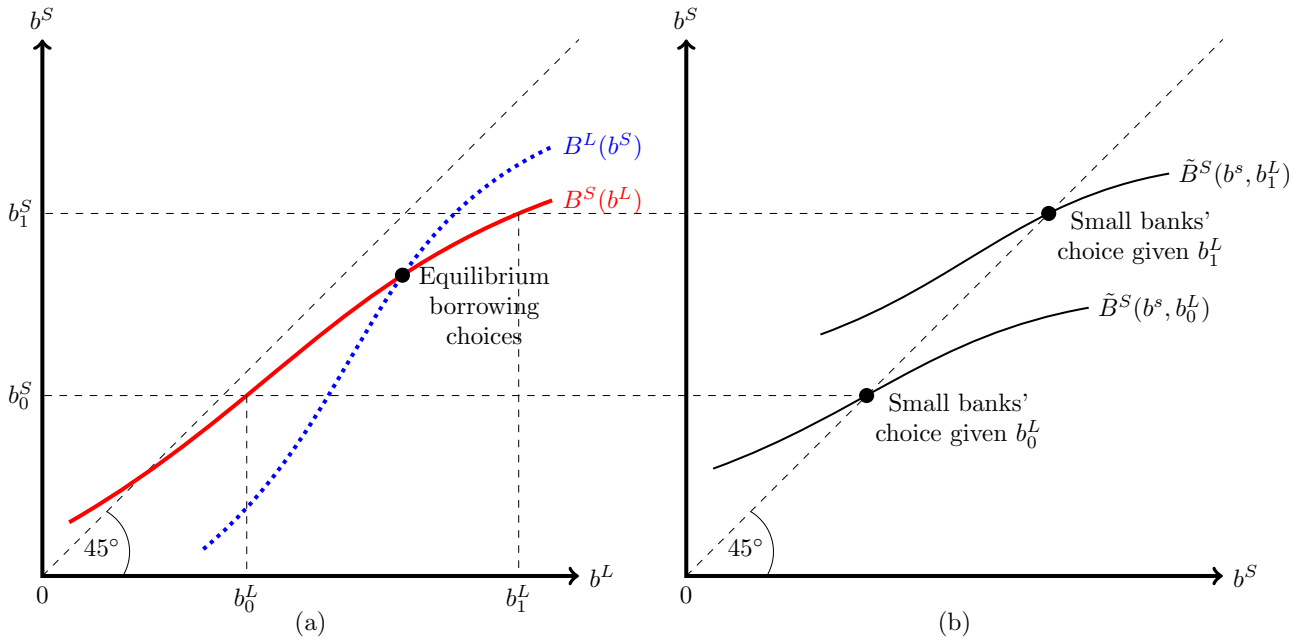


Figure 3: Equilibrium determination

**Note:** Figure 3a shows the best response of large banks (blue dashed line), given the borrowing choices of small banks, and the aggregate best response of small banks (red solid line), given the best responses of large banks. Figure 3b shows the best responses of a small bank given the borrowing choices of other small banks for two given values of large bank borrowing ( $b_0^L$  and  $b_1^L$ ). By varying the level of  $b_0^L$  in Figure 3b, we can trace the aggregate best response of small banks (solid red line) in Figure 3a.

**Corollary. (Banking systems with larger banks are associated with higher system-wide leverage)** *All else constant, when larger banks are present, aggregate leverage is higher and government bailouts are larger and more frequent.*

In summary, the presence of large banks leads to an unambiguous increase in system-wide leverage and financial sector risk, implying that the government is forced to rely more frequently on larger bank bailouts than when banks are small. However, the effect of large banks on the likelihood of bank failures is ambiguous, since banks create more system-wide risk, but the government simultaneously responds with increased support. Our quantitative exercise below illustrates these competing forces.

### Industry concentration and multiplier effects

We have established that the presence of large banks, or more generally increases in industry concentration, lead to higher system-wide leverage. By exploiting monotone methods, we have so far emphasized directional/qualitative results. We now show analytically that the quantitative implications of the mechanisms that we study in this paper are potentially significant because strategic complementarities amplify the initial impulse of an increase in concentration. In Section

5, we further explore the quantitative importance of our results by simulating the model for empirically plausible parameters.

For concreteness, suppose that there is one large bank with mass  $\lambda$  and that the economy is in a stable equilibrium of the form illustrated in Figure 1. Now consider an increase in industry concentration, that is, an increase in the size  $\lambda$  of the large bank. One interpretation of this change is a merger between the large bank and a subset of small banks.

First, hold constant the leverage choice  $b^L$  of the large bank, and consider the response of the remaining small banks. As before, this is determined by the fixed-point equation  $b^S = \tilde{B}^S(b^S, b^L; \lambda)$ , where we have made explicit the dependence of best responses on industry structure. It is easy to see that, holding constant borrowing choices in the neighborhood of an equilibrium, the best response of a small bank is increasing in  $\lambda$  with  $\partial \tilde{B}^S / \partial \lambda > 0$ . Intuitively, because  $b^L > b^S$  in equilibrium, the increase in  $\lambda$  shifts weight from high-leverage to low-leverage banks, which increases aggregate leverage and leads to more generous government bailouts. By Lemma 1, this makes leverage more attractive for each small bank. However, once each small bank increases its leverage, aggregate leverage increases again, and we move into a second round of adjustments. Overall, we can characterize the response of the small bank sector as

$$\frac{\partial b^S}{\partial \lambda} = M^S \times \frac{\partial \tilde{B}^S}{\partial \lambda}$$

where the small bank multiplier  $M^S$  is defined as

$$M^S \equiv \left(1 - \frac{\partial \tilde{B}^S}{\partial b^S}\right)^{-1} > 1. \quad (14)$$

Even before large banks respond, small banks respond by increasing leverage, and this effect is amplified by strategic complementarities, as captured by the multiplier  $M^S > 1$ .

Second, the large bank responds to the change by adjusting its own leverage, for two reasons. On one hand, small banks have raised their borrowing, making borrowing more attractive. On the other hand, the large bank is now larger than before, and internalizes an even stronger effect of its choices on government bailouts. Computing total changes yields

$$\begin{aligned} \frac{db^L}{d\lambda} &= \bar{M}(M^S) \times \left( M^S \frac{\partial \tilde{B}^S}{\partial \lambda} \frac{\partial B^L}{\partial b^S} + \frac{\partial B^L}{\partial \lambda} \right), \\ \frac{db^S}{d\lambda} &= \bar{M}(M^S) \times \left( M^S \frac{\partial \tilde{B}^S}{\partial b^L} \frac{\partial B^L}{\partial \lambda} + M^S \frac{\partial B^S}{\partial \lambda} \right), \end{aligned}$$

where the aggregate multiplier  $\bar{M}(M^S) > 1$ , which is itself a function of the small bank multiplier  $M^S$ , is defined as

$$\bar{M}(M^S) \equiv \left(1 - M^S \frac{\partial \tilde{B}^S}{\partial b^L} \frac{\partial B^L}{\partial b^S}\right)^{-1} > 1. \quad (15)$$

Equation (15) reveals that industry concentration has an effect on leverage that is amplified on two levels. Small banks encourage each other to take more leverage, in line with the collective moral hazard argument of Farhi and Tirole (2012), and as reflected by the multiplier  $M^S$  in Equation (14). Moreover, large banks respond by increasing their leverage, which induces further amplification via the multiplier  $\bar{M}(M^S) > 1$  in Equation (15). The two effects reinforce each other since the aggregate multiplier  $\bar{M}(M^S)$  is itself increasing in the small bank multiplier  $M^S$ .

### 3 Optimal ex-ante policies

In our model, there is a clear case for prudential regulation. In particular, banks do not internalize the impact of their leverage on the social cost of ex-post bailouts. On the contrary, they endeavour to attract bailouts because funding markets at date 0 reward them for large implicit subsidies.

#### Constrained efficient choices

As a benchmark for policy, we consider a benevolent social planner who can dictate banks' borrowing choices  $\mathbf{b}$  at date 0, but cannot overcome financing frictions (that is, the costs of default and the social cost of equity issuance). His choices are called *constrained efficient*.

We first compute a general expression for expected social welfare at date 0. Given bank  $\mathbf{b}$  and a state-contingent bailout policy  $t(s)$  at date 1 (not necessarily equal to the ex-post optimal policy  $t(\mathbf{b}|s)$ ), expected welfare at date 0 is

$$\begin{aligned} W_0(\mathbf{b}, t(s)) &= \mathbb{E}[u] - \mathbb{E}[\kappa(t(s))], \\ &\quad - (1 - \phi) \int \Pr[\mathcal{D}^i] \mathbb{E}[u|\mathcal{D}^i] d\mu \\ &\quad - (\psi - \bar{\psi}) \int \Pr[\mathcal{N}^i] \mathbb{E}[t(s) + u - b^i|\mathcal{N}^i] d\mu. \end{aligned} \tag{16}$$

This is intuitive: The constrained social planner measures welfare as the expected value of asset returns, less the deadweight social costs of bailout transfers, bank default, and equity issuance.

Two maximization problems are of potential interest. First, we can assume that the planner can commit to any state-contingent bailout policy  $t(s)$  at date 0. Then he solves

$$W^c = \max_{\{\mathbf{b}, t(s)\}} W_0(\mathbf{b}, t). \tag{17}$$

Second, we can assume that the planner cannot commit to transfers, and chooses them optimally ex-post as in Section 2.1. In this case he solves

$$W^{nc} = \max_{\{\mathbf{b}, t(s)\}} \{W_0(\mathbf{b}, t(s)) \text{ subject to } t(s) = t(\mathbf{b}|s)\}, \quad (18)$$

where  $t(\mathbf{b}|s)$  is the government's ex-post best response, defined in (3). Clearly, the loss of commitment in (18) cannot increase the maximized value of welfare, so that  $W^c \geq W^{nc}$ . Moreover, we can show that a lack of commitment does not reduce welfare in this instance:

**Lemma 2. (Commitment is irrelevant when the planner controls banks)** *When the planner perfectly controls banks' borrowing decisions  $\mathbf{b}$ , the solutions to problems (17) and (18) coincide and satisfy  $W^c = W^{nc}$ .*

Intuitively, commitment provides no additional value when the planner controls the banks, because in any case, the solution with commitment involves choosing bailouts that are ex-post optimal. When the planner does not control the banks, by contrast, commitment may be beneficial because it allows the planner to distort bailouts away ex-post optimality in order to curb moral hazard. We return to this issue below.

Lemma 2 allows us to characterize the planner's optimal borrowing choices:

**Proposition 3. (Efficient leverage is independent of bank size)** *The constrained efficient choice is to set  $b^i = b^*$  for almost all  $i$ , regardless of the distribution  $\mu$  of bank sizes, and regardless of whether the planner can commit to a transfer policy.*

Proposition 3 shows that the planner chooses symmetric policies for all banks, and in particular, that the socially optimal borrowing level  $b^i$  is independent of bank size. This is a natural consequence of constant returns to scale: A large bank has no technological reason to take more or less leverage than a small bank. This policy is in contrast to the laissez-faire equilibrium of Section 2.1, where large banks unambiguously chose larger borrowing levels. These equilibrium choices were motivated not by technological or contractual differences, but rather by the desire to maximize an implicit government subsidy. Since the planner internalizes that such a subsidy is socially wasteful, he does not respond to the same incentives.

Before considering ways to implement the optimal allocation, it is useful to explicitly characterize the best borrowing level  $b^*$ . When all banks choose the same borrowing level  $b$ , we can write ex-ante welfare as

$$\bar{W}_0(b, t(s)) = V(b, t(s)) + \bar{\psi} \Pr[\mathcal{N}] \mathbb{E}[t(s) + u - b|\mathcal{N}] - \mathbb{E}[t(s) + \kappa(t(s))],$$

where  $V(b, t(s))$  is the private value of an individual bank in Equation (8), and  $\mathcal{N} = \{t(s) + u \geq b\}$  is the event of default. The first term is aligned with the bank's objective. The second term

captures the fact that the costs of equity issuance are not fully social costs if  $\bar{\psi} > 0$ . The last term arises because, unlike the bank, the social planner internalizes the full social cost  $t(s) + \kappa(t(s))$  of the bailout.

Since the welfare maximization problems with and without commitment are equivalent, we can assume that the planner is already committed to the optimal ex-post transfer  $t(b^*|s)$ . Then the choice of  $b^*$  must maximize welfare taking this commitment as given, thus solving the fixed point equation

$$b^* = \arg \max \bar{W}_0(b, t(b^*|s))$$

The first-order condition in this problem gives a characterization of socially optimal borrowing:

$$\frac{\partial V(b^*, t(b^*|s))}{\partial b} - \bar{\psi} \Pr[\mathcal{N}^*] = 0, \quad (19)$$

where  $\mathcal{N}^* = \{t(b^*|s) + u > b^*\}$  is the non-default event under the optimal policy. Intuitively, the planner considers the impact of debt choices on the value of the bank, adjusted for the part of private equity issuance costs which is explained by transfers. One might expect the planner to also consider the impact of debt choices on the ex-post transfer. Formally, Equation (19) includes the term  $\mathbb{E} \left[ \frac{\partial W_0}{\partial t(b^*|s)} \frac{\partial t(b^*|s)}{\partial b} \right]$ . However, since transfers are chosen optimally, marginal changes in transfers have only a second-order welfare effect, and this term vanishes after an application of the envelope theorem.

## Optimal capital requirements

Dictating banks' choices  $b^i$  is tantamount to quantity regulation. Indeed, the constrained efficient choice  $b^*$  can be achieved by imposing binding capital requirements, as included in the Basel III Accord, which limit borrowing as a fraction of risky assets (recall that in our model, borrowing choices  $b^i$  are already expressed per unit of risky capital). The following result is a direct corollary of Proposition 3:

**Corollary. (Optimal capital requirements are independent of bank size)** *The constrained efficient allocation can be implemented by imposing binding capital requirements that are independent of bank size.*

It follows that strategic differences between large and small banks are insufficient to justify size-dependent capital regulation. Even though the incentives to take leverage remain stronger for large banks when capital requirements are in place (the Lagrange multiplier on a large bank's capital constraint will be greater), the optimal level of capital that a regulator wishes to enforce is independent of bank size, as long as technologies exhibit constant returns to scale.

Naturally, this conclusion changes when policy is conducted via Pigouvian taxes, which we examine next.

## Optimal Pigouvian taxes

We now assume now that the social planner cannot directly control banks' borrowing quantities  $\mathbf{b}$ . Moreover, we focus on the case where the planner has no commitment power; in particular, he cannot credibly announce a date 1 bailout policy at date 0. Market participants instead expect that the date 1 bailout policy will be chosen to maximize welfare ex-post.

The socially optimal choices  $\mathbf{b}^*$  can be implemented by taxing banks in proportion to their borrowing choices at date 0. We let  $\tau^i$  denote the Pigouvian tax levied on bank  $i$ , who consequently pays  $b^i \tau^i$  to the government; tax revenues are rebated to financiers as a lump sum. Under Pigouvian taxation, the bank maximizes its value net of tax,  $V(b^i, t(\mathbf{b}|s)) - b^i \tau^i$ . As before, small banks take the bailout policy  $t(\mathbf{b}|s)$  as fixed. Large banks, on the other hand, realize that the government lacks commitment and take into account their impact on the ex-post optimal bailout. A standard argument then leads to optimal taxes:

**Proposition 4.** *The following Pigouvian taxes implement the social planner's choice  $b^i = b^*$  in equilibrium:*

- If  $i$  is a small bank, then set

$$\tau^i = \bar{\psi} Pr[\mathcal{N}^*]. \quad (20)$$

- If  $j$  is a large bank, then set

$$\tau^j = \tau^i + \mathbb{E} \left[ \frac{\partial t(\mathbf{b}|s)}{\partial b^j} \Big|_{\mathbf{b}=\mathbf{b}^*} (1 - \psi \mathbf{1}(\mathcal{N}^*)) \right] + (1 - \phi) \int_{\partial \mathcal{D}^*} \frac{\partial t(\mathbf{b}|s)}{\partial b^j} \Big|_{\mathbf{b}=\mathbf{b}^*} (b^* - t(b^*|s)) dF, \quad (21)$$

where  $\partial \mathcal{D}^* = \{t(b^*|s) + u = b^*\}$  is the boundary of the optimal default region.

To implement the efficient outcome, each small bank is charged in proportion to the expected wedge between private and social costs of equity issuance. Second, large banks are charged a “Too-Big-To-Fail” top-up tax in order to account for their risk taking incentives. The top-up is designed to counteract the part of large banks' incentives that stems from their desire to maximize implicit subsidies. In particular, the second term in (21) offsets a large bank's incentive to attract larger subsidies for its financiers, while the third term offsets the incentives generated by the fact that larger subsidies reduce the expected costs of default.

## 4 Policy implications

The prescription of the optimal policy is as follows. If large banks are present, regulators need to be wary of significant and amplified increases in risk taking incentives. If binding



capital requirements can be imposed to correct all externalities, then constant returns to scale still guarantee that there is no need to make capital requirements size-dependent. However, if regulators choose to use price instruments to combat systemic risk, then a top-up tax in line with Equation (21) should be charged to large banks. We now discuss some further implications of our results, which concern (i) the interaction between financial policy and antitrust tools that can directly affect the bank size distribution, and (ii) cases in which the implementation of quantity or price controls is imperfect.

### **Prudential and antitrust policy are complements**

Consider again the thought experiment in which the economy starts out with only small banks, but a subset of them propose a merger in order to form a large bank. Should antitrust authorities prevent this? The traditional tests for allowing the merger would be based on concerns about market power and reductions in consumer surplus. Our model abstracts from consumer surplus, since banks capture all available surplus in equilibrium, but points towards different trade-offs.

The arguments in Section 2.1 imply that a merger among banks can have significant and amplified effects on risk taking when (i) banks benefit from systemic bailouts and (ii) the banking sector is unregulated. In a financial sector with weak or absent regulation, financial stability ought to be a first-order concern when assessing mergers. This is especially salient when banks in our model are taken to be “shadow banks” that fall outside the regulatory perimeter.

Antitrust policy can be more lenient when financial regulation is strong. If regulators are already implementing the optimal quantity constraint  $b^*$ , then the merger should be permitted, modulo considerations about consumer surplus, since risk taking will not change as a result. If regulators are imposing the optimal Pigouvian tax on small banks, as defined in Equation (20), then the merger should be permitted as long as prudential regulators are ready to respond by charging the appropriate top-up tax, defined in Equation (21), to the newly created large bank.

It follows that prudential and antitrust policy are complements. Mergers should be waved through more frequently when prudential regulation is strong. Conversely, prudential regulation – especially when implemented via Pigouvian taxes – can be more lenient when the antitrust authority does not permit banks to merge and form large, dominant entities.

One implication of our model, therefore, is that caps on bank size can be valuable when prudential regulation is imperfect. While this paper clearly points to an additional marginal benefit of size caps, other defensible arguments exist in favor of large financial institutions. Better diversification and risk management, economies of scale, ability to handle large projects, creation of insensitive claims a la Gorton and Pennacchi (1990) or reduction of international frictions as in Freixas and Holthausen (2005) are relevant arguments on the opposite side of

the debate. Trading off these considerations will determine the optimal size distribution for the banking sector.

### Discussion of second-best policy

We have focused on first-best policy, that is, on the exact implementation of the constrained efficient outcome. There is a stark contrast between quantity and price controls in this case: Capital requirements ought to be independent of bank size, while optimal Pigouvian taxes call for a top-up tax on large banks. This dichotomy becomes less strict when we relax the assumption of first-best policy.

For example, consider the second-best case in which the regulator cannot push borrowing limits all the way to  $b^*$ , for example due to political constraints that are generated by lobbying. In this case, there may again be a case for increased capital requirements for large banks; these would curtail large banks' leverage and, via strategic complementarities, reduce risk-taking incentives for small banks.

Alternatively, consider a model in which banks can deviate from binding capital requirements: If the regulator requires bank  $i$  to choose  $b^i = \bar{b}$ , then the bank can extend its borrowing to  $\bar{b} + \delta$  at a cost  $\chi$  per unit of capital. This cost can be interpreted as an outright bribe that entices the regulator to turn a blind eye, or as the cost of a more indirect strategy, such as gaming regulatory risk models. If this cost is intermediate, small banks do not find it worth it to deviate from the capital requirement. Large banks, on the other hand, may still choose to deviate because they realize that doing so increases their implicit subsidy and therefore improves their valuation at date 0. Therefore, it is reasonable to assume that large banks have a stronger incentive to “cheat” on capital requirements. For intermediate costs  $\chi$ , the second-best policy is therefore to impose a higher capital requirement on large banks in anticipation of some cheating in equilibrium.

## 5 Quantitative assessment

As formally shown above, changes in industry composition have the potential to generate substantial amplification due to the presence of strategic complementarities. To gauge the strength of the complementarities and, more generally, to illustrate how bank size affects aggregate leverage, the likelihood of bank failure, and the magnitude of government bailouts in equilibrium, we calibrate our model using data from the US economy. Given that our model seeks to capture long-term funding decisions, we adopt a biannual calibration. Our reference period is 1976Q1 to 2013Q4.

## 5.1 Calibration

**Functional forms** In order to explicitly solve the model, we must make specific functional form assumptions, which were not needed to derive our theoretical results. First, regarding the industry composition, we assume that there exists a finite number  $N$  of large banks that hold a share  $\lambda$  of total bank assets, and a set of small banks that hold a share  $1 - \lambda$  of total assets. When  $N = 1$ , this is the same formulation used to draw Figure 3. Figure 4 illustrates the distribution of bank's assets in the economy. Although our framework allows us to match the whole distribution of bank assets at a small computational cost, the current formulation is more parsimonious and allows us to easily parametrize the effect of changes in the industry composition.

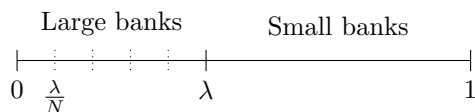


Figure 4: Distribution of banks' assets

Second, we assume that the cost function of the government is quadratic in the size of the bailout transfer. Formally,  $\kappa(t)$  is given by

$$\kappa(t) = k_0 t + \frac{k_1}{2} t^2,$$

where  $k_0$  and  $k_1$  are non-negative constants, so that  $\kappa'(t) = k_0 + k_1 t$ .

Finally, we assume that the return on banks' assets  $u$  and the signal  $s$  are normally distributed as follows:

$$u \sim N(\mu_u, \sigma_u) \quad \text{and} \quad s = u + \varepsilon_s,$$

where  $\varepsilon_s \sim N(0, \sigma_s)$ . Therefore, after observing the signal  $s$ , the government perceives the return  $u$  to be distributed as  $u|s \sim N\left(ws + (1-w)\mu_u, \frac{\sigma_u^2 \sigma_s^2}{\sigma_u^2 + \sigma_s^2}\right)$ , where the weight given to the signal corresponds to  $w = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_s^2}$ . Although assuming a Gaussian structure for returns and signals simplifies the government inference problem; its drawback is the possibility of experiencing negative payoffs. Our parametrization is such that the probability of  $u$  taking negative values is negligible. Similar results emerge assuming that  $u$  is log-normally distributed.

**Parameter values** Parameter values are summarized in Table 1. We need to assign values to nine parameters, which can be classified in three categories.

The first set of parameters determines banks' profitability and their capital structure. Our strategy is to select parameters to target the average cross-sectional values of bank's return on assets and debt-to-asset ratios, letting the model endogenously generate differences in behavior

between large and small banks. We set  $\mu_u = 1.05$  and  $\sigma_u = 0.15$  to match the average return on assets (ROA) and the average standard deviation across all banks during the period of interest. We set the value of deadweight losses associated with default to be 15%, of banks' value. This choice is consistent with the existing literature on capital structure, as shown by Davydenko, Strebulaev and Zhao (2012) and Strebulaev, Whited et al. (2012). We set the value of  $\psi = 0.15$  to target an average debt-to-asset ratio of 0.9 which is on the high end of estimates used in Hennessy and Whited (2005), but which is necessary to generate the large levels of leverage observed in the banking sector. Consistent with our agnostic view on the social vs. private costs of equity we set  $\bar{\psi}$  equal to  $\frac{\psi}{2}$ .

Table 1: Parameter values

Parameter	Definition	Value
<i>Banks' profitability and capital structure</i>		
$1 - \phi$	Default Deadweight Loss	0.15
$\psi, \bar{\psi}$	Cost of Equity Issuance	0.15, 0.075
$\mu_u$	Average ROA	1.05
$\sigma_u$	Standard Deviation ROA	0.14
<i>Industry composition</i>		
$\lambda$	Large Banks' Share	0.5
$N$	Number of Large Banks	5
<i>Government</i>		
$k_0, k_1$	Bailout Costs	0.14, 1.6
$\sigma_s$	Government's Signal Precision	0.2

The second set of parameters pins down the industry composition. Consistently with our description of recent US data in Figure 1, we set values of  $\lambda = 0.5$  and  $N = 5$ . The choice of  $N$  seeks to capture the persistence in the size rankings of a handful of banks. In particular, Bank of America, Citibank, JP Morgan Chase, and Wells Fargo have persistently ranked among the Top 5 banks by asset size since the beginning of our period of study. Our benchmark choice of  $\lambda$  is consistent with current levels of concentration, although we describe below in detail how alternative values of  $\lambda$  affect the outcomes of the model.

The third set of parameters determines the scope and magnitude of the bailout policy. We set the value of  $k_0$  to match a marginal value of public funds with no intervention of 0.14, which is an average estimate in the literature. We set the values of  $k_1$  and  $\sigma_s$  to jointly target a 1% expected bailout transfer and a probability of a significant intervention, defined as the probability

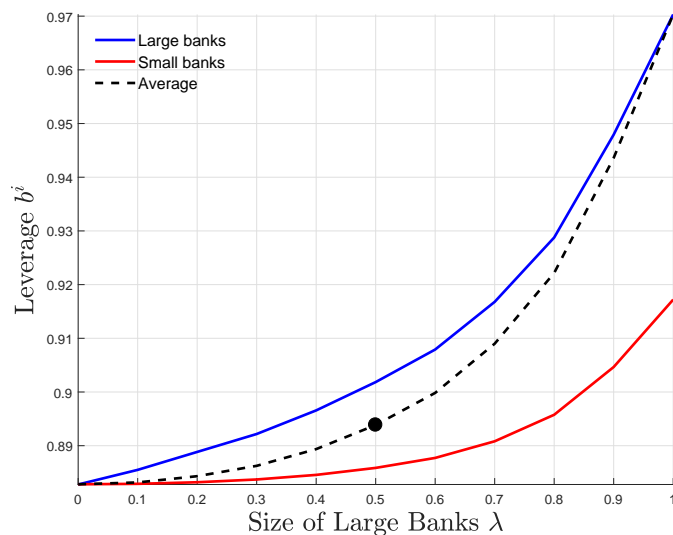


Figure 5: Borrowing choices

**Note:** Figure 5 shows the optimal equilibrium debt-to-asset ratio chosen by large banks (blue solid line) and by small banks (red solid line). It also shows the average debt-to-asset ratio in the economy (dashed black line). Note that average value equals the debt-to-asset ratio of small banks when  $\lambda = 0$  and the debt-to-asset ratio of large banks when  $\lambda = 1$ .

of receiving a transfer higher than 3%, to be 10%. These values are consistent with experiencing a significant intervention every 20 years, as in Mendicino, Nikolov and Suarez (2017), and with an average bailout transfer of 10% of banks' value, which is within the reasonable range of values described in Laeven and Valencia (2013) and Hüttel, Schoenmaker et al. (2016).

## 5.2 Model results and industry concentration counterfactuals

Figures 5 and 6 summarize our results for the baseline calibration and clearly illustrate how changes in industry composition modify the leverage decisions and equilibrium outcomes for large and small banks. Our calibration is designed to match an average value for debt-to-assets ratios of 0.9. The blue and red solid lines, which show the borrowing choices of large and small banks respectively, are endogenously generated by the mechanisms highlighted in this paper.

Consistently with our theoretical results, Figure 5 shows that increases in the level of industry concentration are associated with a significant and nonlinear effect on the leverage choices of both large and small banks. Our results show that increases in industry concentration have a significant impact in system-wide borrowing for values of  $\lambda$  higher than 0.5. In particular, a shift from  $\lambda = 0.5$  to  $\lambda = 0.8$  would be associated with an increase in system-wide borrowing of roughly 3 percentage points. Translating this change to leverage ratios, the shift induces a 25% increase in leverage (from 10 to 12.5).<sup>13</sup>

<sup>13</sup>The leverage ratio is defined as  $L = \frac{assets}{assets - debt} = \frac{1}{1 - debt/assets}$ .

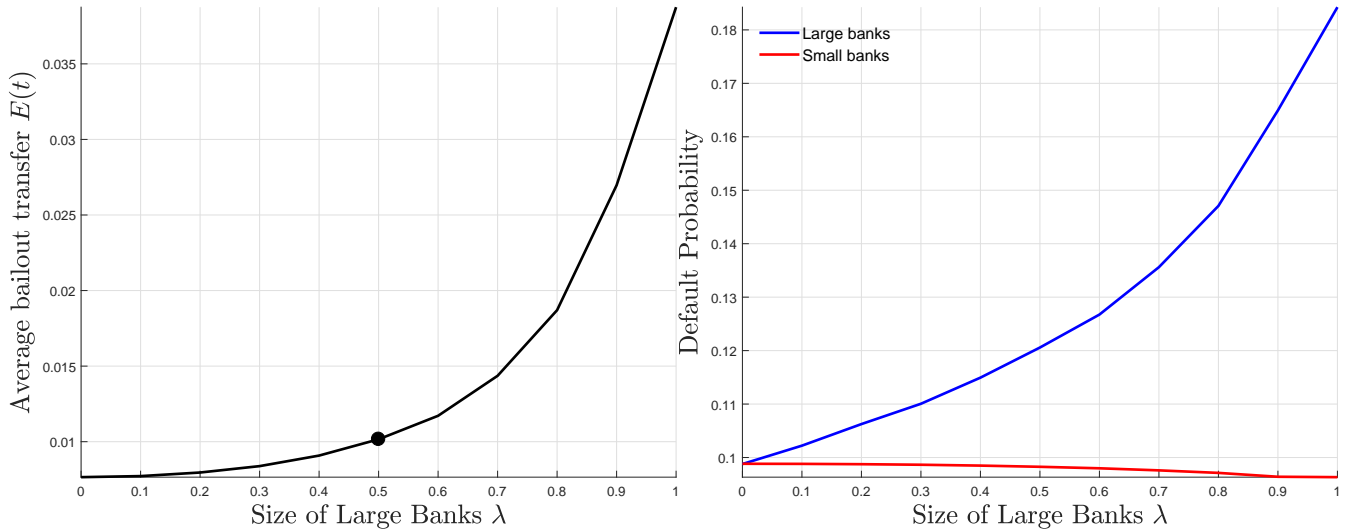


Figure 6: Bank's default probabilities and average bailout transfer

**Note:** Figure 6a shows the average bailout transfer in equilibrium. Figure 6b shows the probability of default for large banks (blue solid line) and small banks (red solid line).

Figure 5a) shows that the equilibrium magnitude of bailouts increases monotonically with the level of industry concentration. Intuitively, given that both large and small banks borrow more, all else constant, the probability of failure is larger, which makes more appealing for the government to bail out banks. In the baseline scenario, the expected bailout transfer corresponds to 1% of bank's assets. A shift from  $\lambda = 0.5$  to  $\lambda = 0.8$  would be associated with a nearly twofold increase in the average expected transfer, from 1% to close to 2% of banks assets.

Figure 5b) shows that the probability of bank failure increases for large banks but decreases for small with the level of industry concentration. While the result for large banks is intuitive, the finding for small banks is somewhat surprising, in particular given that we know from Figure 5 that small banks borrow more when  $\lambda$  is higher. In this case, the reduction in the probability of default is due to the increase in the ex-post transfer associated with the large bank taking on more leverage, which counteracts the direct effect of higher leverage by small banks in the probability of default.

### 5.3 Optimal Policy

Figure 7 quantitatively assesses the magnitude of the optimal Pigouvian policy. Given that we have assumed that  $\bar{\psi}$  is non-zero, it is optimal for the planner to set a corrective tax to both large and small banks. This baseline tax is of the order of 7%, and is mechanically related to the value of  $\bar{\psi}$ , as implied by the optimal tax in Equation (20).

However, the main object of interest for us is the differential tax charged to large banks

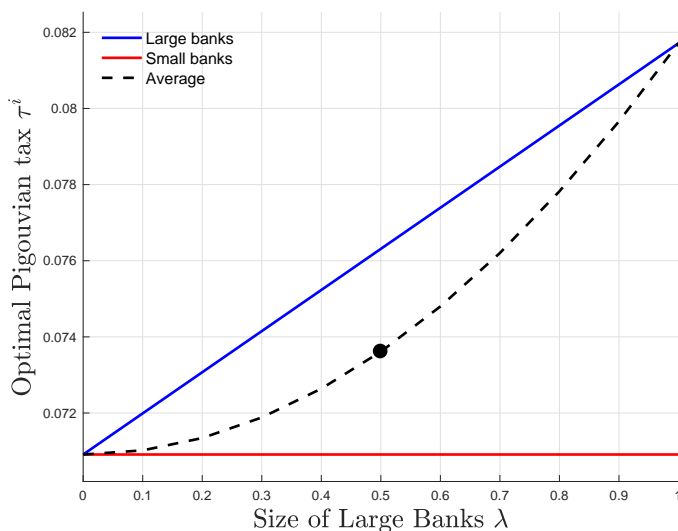


Figure 7: Optimal Too-Big-To-Fail Tax

**Note:** Figure 7 shows the optimal Pigouvian tax levied on large banks (blue solid line). We also show that small banks are subject to a uniform tax (red solid line) that is independent of bank size, consistently with our results in Proposition 3. The average tax paid by all banks is shown as a black dashed line. The optimal Too-Big-To-Fail tax, corresponds to the difference between the blue and the red solid lines.

relative to small banks. In our baseline scenario, large banks face an additional 0.5% additional tax relative to small under the optimal ex-ante policy: we refer to this additional as a “Too-Big-To-Fail tax”. This optimal Too-Big-To-Fail tax increases up to roughly 1% if the share of assets held by the 5 largest banks reaches 80%.

## 6 Conclusion

We have shown that the size distribution of financial institutions does matter for the ex-ante determination of leverage when bailouts are possible. Large banks, by internalizing that their actions affect the government’s bailout response, find it optimal to increase their leverage in equilibrium. Their increased leverage increases the size of bailouts, thereby encouraging small banks to take on more leverage. Both effects are mutually reinforcing, and generate further increases system-wide leverage in equilibrium. Hence, aggregate leverage and the size of government bailout interventions are larger, and this effect is amplified, when large banks are present.

Our results rely on mild assumptions about strategic complementarities created by the policy response and are robust to alternative theories of capital structure determination. Our findings support the notion that regulators and policymakers must pay special attention to large financial institutions, since they have a direct motive to take on more risk and also because their behavior disproportionately influences the decisions of small players in equilibrium. In this model, a

regulator that closely monitors and restricts funding decisions of large financial institutions arises as a natural optimal policy.

A quantitative assessment of the model implies that further increases beyond the current levels of assets held by the largest banks will be associated with higher leverage choices made by both large and small banks. The optimal ex-ante corrective policy in our model can be implemented with Too-Big-To-Fail taxes on bank's debt of the order of 0.5%.



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# APPENDIX

## A Quotations

**Breaking up big banks wouldn't really solve our problems**, because it's perfectly possible to have a financial crisis that mainly takes the form of a run on smaller institutions.

(...) Breaking up big financial institutions wouldn't prevent future crises, nor would it eliminate the need for bailouts when those crises happen. **The next bailout wouldn't be concentrated on a few big companies - but it would be a bailout all the same.** I don't have any love for financial giants, but I just don't believe that breaking them up solves the key problem.

*Paul Krugman. The New York Times, 04/01/2010*

Most observers who study this believe that to try to break banks up into a lot of little pieces would hurt our ability to serve large companies and hurt the competitiveness of the United States. But that's not the important issue. They believe that it would actually make us less stable, because the individual banks would be less diversified and, therefore, at greater risk of failing, because they would haven't profits in one area to turn to when a different area got in trouble.

And most observers believe that **dealing with the simultaneous failure of many small institutions would actually generate more need for bailouts** and reliance on taxpayers than the current economic environment.

*Lawrence Summers. Interview with Jeffrey Brown, PBS Newshour, 04/22/2010*

But, while regulation must address the oversized bank balance sheets that were at the root of the crisis, the IMF is right not to focus excessively on fixing the "too big to fail" problem. **A surprising number of pundits seem to think that if one could only break up the big banks, governments would be far more resilient to bailouts**, and the whole "moral hazard" problem would be muted. **That logic is dubious**, given how many similar crises have hit widely differing systems over the centuries. **A systemic crisis that simultaneously hits a large number of medium-sized banks would put just as much pressure on governments to bail out the system as would a crisis that hits a couple of large banks.**

*Kenneth Rogoff. All for One Tax and One Tax for All? Project Syndicate, 04/29/2010*

## B Proofs and derivations

### B.1 Section 2.1

#### Government's problem

For a given signal realization  $s$ , the government optimally chooses a transfer  $t(\mathbf{b}|s)$  at date 1 to maximize:

$$\max_{t \geq 0} W_1(\mathbf{b}, t|s),$$

where  $W_1(\mathbf{b}, t|s)$  is given by

$$W_1(\mathbf{b}, t|s) = \int_0^\infty u dF_u(u|s) - (1 - \phi) \int \left[ \int_0^{b^i - t} u dF_u(u|s) \right] d\mu - (\psi - \bar{\psi}) \int \left[ \int_{b^i - t}^\infty (t + u - b^i) dF_u(u|s) \right] d\mu - \kappa(t),$$

which corresponds to Equation (2) in the text. Note that the outer integrals in the second and third terms are cross-sectional integrals over banks  $i$ , while the inner ones are integrals over the possible realizations of  $u$  given the signal  $s$ .

The first-order and second-order conditions to this problem correspond to

$$\begin{aligned} \frac{\partial W_1(\mathbf{b}, t|s)}{\partial t} &= (1 - \phi) \int f_u(b^i - t|s) (b^i - t) d\mu - (\psi - \bar{\psi}) \int [1 - F_u(b^i - t|s)] d\mu - \kappa'(t) \\ \frac{\partial^2 W_1(\mathbf{b}, t|s)}{\partial t^2} &= -(1 - \phi) \int [f'_u(b^i - t|s) (b^i - t) + f_u(b^i - t|s)] d\mu - (\psi - \bar{\psi}) \int f_u(b^i - t|s) d\mu - \kappa''(t) \leq 0. \end{aligned}$$

Note that the second-order condition is always satisfied with strict inequality under our regularity condition (1).<sup>14</sup> It immediately follows that  $\lim_{t \rightarrow \infty} \frac{\partial W_1(\mathbf{b}, t|s)}{\partial t} < 0$ , which guarantees that the optimal  $t$  is bounded above. Note further that

$$\left. \frac{\partial W_1(\mathbf{b}, t|s)}{\partial t} \right|_{t=0} = (1 - \phi) \int f_u(b^i|s) b^i d\mu - (\psi - \bar{\psi}) \int [1 - F_u(b^i|s)] d\mu - \kappa'(0),$$

which implies that the optimal transfer  $t(\mathbf{b}|s)$  is zero when  $(1 - \phi) \int f_u(b^i|s) b^i d\mu \leq \kappa'(0) + (\psi - \bar{\psi}) \int [1 - F_u(b^i|s)] d\mu$ , and determined uniquely by the first-order condition otherwise.

Totally differentiating the first-order condition with respect to  $b^j$ , we have

$$\begin{aligned} 0 &= \frac{\partial^2 W_1(\mathbf{b}, t|s)}{\partial t^2} \times \frac{\partial t}{\partial b^j} + \frac{\partial^2 W_1(\mathbf{b}, t|s)}{\partial t \partial b^j} \\ &= \frac{\partial^2 W_1(\mathbf{b}, t|s)}{\partial t^2} \times \frac{\partial t}{\partial b^j} + \mu(j) \times [(1 - \phi) (f'_u(b^j - t|s) (b^j - t) + f_u(b^j - t|s)) + (\psi - \bar{\psi}) f_u(b^j - t|s)], \end{aligned}$$

and it follows that

$$\frac{\partial t(\mathbf{b}|s)}{\partial b^j} = \left( -\frac{\partial^2 W_1(\mathbf{b}, t|s)}{\partial t^2} \right)^{-1} \mu(j) [(1 - \phi) (f'_u(b^j - t|s) (b^j - t) + f_u(b^j - t|s)) + (\psi - \bar{\psi}) f_u(b^j - t|s)].$$

Note that first factor is strictly positive, given the second-order condition, which implies Equation (5).

## Banks' market value

The ex-post payoffs to debtholders and shareholders are defined in Equations (6) and (7) in the text. Taking expectations under the joint distribution of returns and signals  $F(u, s)$  yields the date 0 value of bonds and shares for bank  $i$ , respectively given by

$$\begin{aligned} q^i b^i &= \int_{\mathcal{N}^i} b^i dF + \int_{\mathcal{D}^i} (\phi u + t(\mathbf{b}|s)) dF \\ e^i &= (1 - \psi) \int_{\mathcal{N}^i} (u + t(\mathbf{b}|s) - b^i) dF, \end{aligned}$$

<sup>14</sup>Note that when  $u|s$  is normally distributed,  $x \frac{f'_u(x)}{f_u(x)} = \frac{x - \mu_{u|s}}{\sigma_{u|s}} \frac{1}{\sigma_{u|s}}$ , so Condition 1 is satisfied whenever  $\sigma_{u|s}$  is sufficiently large.

where the default and repayment regions are defined as  $\mathcal{D}^i = \{t(\mathbf{b}|s) + u < b^i\}$  and  $\mathcal{N}^i = \{t(\mathbf{b}|s) + u \geq b^i\}$ . Adding up both, we can express the market value of the bank as follows

$$\begin{aligned} q^i b^i + e^i &= \int_{\mathcal{N}^i} [u + t(\mathbf{b}|s) - \psi(u + t(\mathbf{b}|s) - b^i)] dF + \int_{\mathcal{D}^i} [u + t(\mathbf{b}|s) - (1 - \phi)u] dF \\ &= \int (u + t(\mathbf{b}|s)) dF - (1 - \phi) \int_{\mathcal{D}^i} u dF - \psi \int_{\mathcal{N}^i} (u + t(\mathbf{b}|s) - b^i) dF \\ &= \mathbb{E}[u + t(\mathbf{b}|s)] - (1 - \phi) \Pr[\mathcal{D}^i] \mathbb{E}[u|\mathcal{D}^i] - \psi \Pr[\mathcal{N}^i] \mathbb{E}[u + t(\mathbf{b}|s) - b^i|\mathcal{N}^i], \end{aligned} \quad (\text{A.1})$$

which corresponds to the definition of  $V(b^i, t(\mathbf{b}|s))$  in Equation (8).

### Banks' leverage choices

The bank maximizes its market value. Let  $\mathcal{S}$  denote the support of the signal  $s$ , and recall that  $G(s)$ ,  $s \in \mathcal{S}$ , is the marginal distribution of signals. We can write the bank's value, from (A.1), more explicitly as

$$V(b^i, t(\mathbf{b}|s)) = \int_{\mathcal{S}} \left[ t(\mathbf{b}|s) - (1 - \phi) \int_0^{b^i - t(\mathbf{b}|s)} u dF_u(u|s) - \psi \int_{b^i - t(\mathbf{b}|s)}^{\infty} (u + t(\mathbf{b}|s) - b^i) dF_u(u|s) \right] dG(s).$$

Partially differentiating with respect to  $b^i$  gives

$$\begin{aligned} \frac{\partial V}{\partial b^i} &= \int_{\mathcal{S}} \left[ -(1 - \phi) (b^i - t(\mathbf{b}|s)) f_u(b^i - t(\mathbf{b}|s)|s) + \psi \int_{b^i - t(\mathbf{b}|s)}^{\infty} dF_u(u|s) \right] dG(s) \\ &= \psi \Pr[\mathcal{N}^i] - (1 - \phi) \int_{\partial \mathcal{D}^i} u dF, \end{aligned}$$

which corresponds to Equation (10) in the text. The total effect of increasing  $b^i$  further takes into account the effect of  $b^i$  on optimal transfers, and is given by

$$\begin{aligned} \frac{dV}{db^i} &= \frac{\partial V}{\partial b^i} + \int_{\mathcal{S}} \frac{\partial t(\mathbf{b}|s)}{\partial b^i} \left[ 1 + (1 - \phi) (b^i - t(\mathbf{b}|s)) f_u(b^i - t(\mathbf{b}|s)|s) - \psi \int_{b^i - t(\mathbf{b}|s)}^{\infty} dF_u(u|s) \right] dG(s) \\ &= \frac{\partial V}{\partial b^i} + \mathbb{E} \left[ \frac{\partial t(\mathbf{b}|s)}{\partial b^i} (1 - \psi \mathbf{1}(\mathcal{N}^i)) \right] + (1 - \phi) \int_{\partial \mathcal{D}^i} \frac{\partial t(\mathbf{b}|s)}{\partial b^i} u dF, \end{aligned}$$

which corresponds to Equation (11) in the text. The first-order conditions (10) and (11) follow by noting that  $\frac{\partial t(\mathbf{b}|s)}{\partial b^i} = 0$  for small banks.

### Proof of Lemma 1 (Effect of large bank leverage on small banks' incentives.)

*Proof.* Differentiating the bank's value function in (8) with respect to  $b^j$  gives

$$\frac{dV(b^i, t(\mathbf{b}|s))}{db^j} = \mathbb{E} \left[ \frac{\partial t(\mathbf{b}|s)}{\partial b^j} (1 - \psi \mathbf{1}(\mathcal{N}^i)) \right] + (1 - \phi) \int_{\partial \mathcal{D}^i} \frac{\partial t(\mathbf{b}|s)}{\partial b^j} u dF > 0,$$

where the inequality follows from the properties of optimal bailouts. Indeed, (5) implies that  $\frac{\partial t(\mathbf{b}|s)}{\partial b^j} \geq 0$ , with strict inequality for the (positive measure) set of public signals  $s$  such that  $t(\mathbf{b}|s) > 0$ .

Differentiating again with respect to  $b^i$  gives

$$\frac{d^2 V(b^i, t(\mathbf{b}|s))}{db^i db^j} = \psi \int_{\mathcal{D}^i} \frac{\partial t(\mathbf{b}|s)}{\partial b^j} dF + (1 - \phi) \int_{\mathcal{D}^i} \frac{\partial t(\mathbf{b}|s)}{\partial b^j} \left\{ 1 + \frac{u f'_u(u|s)}{f_u(u|s)} \right\} dF > 0,$$

where the inequality follows from our regularity condition.  $\square$

### Proof of Proposition 1 (Large banks borrow more.)

*Proof.* Take any equilibrium with leverage choices  $\hat{\mathbf{b}}$  and ex-post optimal transfer  $\hat{t} = t(\hat{\mathbf{b}}|s)$ . Suppose that  $j$  is a large bank, and let  $t^j(b^j|s) = t(\mathbf{b}|s)|_{\hat{\mathbf{b}}^{-j} = b^j}$  be the transfer which becomes ex-post optimal if a large bank  $j$  chooses borrowing level  $b^j$ , while all other banks play their equilibrium strategy (note that  $t^j(\hat{b}^j) \equiv \hat{t}$ ).

First, suppose that  $\hat{b}^i > \hat{b}^j$  for a small bank  $i$  and a large bank  $j$ . Optimality implies that neither bank has a profitable deviation by copying the other's strategy:

$$\begin{aligned} V(\hat{b}^i, \hat{t}) &\geq V(\hat{b}^j, \hat{t}), \\ V(\hat{b}^j, \hat{t}) &\geq V(\hat{b}^i, t^j(\hat{b}^i)). \end{aligned}$$

Combining,

$$0 \geq V(\hat{b}^i, t^j(\hat{b}^i|\cdot)) - V(\hat{b}^i, t^j(\hat{b}^j|\cdot)) = \int_{\hat{b}^j}^{\hat{b}^i} \frac{dV(\hat{b}^i, t(\mathbf{b}|s))}{db^j} \Big|_{\mathbf{b}^{-j} = \hat{\mathbf{b}}^{-j}} db^j,$$

which contradicts Lemma 1. Therefore,  $\hat{b}^j \geq \hat{b}^i$ .

Second, suppose that  $\hat{b}^j = \hat{b}^i$ . We begin by showing that the small bank makes an interior choice in equilibrium, with  $0 < \hat{b}^i < \infty$ . Taking limits of the derivative in (10), we get

$$\lim_{b^i \rightarrow 0} \frac{\partial V(b^i, \hat{t})}{\partial b^i} = \psi \Pr[\mathcal{N}^i] - (1 - \phi) \int_{\mathcal{D}^i} (-t(s)) dF > 0.$$

Thus the small bank must choose  $\hat{b}^i > 0$ . Moreover, we have

$$\lim_{b^i \rightarrow \infty} \frac{\partial V(b^i, \hat{t})}{\partial b^i} = -(1 - \phi) \lim_{b^i \rightarrow \infty} \int_{\mathcal{D}^i} (b^i - t(s)) dF.$$

Note that the integral is strictly positive for a given  $b^i$  if and only if  $b^i > \mathbb{E}[t(s)|\mathcal{D}^i]$ . The convexity of the cost  $\kappa(t)$  of bailouts implies that  $t(s)$  is bounded above. Since the small bank takes  $t(s)$  as given, it follows that the integral is positive for large enough  $b^i$ , so that  $\lim_{b^i \rightarrow \infty} \frac{\partial V(b^i, \hat{t})}{\partial b^i} < 0$ , which establishes that the optimal choice  $\hat{b}^i < \infty$ . Therefore small banks are at an interior solution with  $\hat{b}^i \in (0, \infty)$ , and the first-order condition

$$\frac{\partial V(\hat{b}^i, \hat{t})}{\partial b^i} = 0.$$

holds with equality. The large bank's first-order condition, using the conjecture  $\hat{b}^j = \hat{b}^i$ , can in turn be written as

$$\frac{\partial V(\hat{b}^i, \hat{t})}{\partial b^i} + \frac{dV(\hat{b}^i, t(\mathbf{b}|s))}{db^i} = 0.$$

Lemma 1 implies that the second term is positive, and we obtain  $\frac{\partial V(\hat{b}^i, \hat{t})}{\partial b^i} < 0$ , a contradiction.  $\square$

**Proof of Proposition 2 (When large banks are present, small banks take more leverage.)**

*Proof.* Let  $t_0(b|s)$  denote the ex-post optimal transfer when there are only small banks who play the symmetric strategy  $b^i = b$ , and let  $BR_0(b) = \arg \max_{b^i} V(b^i, t_0(b|s))$  be a small bank's best response to this transfer.  $b$  is a symmetric equilibrium if  $b \in BR_0(b)$ . Since  $\frac{\partial V(b^i, t)}{\partial b^i} \Big|_{b^i=0} > 0$  regardless of transfers, we know that  $BR_0(0) > 0$ . Since  $b_0$  is the smallest equilibrium, we have  $\inf BR_0(b) > b$  for all  $b < b_0$ .

Now take any economy with large banks, and any equilibrium (not necessarily symmetric) with leverage choices  $\hat{\mathbf{b}}$  and ex-post optimal transfer  $\hat{t} = t(\hat{\mathbf{b}}|s)$ . Let the lowest borrowing level arising in equilibrium be  $b_1 \equiv \inf_i \hat{b}^i$ . Proposition 1 implies that a positive measure of banks (at least all large banks) chooses to borrow strictly more than  $b_1$ . Moreover, a parallel argument to Lemma 1 implies that incentives to borrow for small banks are strictly stronger under the equilibrium transfer  $\hat{t}$ , than under the transfer  $t_0(b_1|s)$  which would obtain if everybody chose  $b_1$ :

$$\frac{\partial V(b^i, \hat{t})}{\partial b^i} > \frac{\partial V(b^i, t_0(b_1|\cdot))}{\partial b^i}. \tag{A.2}$$

We need to show that  $b_1 > b_0$ .

First, suppose that  $b_1 < b_0$ . Let  $\tilde{b}_1 = \inf BR_0(b_1)$  be the lowest borrowing level which small banks pick if everybody else chooses  $b_1$ . We know that  $\tilde{b}_1 > b_1$ . Since  $\tilde{b}_1$  maximizes bank value given the transfer  $t_0(b_1|s)$ , we have

$$V(\tilde{b}_1, t_0(b_1|s)) \geq V(b_1, t_0(b_1|s))$$

Moreover, since  $b_1$  maximizes some (small) bank's value given the equilibrium transfer  $\hat{t}$ , we have

$$V(b_1, \hat{t}) \geq V(\tilde{b}_1, \hat{t}).$$

Combining,

$$V(\tilde{b}_1, t_0(b_1|s)) - V(b_1, t_0(b_1|s)) \geq 0 \geq V(\tilde{b}_1, \hat{t}) - V(b_1, \hat{t}),$$

which implies

$$\int_{b_1}^{\tilde{b}_1} \left( \frac{\partial V(b^i, t_0(b_1|s))}{\partial b^i} - \frac{\partial V(b^i, \hat{t})}{\partial b^i} \right) \geq 0,$$

contradicting (A.2).

Second, suppose that  $b_1 = b_0$ . Since  $b_0$  is optimal if everybody else chooses  $b_0$ , we have the first-order condition for a small bank

$$\frac{\partial V(b_0, t_0(b_0|s))}{\partial b^i} = \frac{\partial V(b_1, t_0(b_1|s))}{\partial b^i} = 0.$$



Moreover, since some small bank optimally chooses  $b_1$  in equilibrium, we have

$$\frac{\partial V(b_1, \hat{t})}{\partial b^i} = 0 = \frac{\partial V(b_1, t_0(b_1|s))}{\partial b^i},$$

again contradicting (A.2).  $\square$

## B.2 Proofs: Section 3

### Proof of Lemma 2 (Commitment is irrelevant when the planner controls banks.)

*Proof.* Taking expectations over signals in (2) and comparing to (16) we obtain, for any (not necessarily optimal) bailout policy  $t(s)$ ,

$$W_0(\mathbf{b}, t(s)) = \mathbb{E}[W_1(\mathbf{b}, t(s)|s)].$$

Suppose that  $W^c > W^{nc}$ . Then the constraint in  $W^{nc}$  must bind in some states, that is, the policy achieving  $W^c$  is not ex-post optimal for a set of signals  $s$  with positive probability measure. Call this policy  $\{\mathbf{b}^c, t^c(s)\}$  and consider replacing the transfer policy with the ex-post best response to  $\mathbf{b}^c$ , setting  $t'(s) = \arg \max_t W_1(\mathbf{b}^c, t|s)$  for almost all  $s$ . By ex-post optimality,  $W_1(\mathbf{b}^c, t'|s) \geq W_1(\mathbf{b}^c, t^c|s)$ , with strict inequality for a positive measure of signals. The policy  $\{\mathbf{b}^c, t'(s)\}$  yields ex-ante welfare  $W_0(\mathbf{b}^c, t'(s)) = \mathbb{E}[W_1(\mathbf{b}^c, t'(s)|s)] > \mathbb{E}[W_1(\mathbf{b}^c, t^c(s)|s)]$ , contradicting optimality of  $\{\mathbf{b}^c, t^c(s)\}$ .  $\square$

### Proof of Proposition 3 (Efficient leverage is independent of bank size.)

*Proof.* Lemma 2 shows that the maximization problems with and without commitment are equivalent. We consider the problem (17) with commitment. Suppose policy  $\{\mathbf{b}^c, t^c(s)\}$  solves this problem. Note that we may write welfare in terms of bank value, the wedge between private and social equity issuance costs, and transfers:

$$W_0(\mathbf{b}, t(s)) = \int [V(b^i, t(s)) + \bar{\psi} \Pr[\mathcal{N}^i] \mathbb{E}[t(s) + u - b^i]] d\mu - \mathbb{E}[t(s) + \kappa(t(s))].$$

Since  $t(s)$  may be chosen independently of  $\mathbf{b}$ , the first-order condition for the optimal  $\mathbf{b}$  is obtained by differentiating pointwise under the integral, and we obtain

$$\frac{\partial V(b^{c,i}, t^c(s))}{\partial b^i} = \bar{\psi} \Pr[\mathcal{N}^i]$$

for all  $i$ . But under our regularity condition, the pointwise maximization problem is strictly concave in  $b^i$  so that we have  $b^{c,i} = b^{c,j} = \bar{b}$  for almost all  $i, j$ .  $\square$

## C Computational algorithm

1. We first characterize the optimal ex-post transfer given a signal as a function of the following primitives

$$t(\mathbf{b}, s, \phi, \kappa, \lambda, \mu_u, \sigma_u, \sigma_s),$$

which allows us to characterize  $\frac{\partial t}{\partial b^j}(\mathbf{b}, s, \phi, \kappa, \lambda, \mu_u, \sigma_u, \sigma_s)$  as a function of the same primitives.

2. We can compute bank value as follows. Note that the the marginal distribution of signals is  $s \sim N(\mu_s, \sigma_s^2)$ , where  $\sigma_s^2 = \sigma_u^2 + \sigma_s^2$ . We write  $\varphi(z)$  and  $\Phi(z)$  for the standard normal density and pdf respectively.

The value of a bank, given  $b^i$  and signal-contingent transfer policy  $t(s)$ , is

$$V(b^i, t) = \mathbb{E}[u + t(s)] - (1 - \phi) \Pr[\mathcal{D}^i] \mathbb{E}[u|\mathcal{D}^i] - \psi \Pr[\mathcal{N}^i] \mathbb{E}[t(s) + u - b^i|\mathcal{N}^i] \quad (\text{A.3})$$

$$= \mu_u + \int \hat{V}(s) \varphi\left(\frac{s - \mu_s}{\sigma_s}\right) ds, \quad (\text{A.4})$$

where

$$\hat{V}(s) = t(s) - (1 - \phi) \Pr[\mathcal{D}^i|s] \mathbb{E}[u|\mathcal{D}^i, s] - \psi \Pr[\mathcal{N}^i|s] \left\{ t(s) + E[u|\mathcal{N}^i, s] - b^i \right\}.$$

The cutoff for default given  $s$  is  $u = b^i - t(s)$ . Define the normalized cutoff

$$v(s) = \frac{b^i - t(s) - \mu_{u|s}}{\sigma_{u|s}}$$

We can then compute  $\hat{V}(s)$  by noting that

$$\Pr[\mathcal{D}^i|s] = \Pr[u \leq b^i - t(s) | s] = \Phi(v(s))$$

$$\Pr[\mathcal{N}^i|s] = 1 - \Phi(v(s))$$

and

$$\mathbb{E}[u|\mathcal{D}^i, s] = \mathbb{E}[u|u \leq b^i - t(s), s] = \mu_{u|s} - \sigma_{u|s} \frac{\varphi(v(s))}{\Phi(v(s))},$$

$$\mathbb{E}[u|\mathcal{N}^i, s] = \mathbb{E}[u|u > b^i - t(s), s] = \mu_{u|s} + \sigma_{u|s} \frac{\varphi(v(s))}{1 - \Phi(v(s))}.$$

3. We then characterize the best response of a small bank, given the borrowing choices of other small and large banks, by solving

$$\frac{\partial V^i}{\partial b^i} = \psi \Pr[\mathcal{N}^i] - (1 - \phi) \int_{\partial \mathcal{D}^i} (b^i - t(s)) dF = 0,$$

which allows us to find

$$b^{i*} \left( b^i, b^j, \psi, \phi, \kappa, \lambda, \mu_u, \sigma_u, \sigma_s \right).$$

We can then characterize the aggregate best response of all small banks, given the borrowing choices of large banks, as the solution in  $b^i$  of  $b^i = b^{i*} \left( b^i, b^j, \psi, \phi, \kappa, \lambda, \mu_u, \sigma_u, \sigma_s \right)$ .

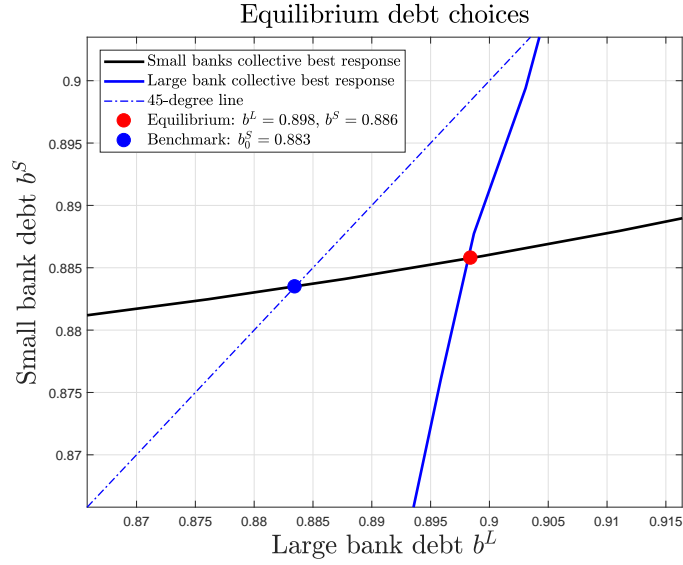


Figure A.1: Equilibrium and best responses

**Note:** This figure is the counterpart of Figure 3 in the text for our baseline parametrization, in which  $\lambda = 0.5$ .

4. For large banks, we optimize directly the bank's objective function, to allow for possible non-concavities in the objective function of large banks. At an interior optimum, large banks best response satisfies

$$\begin{aligned} \frac{\partial V^i}{\partial b^i} &= \psi \Pr[\mathcal{N}^i] - (1 - \phi) \int_{\partial \mathcal{D}^i} (b^i - t(s)) dF \\ &+ \mathbb{E} \left[ \frac{\partial t(s)}{\partial b^i} (1 - \psi \mathbf{1}(\mathcal{N}^i)) \right] + (1 - \phi) \int_{\partial \mathcal{D}^i} \frac{\partial t(s)}{\partial b^i} (b^i - t(s)) dF = 0 \end{aligned}$$

5. Finally, we combine both responses and solve for the value of  $b^i$  for both large and small banks that jointly satisfy banks' best responses. Figure A.1 is the counterpart of Figure 3a), under the baseline calibration of the model.