A macroeconomic model of banks' systemic risk taking

Jorge Abad
Bank of Spain

David Martinez-Miera
UC3M and CEPR

Javier Suarez
CEMFI and CEPR

July 2024

Abstract

We study banks' systemic risk-taking decisions in a dynamic general equilibrium model, highlighting the macroprudential role of bank capital requirements. Bankers decide on the unobservable exposure of their banks to systemic shocks by balancing risk-shifting gains against the value of preserving their capital after such shocks. Capital requirements reduce systemic risk taking but at the cost of reducing credit and output in calm times, generating welfare trade-offs. We find that systemic risk taking is maximal after long periods of calm and may worsen if capital requirements are countercyclically adjusted. Removing deposit insurance introduces market discipline but increases the bank capital necessary to support credit, implies lower (though far from zero) optimal capital requirements, and has nuanced social welfare effects.

Keywords: Capital requirements, Risk shifting, Deposit insurance, Systemic risk, Financial crises, Macro-prudential policies.

JEL Classification: G01, G21, G28, E44

* This paper provides a significant reformulation and expansion of the analysis in Martinez-Miera and Suarez (2014). We would like to thank Matthieu Darracq Pariès, Giovanni Dell'Ariccia, Gianni De Nicolo, Mathias Dewatripont, Martin Ellison, Helmut Elsinger, Carlos González-Aguado, Hans Gersbach, Kebin Ma, Frederic Malherbe, Claudio Michelacci, Enrico Perotti, Rafael Repullo, Diego Rodriguez-Palenzuela, Ruben Segura, Philipp Schnabl, Nicholas Trachter, Harald Uligh, Alexandros Vardoulakis, Wolf Wagner, several anonymous referees, and the audiences at numerous conferences and seminars for helpful comments and suggestions on the old paper. We acknowledge financial support from Bank of Spain and Spanish government grants ECO2010-17158 and JCI-2011-08963 (Martinez-Miera) and from the European Central Bank and Spanish government grants ECO2011-26308, PGC2018-097044-B-I00, and PID2022-142998NB-I00 (Suarez). Contact emails: jorgeabad@bde.es, dmmiera@emp.uc3m.es, suarez@cemfi.es.

1 Introduction

Ben Bernanke, while serving as Chairman of the Federal Reserve Board, defined systemic risk as "developments or events that threaten the stability of the financial system as a whole and consequently the broader economy, not just that of one or two institutions."[1] One such development is banks' exposure to a common source of risk (e.g., subprime mortgages in 2007-2008, sovereign debt of peripheral European countries in 2010-2011, or interest rate risk in 2023). From the perspective of banking papers emphasizing the importance of moral hazard, those exposures should be seen as the result of (unobservable) risk-taking decisions distorted by banks' high leverage and, thus, critically shaped by capital requirements.[2] However, even during systemic crises, not all banks perform the same, suggesting heterogeneity in their ex ante exposures to the undiversifiable sources of risk.[3] According to the risk taking view, banks that fail in a systemic crisis are those that decided to be more exposed to the underlying risk and got trapped by the unfavorable events that trigger a crisis.[4]

Reasoning along these lines, risk-taking incentives vis-à-vis common sources of risk play a crucial role in determining the severity of systemic crises and, therefore, bank capital regulation should be designed with a view on its effects on systemic risk taking.[5] However, adopting this perspective requires answering several fundamental questions: How is banks' systemic risk taking determined in dynamic general equilibrium? Why not all banks are systemic risk takers? Can banks' systemic risk taking explain the contraction in credit and economic activity observed around systemic crises? How effective are capital requirements in mitigating the effects of banks' risk taking on economic performance? What are the economic and welfare trade-offs associated with the use of capital requirements with these purposes?

We address these questions by combining elements of models in the banking tradition with the approach of quantitative macroeconomics. We develop a general equilibrium model that explores the dynamic trade-offs underlying banks' unobservable decision to become exposed to rare but devastating common shocks (that we call *systemic shocks*). We model such

[1] See "Bernanke Offers Broad Definition of Systemic Risk" by Corey Boles (Wall Street Journal, November 18, 2009). This definition is compatible with common measures of systemic risk, including Adrian and Brunnermeier (2016) and Acharya et al. (2017), built on the concurrence of bank equity shortfalls.

[2] See Kareken and Wallace (1978), Keeley (1990), Hellmann et al. (2001), and Repullo (2004), among many other.

[3] In fact, Kim (2024) documents a significant increase in the cross sectional dispersion of bank performance indicators during financial crises, complementing the view in Baron et al. (2021) that banking crisis are characterized by large declines in aggregate bank capital.

[4] This would have been the case of several global investment banks with exposures to subprime mortgages in 2007-2008, many small savings banks with exposures to Spanish real estate in 2008-2009, and banks such as First Republic and Silicon Valley Bank with large exposures to interest rate risk in early 2023 . These examples are consistent with the empirically motivated argument in Coimbra and Rey (2023) that accounting for bank heterogeneity in risk taking is important to explain banking sector performance during crises.

[5] This view is supported by empirical evidence in Jordà et al. (2021) that bank capital ratios do not help predict banking crises but a "more weakly capitalized financial sector going into the crisis is associated with a deeper recession and a slower recovery" (p. 262).

systemic risk taking decisions as primarily influenced by standard limited liability distortions (that push for risk taking) and dynamic considerations regarding the preservation of bank equity in the states where it is more scarce and, hence, more valuable (that push in the opposite direction). We solve for dynamic equilibria in which some banks decide to be systemic risk takers (which implies failing when crises occur) while other avoid the exposure (and survive the crises). We show that capital requirements contribute to reduce systemic risk taking and use our model to analyze their socially optimal level, the trade-offs involved in making the transition to higher capital requirements gradual, and the introduction of cyclical adjustments in the requirements.

In our otherwise standard dynamic stochastic general equilibrium model, there are ex-ante homogeneous banks that finance some bank-dependent investment activities potentially exposed to systemic shocks. Banks can unobservably make their investment exposed to these shocks (systemic) or not exposed (non-systemic). As in the microeconomic literature on risk shifting, the systemic investment mode yields lower expected returns than the non-systemic mode but pays a positive excess return if no systemic shock realizes.[6] Banks are financed with a combination of equity and deposits, managed by some *bankers* in the interest of their equityholders, and subject to a capital requirement that imposes a minimum proportion of equity funding per unit of assets. Risk-shifting incentives arise from the combination of equityholders' limited liability (which makes their levered payoffs convex in asset returns) and the unobservability of banks' investment mode (which precludes using contracts contingent on it).[7]

Bankers dynamically manage the investment of the *representative household* in bank equity in order to maximize the present value of the net dividends paid to the household. They allocate equity across non-systemic and systemic banks, and decide on the discretionary dividends paid back to the household or the new equity funding raised from it. Importantly, equity issuance costs create a (time-varying) wedge between the value of funds already under bankers' management (*bank equity*) and the rest of the household's wealth (invested both in non-bank-dependent activities and in bank deposits). Intuitively, this wedge is ultimately related to banks' intermediation margins, which increase when the greater scarcity of bank equity induces bank-dependent investment to shrink.[8] In our setup, this wedge creates a *scarce-equity-preservation incentive* that operates in opposite direction to the conventional

[6] For seminal references on risk shifting, see Jensen and Meckling (1976) and Stiglitz and Weiss (1981).

[7] Our focus on risk taking regarding banks' exposure to the common systemic shocks makes our contribution related to the analytical contribution of Farhi and Tirole (2012). They show that banks may strategically coordinate to be collectively exposed to the same shocks or sources of risk on the basis of the expectation that, if sufficiently many banks fail at the same time, policy makers may resort to bailing them out. Our analysis abstracts from discretionary bailouts, meaning that we focus on risk shifting distortions not amplified by strategic considerations regarding the subsequent policy response.

[8] This type of wedge is common to papers in the financial accelerator tradition (Kiyotaki and Moore, 1997; Bernake et al., 1999), including those that explicitly incorporate financial intermediaries with limited net worth (e.g. Meh and Moran, 2010; Gertler and Karadi, 2011; He and Krishnamurthy, 2012; Brunnermeier and Sannikov, 2014; Nuño and Thomas, 2017).

risk-shifting incentives. The resulting trade-off explains the existence of interior allocations of bank equity across non-systemic and systemic banks and the dynamics of the equilibrium proportion of bank equity invested in systemic banks (our measure of systemic risk taking). Intuitively, the endogenous level of risk taking is such that, at the margin, the static risk-shifting gains earned by investing in equity of a systemic bank equal the state-contingent equity-preservation gains earned by a non-systemic bank when a systemic shock wipes out the equity of systemic banks.[9] One key feature of our setup is that the existence of a (less efficient) systemic investment opportunity generates a negative externality on (more efficient) non systemic investment. Investment in systemic banks reduces the overall returns banks can appropiate from their investment, due to decreasing returns on capital that operate at the general equilibrium level, reducing the incentives to invest in the non-systemic banks, and in doing so overall expected output and welfare.

We calibrate the model to match steady state and bank crisis moments of the US economy around the 2008-2009 financial crisis. In this baseline parameterization, the capital requirement is 8% (matching the standards set by the Basel agreements prior to the reforms initiated in 2009) and bank deposits are fully guaranteed by a deposit insurance scheme (capturing a feature of reality that we later remove in one of our main counterfactual exercises). We set some of the main parameters governing risk taking and the substitutability between bank-dependent and non-bank-dependent investment for systemic crises to produce declines in the bank credit to GDP and the bank to non-bank ratios similar to those observed in the data. Under that calibration, an average of around 75% of bank equity is invested in a systemic manner and a systemic shock (happening with an unconditional probability of 4% per year) produces average cumulative output and consumption losses of 23.9% and 34.5%, respectively, in the four subsequent years.

The analysis of policy functions and impulse response functions (showing the dynamics of equilibrium variables after the arrival of a systemic shock) reveals that systemic risk taking is, for a given level of the capital requirement, increasing in the aggregate volume of bank equity. This untargeted property, caused by the decrease of the scarce-equity-preservation incentive when bank equity is more abundant, implies that the economy is more vulnerable to systemic shocks after a long time span without experiencing those shocks, when more funds have accumulated under bankers' management.

We then perform a series of counterfactual exercises directed to inform about the role and optimal design of capital requirements in our setup. We first analyze the effects on systemic risk taking and social welfare of changes in the level of the capital requirements. We find that under tighter capital requirements, bank capital becomes effectively scarcer, which enhances the equity-preservation incentive. This effect adds to the standard reduction in risk-shifting

[9] This mechanism resembles the charter value effect of prior literature (e.g. Keeley, 1990) as well as the "last bank standing effect" of Perotti and Suarez (2002), but is different from either of these other mechanisms in that it applies at the level of individual units of preserved equity and is based on scarcity rents instead of market power.

incentives when leverage declines, jointly contributing to reduce the equilibrium level of systemic risk taking.[10] However, changing the level of the capital requirement also comes at the cost of reducing the aggregate investment intermediated by banks, producing a welfare trade-off. Computing the welfare of the representative household under alternative values of the requirement, we find that the socially optimal capital requirement is 15% (almost twice as big as the baseline level). Under this requirement, the bank equity exposed to a systemic shock declines to an average of 48% and the average cumulative impact of a shock on output and consumption (in the four years following the shock) falls to 13.3% and 17.7%, respectively.

The optimal capital requirement does not reduce systemic risk taking to zero (which would be possible with requirements higher than 27%) because of the aggregate investment-reducing effects of forcing banks to operate with lower leverage. Specifically, in the economy with the optimal capital requirement, bank-dependent investment is, on average, 21% lower, bank credit to GDP ratio is 20 percentage points lower (down from 99%), and the ratio of bank to non-bank investment is 16 percentage points lower (down from 66%) than in the baseline economy. While non bank-dependent investment partially substitutes for the decline in bank-dependent investment, output under the optimal capital requirement is on average 1.6% lower. In spite of this, the lower losses associated with systemic risk taking make consumption 13 basis points higher on average, and explain overall welfare gains equivalent to 19 basis points of permanent consumption relative to the baseline economy.

In our second counterfactual exercise we remove deposit insurance, an institution mainly justified to prevent bank runs (that the model does not have) and commonly attributed an adverse effect on banks' risk taking incentives (to the extent that it allows banks to be funded by depositors at risk-insensitive rates). The main purpose of this exercise is to evaluate the importance of deposit insurance for our results and, more generally, to learn how our model works after introducing market discipline. Importantly, banks wanting to adopt the safer non-systemic investment mode and benefit from lower deposit rates need to exhibit incentives compatible with such a strategy. We identify and explore the properties of an equilibrium where some banks commit to a non-systemic risk profile by operating with a voluntary capital buffer in excess of the regulatory minimum, while the rest stick to the regulatory minimum, adopt the systemic investment mode, and pay higher rates on their deposits.[11] So, additionally to the trade-offs operating when deposits are fully insured, banks assessing the comparative value of being non-systemic need to also consider the cost of the additional equity and the benefit of cheaper deposit funding.

We find that without deposit insurance, higher capital requirements primarily affect

[10] Intuitively, with higher requirements, making the non-systemic bank equity returns as attractive to bankers as the systemic ones (an equilibrium indifference condition) does not call for as large aggregate bank equity losses after a systemic shock (to enhance the value of preserving equity) as with lower requirements.

[11] Akin to the "market imposed" capital requirements in Holmstrom and Tirole (1997), the capital buffer chosen by the non-systemic banks is the minimum necessary to guarantee the incentive compatibility of their risk choice under the prevailing general equilibrium conditions.

systemic banks, for which the regulatory minimum is binding, but also have an effect on the size of the buffer held by non-systemic banks. As higher capital requirements make bank capital scarcer and worthier to preserve, a lower equilibrium buffer is needed to make the non-systemic investment mode incentive compatible. We find that, similarly to the setup with deposit insurance, as capital requirements increase systemic risk taking decreases but aggregate investment also falls, so there is a welfare trade-off. The resulting socially optimal level of capital requirements is 13.5%, that is, 1.5 percentage points lower than in the full deposit insurance baseline. Consistent with the notion of market discipline, eliminating deposit insurance under a fixed capital requirement reduces aggregate risk taking (only about 33% of bank equity is invested at systemic banks under the baseline requirement). However, since non-systemic banks operate with a positive buffer on top of the regulatory minimum, removing deposit insurance also reduces aggregate investment. In fact, this second effect is strong enough to explain the relevant finding that, for capital requirements above 7%, the economy with deposit insurance generates higher welfare than the one without deposit insurance.[12] This reveals a non-trivial relationship between the coverage of deposit insurance, capital requirements, and social welfare.[13]

Our findings for the case without deposit insurance clarify that some of the distortions typically attributed to safety net guarantees stem from the (more fundamental) unobservability of risk choices and that the removal of deposit insurance may reduce but does not eliminate the welfare-enhancing role of capital requirements. Our findings highlight that the externalities related to banks' unobservable systemic risk taking decisions (a moral hazard problem) are a source of inefficiencies that can be reduced (i) by introducing capital requirements even in the absence of deposit insurance, and, even more, (ii) by combining deposit insurance with a suitably large capital requirement.

Without deposit insurance, if risk choices were observable, or costless to commit to, all banks would choose the efficient non-systemic investment. However, in our setup, banks have to resort to (in equilibrium) costly scarce capital in order to credibly commit to undertaking the non-systemic investment, and the endogenous cost of scarce capital allows for both systemic and non-systemic banks to operate in equilibrium. As in the case with full deposit insurance, the presence of systemic banks in equilibrium generates a negative pecuniary externality on non-systemic banks as they reduce the attractiveness of non-systemic investment. Imposing higher capital requirements (that only bind for the systemic risk taking banks) reduce the relative attractiveness of undertaking the systemic investment and, hence, the overall investment by systemic banks. This in turn increases the returns and attractiveness of the efficient non-systemic investment mode.

On the other hand, full deposit insurance (accompanied with a sufficiently high capital

[12] For capital requirements above 27% both economies perform identically since systemic risk taking vanishes in either economy.

[13] We do not intend to provide a full cost-benefit analysis of the social value of deposit insurance because our model abstracts from bank runs.

requirement in this case binding for all banks) can improve on the equilibrium without deposit insurance by effectively saving on the scarce equity required to sustain bank intermediated investment. Specifically, deposit insurance removes the incentives of the non-risk-taking banks to use large capital buffers to commit to a prudent risk profile (and thus be funded by depositors at lower rates), which expands the bank-intermediated investment that the economy can sustain.

We complete our analysis with two additional quantitative exercises. We assess both the value of gradualism in the transition to a new level of capital requirements and the macroprudential relevance of cyclically adjusted capital requirements. We first evaluate the welfare implications of different combinations of new target levels of capital requirements and speeds of transition to such targets. The optimal speed of transition considers the welfare losses implied by the credit crunch suffered when the requirements are raised but the economy has not yet accumulated the (higher) levels of bank capital that characterize the steady state of the new regime. We show that gradually implemented increases in capital requirements can be optimally more ambitious, i.e. aim at a higher target requirement. We also show that the starting point of the transition is relevant: reforms in crisis times call for longer implementation horizons than reforms started in normal times.

We then analyze the value of adjusting capital requirements cyclically (in the spirit of the countercyclical capital buffer of Basel III). We show that the optimal degree of adjustment depends on the benchmark level of the capital requirement. With a benchmark of 15%, the optimal cyclical adjustment involves a decrease of 2.4 percentage points during a crisis. In contrast, with a capital requirement of 8%, the adjustment during crises is of only 0.8 percentage points. This highlights that trying to soften the effect of a crisis on credit supply when the benchmark capital requirement is too low would imply a too high cost in terms of systemic risk taking.[14]

The rest of the paper is organized as follows. The remaining of this section reviews the related literature. Section 2 describes the model. Section 3 develops key equilibrium conditions and provides a formal definition of equilibrium. Section 4 contains the baseline calibration of the model and its results regarding systemic risk taking and the response of the economy to the realization of a systemic shock. In Section 5 we analyze the performance of the economy under alternative levels of the capital requirement, identifying the level that maximizes social welfare. In Section 6 we present the results for the counterfactual scenario without deposit insurance. Section 7 discusses the additional exercises in which we allow for gradualism in the introduction of higher capital requirements and explore the social value of adding a cyclical adjustment to the level of the capital requirement. The Appendix contains proofs and other analytical results, a complete list of equilibrium conditions, and several other complementary materials referred throughout the main text.

[14] This effect is consistent with the analytical findings of Horváth and Wagner (2017) in a stylized theoretical framework.

Related literature We add to the growing literature which assesses the socially optimal level of bank capital requirements in dynamic macroeconomic models.[15] Our focus on systemic risk taking in the presence of scarce-equity-preservation incentives makes our contribution complementary to the few papers in this literature that consider an explicit decision regarding banks' asset risk. In the pioneer analysis of the welfare costs of capital requirements by Van den Heuvel (2008), limited liability and deposit insurance distort banks' decisions on the riskiness of their loan portfolio and a higher capital requirement implies lower risk taking. Differently from our setup, there is no aggregate uncertainty and banks' equity funding is frictionlessly raised from households in every period so risk taking is not affected by dynamic trade-offs akin to our scarce-equity-preservation incentives. Collard et al. (2017) focus on the interaction between monetary policy and capital requirements in an environment in which levered banks' temptation to adopt an inefficient risky lending strategy randomly varies over time due to an aggregate shock. However, unlike in our setup, the optimal (state contingent) capital requirement is the minimal one that drives risk taking to zero according to a purely static "skin in the game" logic since, again, banks can frictionlessly raise equity in every period and, hence, no scarce-equity-preservation incentive operates. Begenau (2020) develops a model in which stricter capital regulation affects the risk-return characteristics of the assets of a representative bank via monitoring incentives distorted by government guarantees. However, in contrast to our setup, risk taking lacks a systemic risk dimension and is the same for all banks.[16] In a quantitative model of banking industry dynamics with imperfectly competitive banks, Corbae and D'Erasmo (2021) also capture risk taking as a monitoring decision affecting loan performance. They show that increasing capital requirements, additionally to inducing larger monitoring, makes lending more concentrated in more productive and stable banks, which also contributes to improve financial stability.

In most other papers in the quantitative literature on capital requirements, asset risk is either exogenous or only indirectly affected by the impact of the requirements on lending conditions and, hence, the leverage of the borrowers. In Malherbe (2020) excessive leverage incentives induced by the presence of deposit insurance are found to justify having larger requirements during expansions (when aggregate bank capital is more abundant) than during contractions (when it is scarcer). In Begenau and Landvoigt (2022) capital requirements on

[15] All these papers share in common acknowledging the existence of frictions that create costs associated with the rising of capital requirements. These frictions produce trade-offs which counter proposals to solve financial stability problems due to banks by just imposing sufficiently high capital requirements (see, e.g., Admati and Hellwig, 2013).

[16] Begenau (2020) emphasizes that having valuable liquidity services attached to deposits, from which we abstract, can help counter the credit contraction effects of capital requirements (by making deposits scarcer and, as result, cheaper when the requirements rise). The interaction between the special role of deposits and capital requirements is also central in Davydiuk (2017), focused on characterizing the optimal dynamic adjustment of the requirements but without an explicit decision regarding asset risk, and in Pancost and Robatto (2023), where banks make a risk-shifting choice affecting their exposure to idiosyncratic risk and the presence of corporate deposits implies higher optimal capital requirements.

regulated banks additionally help by reducing the distortions that deposit insurance causes to their competition with unregulated shadow banks.

Elenev et al. (2021) and Mendicino et al. (2018, 2024) consider economies with a rich structure of shocks in which the default rates of borrowers with endogenous leverage decisions affect banks' default risk. Capital requirements protect the economy against default costs that banks do not internalize both through their loss-absorbing role and by inducing a tightening of lending conditions that reduces borrowers' leverage.[17] Like in our setting, capital requirements increase banking sector resilience and frictions in the access to equity funding produce credit contraction effects that entail a welfare trade-off.[18] Differently from these papers, improved resilience in our model does not come from increasing banks' loss absorption capacity or reducing borrowers' leverage, but from inducing a lower endogenous exposure to infrequent but devastating systemic shocks.

We also complement the existing literature by comparing the baseline economy with deposit insurance with a counterfactual economy without deposit insurance. This helps us establish a bridge between the insights of Kareken and Wallace (1978), who were among the first to present capital requirements as a substitute for market discipline when deposits are fully insured, and those of Holmstrom and Tirole (1997), where unregulated banks subject to a moral hazard problem self-discipline their behavior by limiting their (observable) leverage. The dynamic general equilibrium effects present in our setup imply that self-disciplined banks which abstain from systemic risk taking can coexist with non-self-disciplined systemic risk takers, and capital requirements, which are only binding for the latter, can help reduce aggregate systemic risk taking.

Our findings regarding the optimality of setting positive regulatory capital requirements even in the absence of deposit insurance (as well as the welfare value of deposit insurance even in the absence of bank run risk) make our contribution related and complementary to the literature in which macroprudential policy corrects pecuniary externalities, including Bianchi (2011, 2016), Bianchi and Mendoza (2018) and, in a banking context, Gersbach and Rochet (2017) and Gersbach, Rochet, and Schefell (2023).[19] In that literature, imposing leverage constraints on borrowers or banks can help reduce the variation in asset prices across states which, typically, disproportionately affect the investment capacity of financially constrained agents during downturns (an externality not internalized by those undertaking high leverage during booms).[20] In our setup, the externality operates across banks' risk profiles and in

[17]The solvency-enhancing role of capital requirements appears also in Gertler et al. (2020), where coordination problems present in sunspot-like panics can be avoided by activating a capital requirement when macroeconomic conditions make banks weak. Angeloni and Faia (2013) make a similar point.

[18]In a related contribution, Mendicino et al. (2020) consider a New Keynesian monetary setup in which the transition to higher capital requirements is optimally accommodated by loosening monetary policy as well as gradualism in the introduction of the higher requirements, as in our extension dealing with this point.

[19]Research on the welfare relevance of pecuniary externalities in the presence of financial constraints was reactivated by Lorenzoni (2008) and has produced numerous contributions that Dávila and Korinek (2018) review using a stylized unifying analytical framework.

[20]Recent quantitative contributions in this tradition include Di Tella (2019), where financial constraints

interaction with the scarce-equity-preservation incentive. Even without deposit insurance, imposing a minimum capital requirement, enhances the scarce-equity-preservation incentive, reduces the attractiveness of risk shifting, reduces the capital buffer that non-systemic banks need to commit to their risk profile, and improves welfare.

2 The model

Consider an infinite horizon economy with time indexed by $t = 0, 1, 2, ...$ and a single consumption good in every date, which is the numeraire. The economy is populated by a representative household comprised of two classes of agents: a mass one of workers and a mass one of bankers. These agents obtain consumption insurance from the household and interact with each other through a representative consumption-good-producing firm, a representative non-bank-dependent (physical-)capital-producing firm, a continuum of bank-dependent (physical-)capital-producing firms, and a continuum of banks.

Workers inelastically supply one unit of labor to the representative consumption-good-producing firm and transfer their wage income to the household. Households can directly invest in the non-bank-dependent capital-producing firms. Firms producing bank-dependent physical capital can only be funded by banks. Banks invest in such firms using a combination of equity and deposit funding provided by the household. Bankers manage the household's investments in banks' equity and banks are subject to frictions further specified below. Finally, there is also a government that sets bank regulation and runs a deposit guarantee scheme (DGS) which can fully, partially or not at all insure bank deposits and is funded with lump sum taxes.

2.1 Production environment

Non-bank-dependent and bank-dependent firms produce one class of physical capital each, labeled h and b, respectively. These classes of physical capital are not perfect substitutes and, hence, can be eventually rented to the consumption-good-producing firms at different equilibrium rental rates.

The representative firm from the non-bank-dependent sector can transform a_t^h consumption good units from the household in period t into $k_{t+1}^h = a_t^h$ units of physical capital of class h in period $t+1$. Renting this capital at $t+1$ yields a per-unit rental rate r_{t+1}^h and the recovery of $1 - \delta^h$ units of consumption good, where δ^h is the depreciation rate.[21] So the gross return of this class of capital is $R_{t+1}^h = 1 + r_{t+1}^h - \delta^h$.

emanate from a limited commitment problem and macroprudential policy takes the form of a tax on leverage (which should optimally increase with asset prices), and Van der Ghote (2021), where imposing leverage limits to financial intermediaries during booms helps to reduce contractions due to market-based funding constraints during busts.

[21] We model physical capital as fully fungible into consumption good after one period to minimize the number of state variables in the model.

A firm j from the bank-dependent sector can transform a^b_{jt} units of consumption good received from banks in period t into $k^b_{jt+1} = \Delta_{t+1}(s_{jt})a^b_{jt}$ units of physical capital of class b in period $t+1$. Renting this capital at $t+1$ yields a per-unit gross return $R^b_{t+1} = 1 + r^b_{t+1} - \delta^b$, where r^b_{t+1} and δ^b are the corresponding rental and depreciation rates. The term $\Delta_{t+1}(s_{jt})$ captures the possibility of undertaking the investment in two different modes, $s_{jt} = 0, 1$, that differ in their exposure to an aggregate binary *systemic shock*, $\xi_{t+1} = 0, 1$ that realizes at $t+1$. Specifically,

$$\Delta_{t+1}(s_{jt}) = \begin{cases} 1 + \mu s_{jt}, & \text{if } \xi_{t+1} = 0, \\ 1 - \lambda s_{jt}, & \text{if } \xi_{t+1} = 1, \end{cases} \tag{1}$$

where $\mu > 0$ and $\lambda \in (0, 1]$. Thus, under the *non-systemic mode* ($s_{jt} = 0$), each unit of investment returns one unit of class b capital independently of ξ_{t+1}. Under the *systemic mode* ($s_{jt} = 1$), there is a differential gain μ if the systemic shock does not realize ($\xi_{t+1} = 0$) and a differential loss λ if the shock realizes ($\xi_{t+1} = 1$). The systemic shock occurs with an identical and independent probability π per period and

$$\mathbb{E}_t[\Delta_{t+1}(1)] = (1 - \pi)(1 + \mu) - \pi(1 - \lambda) < 1, \tag{2}$$

so that the systemic investment mode yields a lower expected amount of physical capital per unit of investment than the non-systemic mode.[22]

The choice of s_{jt} by firm j in period t is only observable to the firm, its funding banks, and the bankers investing equity in those banks. As we will show below, standard limited liability distortions and the unobservability of s_{jt} to depositors and the government can make the inefficient systemic mode attractive to the banks.[23]

The representative consumption-good producing firm combines non-bank-dependent physical capital k^h_t, bank-dependent physical capital k^b_t, and labor l_t to produce

$$y_t = F(k^h_t, k^b_t, l_t) \tag{3}$$

units of the consumption good, where $F(\cdot)$ is a constant-returns-to-scale production function. The firm maximizes its profits $y_t - r^h_t k^h_t - r^b_t k^b_t - w_t l_t$ taking the rental rates r^h_t and r^b_t and the wage rate w_t as given.

2.2 Households

The representative household maximizes the expected discounted value of its utility,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t), \tag{4}$$

[22] This assumption is consistent with those commonly found in the literature on banks' risk shifting, including Keeley (1990), Hellman et al. (2000), and Repullo (2004).

[23] We abstract from similar distortions in the operation of the non-bank-dependent firms. This could be justified by stating that those firms' production mode is observable to their funding households, who, if confronted with the choice, would optimally impose the efficient non-systemic mode.

where β is the subjective discount factor, c_t denotes the overall consumption of its members, and $u(\cdot)$ is a standard concave, twice continuously differentiable utility function. In each period the household is subject to the following budget constraint:

$$c_t + a_t^h + \int_{\theta \in \Theta_t} d_t(\theta) d\theta = w_t + R_t^h a_{t-1}^h + \int_{\theta \in \Theta_{t-1}} \tilde{R}_t^d(\theta) d_{t-1}(\theta) d\theta + M_t - T_t, \tag{5}$$

where a_t^h is the household's direct investment in non-bank-dependent firms, $d(\theta)$ are the holdings of bank deposits in banks of the category $\theta \in \Theta_t$, with Θ_t representing the set of observationally-different categories of banks in the economy at t. On the right hand side of the budget constraints, w_t is the income associated with workers' unit-inelastic supply of labor, the second term are the returns on the investment in non-bank-dependent firms, and the third term aggregates the (potentially risky) gross returns $\tilde{R}_t^d(\theta) d_{t-1}(\theta)$ in period t of the deposits held in each category of banks at $t-1$. Finally M_t denotes the dividends (net of equity injections) from the bank equity investments managed by bankers, and T_t is the lump-sum tax with which the government covers (when applicable) the cost of deposit insurance on a pay-as-you-go basis.

The household decides on its consumption c_t, investment in non-bank-dependent firms a_t^h, and portfolio of deposits $\{d_t(\theta)\}_{\theta \in \Theta_t}$ for each period t, taking wages, the distribution of the per-unit returns on investment in non-bank-dependent firms and deposits, and the distribution of the future bank equity payments and future lump sum taxes as given.

Considering the possibility of several observationally-different categories of banks $\theta \in \Theta_t$ allows us to encompass the description of both pooling and separating equilibria in the deposit market. As we explain in Section 3 a pooling equilibrium emerges under full deposit insurance, where banks face no funding cost advantage from choosing a capital structure that credibly commits them to the investment in non-systemic firms (in this case Θ_t is a singleton). In contrast, separating equilibria may emerge under partial or no deposit insurance, if some banks use (as we will show) their capital structure to credibly commit to invest in non-systemic firms and, as result, be funded at a lower deposit rate than the other banks (in this case Θ_t will contain two categories).

2.3 Bankers

A mass one of bankers indexed by $i \in [0,1]$ manage the household's investment in bank equity.[24] Let n_{it}^b denote the pre-determined wealth with which banker i starts in period t. The banker can vary that wealth by m_{it} at a pecuniary cost $C(m_{it}^+)$ given by an increasing and convex function with $C(0) = C'(0) = 0$ and $m_{it}^+ \equiv \max\{m_{it}, 0\}$. So, reflecting frictions in the equity raising process, equity issuance ($m_{it} > 0$) is costly while discretionary dividends ($m_{it} \in [-n_{it}^b, 0)$) are not.[25]

[24] Bankers can be interpreted as operators of a 100% equity-funded bank holding company that issues its shares to the household and uses its funds to invest in equity of individual banks.

[25] $C(m_{it}^+)$ can be interpreted as a reduced-form representation of costs implied by agency problems between bankers and the household. The costs may correspond to due diligence in the equity raising process, the

The banker can invest the resulting funds, $n^b_{it} + m_{it}$, in equity of any of the banks. As we explain below, banks specialize in the financing of either non-systemic or systemic firms. Bankers observe the risk profile of each bank and decide at t how much to invest in the equity of non-systemic banks, with gross returns R^e_{0t+1} at $t+1$, and systemic banks, with gross returns R^e_{1t+1}, at $t+1$. Bankers take the distribution of R^e_{0t+1} and R^e_{1t+1} as given. Out of the gross returns earned at $t+1$, an exogenous fraction $1-\psi \in (0,1)$ is paid out to the household and the rest is retained under the management of the banker.[26]

With these ingredients and letting x_{it} denote the fraction of the funds $n^b_{it} + m_{it}$ that banker i invests in banks specialized in systemic firms, the banker's optimization problem can be recursively stated as follows:

$$\begin{aligned} V_t(n^b_{it}) \quad = \quad & \max_{\substack{m_{it} \geq -n^b_{it} \\ x_{it} \in [0,1]}} \left(-m_{it} - C(m^+_{it}) + \mathbb{E}_t \left\{ \Lambda_{t+1}(1-\psi)[(1-x_{it})R^e_{0t+1} + x_{it}R^e_{1t+1}] \right\} (n^b_{it} + m_{it}) \right. \\ & \left. + \mathbb{E}_t \left[\Lambda_{t+1} V_{t+1}\left(n^b_{it+1}\right) \right] \right) \qquad (6) \end{aligned}$$

with

$$n^b_{it+1} = \psi[(1-x_{it})R^e_{0t+1} + x_{it}R^e_{1t+1}](n^b_{it} + m_{it}), \qquad (7)$$

where the first two terms in the expression maximized in the right hand side of (6) account for newly raised equity (or discretionary dividends if $m_{it} < 0$) and its issuance costs; the third term reflects the expected discounted value of the exogenously distributed part of the returns generated at $t+1$ by the investment in bank equity in period t; and the fourth term is the expected discounted value of the wealth retained under bankers' management at $t+1$. Equation (7) is the law of motion of that wealth. As the household is the final receiver of all the payoffs from the wealth that bankers manage, future payments and values are discounted with the stochastic discount factor $\Lambda_{t+1} = \beta u'(c_{t+1})/u'(c_t)$.

2.4 Banks

Banks are constant-returns-to-scale intermediaries that operate between any two consecutive periods. They maximize the net present value of the equity that bankers invest in them. They combine this equity with deposits taken from the household to finance investment in bank-dependent capital-producing firms. Banks observe the production mode of their funded firms and we assume, without loss of generality, that they adopt one of two risk profiles, $s = 0, 1$, investing fully in either non-systemic firms (with $s_{jt} = s = 0$) or systemic

adoption of effective governance standards, and the cost of incentive pay.

[26] This setup is isomorphic to the standard one in the literature (e.g., Gertler and Kiyotaki, 2011) in which, in every period, a random fraction of the bankers exit or retire with the net worth that they own and manage. As in this literature, $\psi < 1$ allows us to focus on situations where the scarcity of the wealth managed by the bankers makes equity a privately more costly source of bank funding than deposits. The payouts implied by $\psi < 1$ might be justified as reflecting some unmodeled agency frictions between bankers and the household whose bank equity investment they manage.

firms (with $s_{jt} = s = 1$).[27] In what follows, to simplify the exposition, we will refer to a representative bank of each risk profile.

In period t, bank s raises equity e_{st} and combines it with deposits d_{st} to invest

$$a_{st} = e_{st} + d_{st} \tag{8}$$

in bank-dependent firms with investment mode $s_{jt} = s$. Importantly, e_{st}, d_{st}, and a_{st} are publicly observable, but the risk profile s is not. The deposits of bank s promise to pay back a gross per-unit rate R^d_{st} of which a fraction $\eta \in [0, 1]$ is insured by the DGS.[28]

As under the various versions of the Basel Accord after 1988, we assume banks to be subject to a minimum prudential *capital requirement* of the form

$$e_{st} \geq \gamma a^b_{st}, \tag{9}$$

which imposes that at least a fraction γ of their assets must be funded with equity.[29]

At $t+1$ the bank obtains gross asset returns $R^b_{t+1}\Delta_{t+1}(s)a_{st}$ and pays back to its security holders according to the seniority of their claims. The bank defaults on its deposits when $R^b_{t+1}\Delta_{t+1}(s)a_{st}$ is below the due repayment $R^d_{st}d_{jt}$. In this case, the DGS and the depositors repossess the fractions η and $1 - \eta$ of $R^b_{t+1}\Delta_{t+1}(s)a_{st}$, respectively, and the DGS pays the insured part $\eta R^d_{st}d_{st}$ back to the depositors. Thus, depositors at bank s effectively receive

$$\tilde{R}^d_{st+1}d_{st} = \eta R^d_{st}d_{st} + (1 - \eta)\min\{R^d_{st}d_{st}, R^b_{t+1}\Delta_{t+1}(s)a_{st}\}, \tag{10}$$

whose second term features potential variation with the realizations of R^b_{t+1} and $\Delta_{t+1}(s)$. Thus, depending on how informative are the observable bank decisions about s, the promised deposit rate R^d_{st} may vary with s (in a separating equilibrium) or alternatively reflect depositors' expectations about the underlying mixture of non-systemic and systemic banks (in a pooling equilibrium).

Finally, since bank equity is junior to deposits and protected by limited liability, its payoffs are

$$R^e_{st+1}e_{st} = \max\{R^b_{t+1}\Delta_{t+1}(s)a_{st} - R^d_{st}d_{st}, 0\}. \tag{11}$$

[27] In principle banks could invest in arbitrary combinations of non-systemic and systemic firms. However, under (2), the investment in systemic firms only makes sense as a result of limited-liability and risk-pricing distortions which would lead the corresponding bank to also prefer to fully concentrate its investment in these firms. See Repullo and Suarez (2004) for a formal statement of this result.

[28] So the polar cases of $\eta = 0$ and $\eta = 1$ represent economies with no deposit insurance and full deposit insurance, respectively.

[29] Consistent with the assumption that banks' risk profile s is not observable to depositors and the government, this requirement is not contingent on s. If the capital requirement could be made contingent on s, setting a sufficiently high requirement for the bank with $s = 1$ could discourage it from operating without having to impose any requirement on the non-systemic bank.

2.5 The government

The government sets banks' regulatory capital requirement γ and runs the DGS. The government finances the net cost of the DGS in every period t by imposing a contemporaneous lump-sum tax T_t on the household.

3 Equilibrium

In this section we first discuss in detail bankers' and banks' optimization problems, together with other important equilibrium conditions of the model. We then provide the formal definition of equilibrium.

3.1 Bankers' decision problem

We start by showing that the value function of any banker i is an affine function of the wealth under her management at the start of period t, n_{it}^b. Intuitively, the value function involves a linear term $v_t n_{it}^b$ that implies a constant marginal shadow value v_t of the wealth under the banker's management in period t and also an intercept v_t^0 which accounts for the extra value of the option to raise additional funds from the household (at a convex cost). The affinity of this value function allows us to describe bankers' portfolio and capital distribution/raising decisions as those of a representative banker. Hence, we drop the subscript i hereinafter.

Proposition 1 *The marginal shadow value of each unit of bankers' wealth n_t^b satisfies*

$$v_t = \mathbb{E}_t \max\{\Lambda_{t+1}(1-\psi+\psi v_{t+1})R_{0t+1}^e, \Lambda_{t+1}(1-\psi+\psi v_{t+1})R_{1t+1}^e, 1\}. \tag{12}$$

The representative banker decides on the share of n_t^b invested in systemic banks' equity according to the rule

$$x_t = \begin{cases} 0, & \text{if } \mathbb{E}_t\left(\Lambda_{t+1}^b R_{0t+1}^e\right) > \mathbb{E}_t\left(\Lambda_{t+1}^b R_{1t+1}^e\right), \\ \text{any } x \in [0,1], & \text{if } \mathbb{E}_t\left(\Lambda_{t+1}^b R_{0t+1}^e\right) = \mathbb{E}_t\left(\Lambda_{t+1}^b R_{1t+1}^e\right), \\ 1, & \text{if } \mathbb{E}_t\left(\Lambda_{t+1}^b R_{0t+1}^e\right) < \mathbb{E}_t\left(\Lambda_{t+1}^b R_{1t+1}^e\right), \end{cases} \tag{13}$$

with $\Lambda_{t+1}^b = \Lambda_{t+1}(1-\psi+\psi v_{t+1})$, and raises ($m_t > 0$) or distributes ($m_t < 0$) wealth from/to the household according to the rule

$$m_t = \begin{cases} \text{any } m \in [-n_t^b, 0] & \text{if } v_t = 1, \\ (C')^{-1}(v_t - 1), & \text{if } v_t > 1. \end{cases}. \tag{14}$$

Proof See Appendix A.

Thus bankers invest in the equity of the banks that offer the highest properly-discounted equity returns. The appropriate discount factor for bankers, Λ_{t+1}^b, is the product of the representative household's stochastic discount factor Λ_{t+1} and the term $(1-\psi+\psi v_{t+1})$

which accounts for the marginal value $v_{t+1} \geq 1$ of the wealth that bankers can retain under their management at $t+1$. Whenever $v_{t+1} > 1$, retained equity returns have extra value to bankers as they avoid incurring the equity issuance costs captured by the function $C(\cdot)$.

The presence of v_{t+1} in Λ^b_{t+1} affects bankers' pricing of risk at t in a way similar to how the household's future marginal utility from consumption affects the stochastic discount factor Λ_{t+1}. Hence, other things being equal, equity returns realizing when v_{t+1} is relatively high are more valuable than those realizing when v_{t+1} is relatively low. This mechanism influences bankers' systemic risk-taking decisions, as it introduces an incentive to obtain equity returns in the states where aggregate bank equity is scarcer. Importantly, this forward-looking force works in favor of prudence and opposite to the more-myopic standard risk-shifting incentives potentially associated with leverage. As shown below, it also facilitates having an interior level of systemic risk-taking in the economy, that is, an equilibrium with $x_t \in (0,1)$ in which the indifference condition in (13) holds.

Finally, the equity issuance pattern described by (14) implies that whenever bank equity earns scarcity rents ($v_t > 1$), raising some additional equity from the household is optimal up to the point where the marginal issuance cost, $C'(m_t)$, equals the net present value of such rents, $v_t - 1$.

The evolution of bankers' aggregate wealth under management can be described by the aggregate counterpart of (7):

$$n^b_t = \psi \left[(1-x_{t-1})R^e_{0t} + x_{t-1}R^e_{1t}\right](n^b_{t-1} + m_{t-1}), \tag{15}$$

while the net transfers from bankers to the households in period t are

$$\begin{aligned} M_t &= (1-\psi)[(1-x_{t-1})R^e_{0t} + x_t R^e_{1t}](n^b_{t-1} + m_{t-1}) \\ &\quad - m_t - C(m_t^+), \end{aligned} \tag{16}$$

where the first term is the non-retained part of the gross returns on previous-period equity, the second is the additional wealth raised by the bankers (or additional discretionary dividends if $m_t < 0$), and the third are the associated equity raising costs.

3.2 Banks' decision problem

Conditional on a risk profile $s = 0, 1$, banks aim to maximize the net present value of their equity which is

$$\mathbb{E}_t \left(\Lambda^b_{t+1} R^e_{st+1} e_{st}\right) - v_t e_{st}, \tag{17}$$

where the first term is the expected value of the gross equity returns generated at $t+1$ and the second is the opportunity cost of the equity raised at t (determined by the shadow value of wealth under bankers' management).[30]

[30] Opposite to bankers in (13), banks treat (the distribution of) R^e_{st+1} as a function of their decisions at t.

Using (11) and defining the bank's capital ratio as $g_{st} = e_{st}/a^b_{st}$ (which implies $d_{st}/a^b_{st} = 1 - g_{st}$), its objective function can also be expressed as

$$\left\{\mathbb{E}_t(\Lambda^b_{t+1} \max[R^b_{t+1}\Delta_{t+1}(s) - R^d_{st}(1-g_{st}), 0]) - v_t g_{st}\right\} a_{st}, \tag{18}$$

which is linear in asset size $a_{st} \geq 0$. So a condition for the bank with risk profile s to operate at finite scale in equilibrium is that the expression in curly brackets (net equity return per unit of assets) is not strictly positive:

$$\mathbb{E}_t(\Lambda^b_{t+1} \max[R^b_{t+1}\Delta_{t+1}(s) - R^d_{st}(1-g_{st}), 0]) - v_t g_{st} \leq 0, \tag{19}$$

and for $a_{st} > 0$ to be optimal, (19) must hold with equality.[31]

From here, the discussion on banks' optimal capital structure under each risk profile s can be addressed considering a bank with asset size normalized to one and, hence, with a net equity return given by the left hand side of (19). Other things being equal, this net equity return is decreasing in R^d_{st}, while its dependence on the capital ratio g_{st} is generally ambiguous. However, as further discussed below, when equity funding is scarce (so that v_t is sufficiently larger than one) and/or deposits are insured (that is, the deposit rate R^d_{st} does not fully reflect the risk that the bank can default on its deposits), deposit funding is typically cheaper to the bank than equity funding and thus the term is decreasing in the capital ratio g_{st}. We will guess and verify that this property holds under all the parameterizations explored in our quantitative analysis.

Next we provide further details on how these conditions particularize in each of the deposit insurance regimes that we will explore in the quantitative part.

3.2.1 The case with full deposit insurance

Under full deposit insurance ($\eta = 1$), bank deposits are completely riskless. So the household is willing to invest in deposits of any bank if the common promised gross deposit rate R^d_t satisfies the Euler equation $(\mathbb{E}_t\Lambda_{t+1})R^d_t = 1$. In this case, the competitive representative bank of risk profile, $s = 0, 1$, takes $R^d_t = 1/(\mathbb{E}_t\Lambda_{t+1})$ as given when solving (18). If under this rate the net equity return per unit of assets is decreasing in the capital ratio g_{st}, then both banks satisfy the minimum capital requirement with equality, making

$$g_{0t} = g_{1t} = \gamma. \tag{20}$$

[31] Notice that in terms of equity return per unit of equity, (19) is equivalent to

$$\mathbb{E}_t(\Lambda^b_{t+1} R^e_{st+1}) = \mathbb{E}_t\left(\Lambda^b_{t+1}\frac{\max\{R^b_{t+1}\Delta_{t+1}(s) - R^d_{st}(1-g_{st}), 0\}}{g_{st}}\right) \leq v_t$$

which is compatible with bankers' optimization in (13) in the sense that whenever bankers are willing to allocate some strictly positive equity funding to bank s, such a bank is willing to operate at strictly positive scale and vice versa.

Under the binding capital requirement, condition (19) particularizes to

$$\mathbb{E}_t \left[\Lambda^b_{t+1} \max\{R^b_{t+1}\Delta_{t+1}(s) - R^d_t(1-\gamma), 0\}\right] - v_t\gamma \leq 0, \tag{21}$$

which must hold with equality for $a_{st} > 0$ to be optimal.

3.2.2 The case without full deposit insurance

Without full deposit insurance ($\eta \in [0, 1)$), bank deposits are potentially risky and have to be priced accordingly.[32] However, the gross deposit rate R^d_{st} will be the same for all banks which are observationally equivalent at the time the deposits are taken. Accordingly, households' willingness to invest in deposits of banks of a given observationally-equivalent category $\theta \in \Theta_t$ in period t requires satisfying the Euler equation

$$\mathbb{E}_t \left[\Lambda_{t+1} \left\{[1-\omega_t(\theta)]\tilde{R}^d_{0t+1}(\theta) + \omega_t(\theta)\tilde{R}^d_{1t+1}(\theta)\right\}\right] = 1, \tag{22}$$

with

$$\tilde{R}^d_{st+1}(\theta) = \eta R^d_t(\theta) + (1-\eta)\min\{R^d_t(\theta), R^b_{t+1}\Delta_{t+1}(s)/(1-g_{st})\}, \tag{23}$$

where $\omega_t(\theta)$ measures the proportion of deposits of category θ that households expect to end up in the systemic bank and $\tilde{R}^d_{st+1}(\theta)$ denotes the realized gross returns on the deposits that end up in bank s. The expression for $\tilde{R}^d_{st+1}(\theta)$ comes from evaluating (10) at $R^d_{st} = R^d_t(\theta)$.[33]

Each bank's capital ratio g_{st} and asset size a_{st} are both observable to households. However, given that (18) is linear in a_{st} (banks operate under constant returns to scale), only the capital ratio g_{st} can help households to possibly identify a bank's risk profile s.[34] So, in our analysis of the case with $\eta < 1$, we will explore the possibility of sustaining a fully *separating equilibrium* in which $g_{0t} \neq g_{1t}$ and the household can distinguish each banks' risk profile through its capital ratio.[35]

In a fully separating equilibrium, the set Θ_t contains two categories, one for each risk profile. Letting $\theta = 0$ correspond to banks with $s = 0$ and $\theta = 1$ to banks with $s = 1$, we can write $\omega_t(0) = 0$ and $\omega_t(1) = 1$ and the deposit rates applicable to each profile, $R^d_{0t} = R^d_t(0)$ and $R^d_{1t} = R^d_t(1)$, can be found by evaluating (22) for $\theta = 0$ and $\theta = 1$, respectively.[36]

[32] Specifically, in the parameterizations explored in the quantitative part, the non-systemic bank ($s = 0$) is solvent at all times and its deposits are risk free, while the systemic bank ($s = 1$) is solvent in normal times ($\xi_{t+1} = 0$), but defaults on its deposits when a systemic shock occurs ($\xi_{t+1} = 1$).

[33] We have divided through by d_{st} in (10) and used the definition of g_{it} to write a_{it}/d_{it} as $1/(1-g_{it})$.

[34] While we refer to a representative bank with each risk profile s, there could be an undetermined large number of banks with each profile and generally undetermined individual sizes adding up to a_{st}.

[35] If we restrict attention to equilibria in which all banks of a given risk profile s behave symmetrically, the only other possible type of equilibrium is a pooling equilibrium with $g_{0t} = g_{1t}$.

[36] In contrast, in a pooling equilibrium, risk profiles would be indistinguishable to the household at t. So Θ_t is a singleton and we can drop the argument θ from the equations where it appears. The single pooling deposit rate R^d_t would satisfy (22) taking into account the proportions $1-\omega_t$ and ω_t of deposits that the household expects to end up in the non-systemic and the systemic bank, respectively.

To sustain a separating equilibrium the following incentive constraints must be satisfied: (i) the non-systemic bank, operating under a capital ratio $g_{0t} \geq \gamma$ and paying the gross deposit rate R^d_{0t} implied by the above formulas, must prefer the risk profile $s = 0$ to $s = 1$:

$$\begin{aligned} & \mathbb{E}_t \left[\Lambda^b_{t+1} \max\{R^b_{t+1}\Delta_{t+1}(0) - R^d_{0t}(1 - g_{0t}), 0\}\right] - v_t g_{0t} \\ \geq\ & \mathbb{E}_t \left[\Lambda^b_{t+1} \max\{R^b_{t+1}\Delta_{t+1}(1) - R^d_{0t}(1 - g_{0t}), 0\}\right] - v_t g_{0t}, \end{aligned} \tag{24}$$

and (ii) the systemic bank, operating under a capital ratio $g_{1t} \geq \gamma$ and paying the gross deposit rate R^d_{1t} implied by the above formulas, must prefer the risk profile $s = 1$ to $s = 0$:

$$\begin{aligned} & \mathbb{E}_t \left[\Lambda^b_{t+1} \max\{R^b_{t+1}\Delta_{t+1}(1) - R^d_{1t}(1 - g_{1t}), 0\}\right] - v_t g_{1t} \\ \geq\ & \mathbb{E}_t \left[\Lambda^b_{t+1} \max\{R^b_{t+1}\Delta_{t+1}(0) - R^d_{1t}(1 - g_{1t}), 0\}\right] - v_t g_{1t}. \end{aligned} \tag{25}$$

Additionally, we will guess and verify that, conditional on s and taking into account the dependence of the deposit rate R^d_{st} with respect to the capital ratio g_{st}, each bank's net equity return per unit of assets is decreasing in g_{st} so that, among the values of g_{0t} and g_{1t} that satisfy (24) and (25), respectively, both banks prefer the lowest feasible ones.

Under these conditions, the following partial equilibrium properties can be established:[37] (i) (24) holds for sufficiently high values of g_{0t}, and (ii) (25) holds for an overlapping interval of sufficiently low values of g_{1t}. To see this, notice that, other things equal, risk shifting (the greater variability of $\Delta_{t+1}(1)$ combined with the convexity of equity payoff implied by limited liability) is more attractive at t for the bank that faces higher repayment obligations $R^d_{st}(1-g_{st})$ at $t+1$. Now, repayment obligations at $t+1$ are decreasing in g_{st} and increasing in R^d_{st}, while gross deposit rates in the separating equilibrium feature $R^d_{0t} < R^d_{1t}$ whenever $g_{0t} \geq g_{1t}$.[38]

From a partial equilibrium perspective, the following three possible cases may arise:

1. If the capital requirement γ is lower than the minimum value of the capital ratio g_{0t} that satisfies (24), call it $\bar{g}_{0t}$, then (25) will be satisfied for the capital ratio $g_{1t} = \gamma$, and the separating equilibrium will involve $g_{0t} = \bar{g}_{0t} \geq g_{1t} = \gamma$.

2. If the capital requirement γ is strictly higher than $\bar{g}_{0t}$ but lower than the maximum value of the capital ratio g_{1t} that satisfies (25), call it $\bar{g}_{1t}$, then both (24) and (25) can be satisfied for $g_{0t} = g_{1t} = \gamma > \bar{g}_{0t}$.

3. If the capital requirement γ is strictly higher than $\bar{g}_{1t}$, then (25) cannot be satisfied by any capital ratio $g_{1t} \geq \gamma$, while (24) can be satisfied by just choosing $g_{0t} = \gamma > \bar{g}_{1t} > \bar{g}_{0t}$.

[37] By partial equilibrium, we mean for given distributions of the returns R^b_{t+1} and the stochastic discount factors Λ^b_{t+1} and Λ_{t+1} that enter (24), (25), and the Euler conditions determining the gross deposit rates that banks must promise to attract deposits under each s and g_{st}. These distributions are taken as given by banks when deciding on s, g_{st}, and a_{st}.

[38] To provide further intuition on these properties, Appendix B considers a variation of the model without aggregate uncertainty in which the implied threshold values of g_{0t} and g_{1t} can be written in closed form.

Clearly, in Case 3 ($\gamma > \bar{g}_{1t}$), the separating equilibrium would degenerate in an equilibrium in which only the non-systemic bank is active. In Case 2 (as well as in some instances of Case 1), something similar occurs but not because of the impossibility of satisfying (25) but because of the suboptimality of operating a bank under $s = 1$.[39] Thus, (i) having banks with both risk profiles operating in equilibrium requires being in Case 1 ($\gamma \leq \bar{g}_{0t}$), and (ii) even in Case 1 there is an interval of sufficiently high values of γ for which only the non-systemic bank is active in equilibrium. The quantitative exploration of a possible separating equilibrium in subsection 6 will confirm that these implications also prevail in general equilibrium, when the full variability of the endogenous variables with respect to γ is taken into account.

3.3 Definition of equilibrium

In equilibrium, the state of the economy at any period t can be summarized by the two state variables collected in the vector $\mathbf{N}_t = \{n_t^b, n_t^h\}$: the aggregate wealth under bankers' management at the start of the period n_t^b, and the wealth of the representative household

$$n_t^h \equiv R_t^h a_{t-1}^h + \sum_{s=0,1} \widetilde{R}_{st}^d d_{st-1} + w_t + (1-\psi)[(1-x_t)R_{0t}^e + x_t R_{1t}^e](n_{t-1}^b + m_{t-1}) - T_t, \quad (26)$$

(which is the predetermined part of the household's budget constraint in (5)).

A competitive equilibrium is given by the policy functions of the representative household ($c(\mathbf{N})$, $d_0(\mathbf{N}), d_1(\mathbf{N}), a^h(\mathbf{N})$), the representative banker ($x(\mathbf{N})$, $m(\mathbf{N})$), the representative bank of each risk profile $(a_s^b(\mathbf{N}),\ g_s(\mathbf{N}))_{s=0,1}$, and the representative final-good producing firm ($k^h(\mathbf{N}), k^b(\mathbf{N}), l(\mathbf{N})$), a tuple of equilibrium prices ($v(\mathbf{N})$, $R_0^d(\mathbf{N})$, $R_1^d(\mathbf{N})$, $r^h(\mathbf{N})$, $r^b(\mathbf{N})$ $w(\mathbf{N})$), and a sequence of lump-sum taxes T_t, all defined over some relevant support for $\mathbf{N}$, such that for any sequence of realizations of the systemic shock $\{\xi_t\}_{t=0,1,\ldots}$:

1. The sequence of consumption and saving decisions $\{c_t, d_{0t}, d_{1t}, a_t^h\}_{t=0,1,\ldots}$ implied by ($c(\mathbf{N})$, $d_0(\mathbf{N}), d_1(\mathbf{N}), a^h(\mathbf{N})$) solve the problem of the representative household.

2. The sequences of bank equity allocations $\{x_t\}_{t=0,1,\ldots}$, dividend payments $\{m_t^-\}_{t=0,1,\ldots}$, and equity issuance $\{m_t^+\}_{t=0,1,\ldots}$ implied by ($x(\mathbf{N})$, $m(\mathbf{N})$) solve the problem of the representative banker.

3. The sequences of asset size decisions $\{a_{st}^b\}_{t=0,1,\ldots}$ and capital ratio decisions $\{g_{st}\}_{t=0,1,\ldots}$ implied by ($a_s^b(\mathbf{N})$, $g_s(\mathbf{N})$) solve the problem of the representative bank of risk profile $s \in \{0,1\}$. With full deposit insurance, both risk profiles pool at (i) the minimum capital ratio $g_0(\mathbf{N}) = g_1(\mathbf{N}) = \gamma$, and (ii) a common deposit rate $R_0^d(\mathbf{N}) = R_1^d(\mathbf{N}) = R^d(\mathbf{N})$

[39] In particular, since in a separating equilibrium deposit rates are fairly priced for each risk profile, the assumption in (2) on the inefficiency of the systemic production mode implies that operating the systemic bank while having $g_{0t} = g_{1t} = \gamma$ (or, by continuity, a choice of g_{1t} not sufficiently lower than g_{0t}) cannot be optimal from bankers' standpoint (that is, bankers would optimally set $a_{1t} = 0$ when maximizing (18) or, equivalently, $x_t = 0$ when applying (13)).

that satisfies households' relevant Euler condition. Without full deposit insurance, (i) the non-systemic bank operates under the minimum capital ratio $g_0(\mathbf{N}) \geq \gamma$ that satisfies (24), (ii) the systemic bank either operates under $g_1(\mathbf{N}) = \gamma$ (when (25) is satisfied by $g_1(\mathbf{N}) = \gamma$) or remains inactive (otherwise), and (iii) $R^d_0(\mathbf{N})$ and $R^d_1(\mathbf{N})$ satisfy households' relevant Euler conditions.

4. The sequence of input choices $\{k^h_t, k^b_t, l_t\}_{t=0,1,\ldots}$ implied by $(k^h(\mathbf{N}), k^b(\mathbf{N}), l(\mathbf{N}))$ solves the problem of the representative consumption-good producing firm.

5. The bank equity market, the deposits market, the physical capital markets, and the labor market clear.

6. The government satisfies its budget constraint.

7. The components of the state vector $\mathbf{N}_t$ evolve according to their respective laws of motion.

Appendix C provides the exhaustive list of equilibrium conditions, including those that reflect the optimal solution to the decision problems of the household and the consumption-good-producing firm as well as all the relevant market clearing conditions.

3.4 Functional forms

For the quantitative analysis below, we adopt conventional functional forms for the functions not fully specified in prior subsections. For the household's utility function, we set

$$u(c_t) = \log(c_t). \tag{27}$$

The cost of raising new equity is specified as

$$C(m^+_t) = (\kappa_0 m^+_t)^{\kappa_1}, \tag{28}$$

with $\kappa_0 > 0$ and $\kappa_1 > 1$, which satisfies the properties stated in the model section. The production function of the consumption-good producing firm is Cobb-Douglas with

$$F(k^h_t, k^b_t, l_t) = K(k^h_t, k^b_t)^\alpha l_t^{1-\alpha}, \tag{29}$$

where $\alpha \in (0, 1)$ and $K(k^h_t, k^b_t)$ is a physical capital composite

$$K(k^h_t, k^b_t) = \left[\phi(k^h_t)^\sigma + (1-\phi)(k^b_t)^\sigma\right]^{\frac{1}{\sigma}}, \tag{30}$$

with $\phi \in (0, 1)$ and $\sigma > 0$, that features a constant elasticity of substitution $1/(1-\sigma)$ between the physical capital produced by non-bank dependent firms k^h and that produced by bank dependent firms k^b.

4 Quantitative analysis

In this section, we calibrate the model and explore its quantitative properties, including the response of the baseline economy to the realization of a systemic shock. To fully account for non-linearities, we rely on a global numerical solution method (policy function iteration). As a baseline, we consider the case in which the DGS provides full deposit insurance ($\eta = 1$), thus studying the effects of the capital requirement in a world where deposits expect a full bail-out when banks fail. In Section 6, we explore, as a second counter-factual exercise, the quantitative implications of removing deposit insurance and the effects of capital requirements in the absence of deposit insurance.

4.1 Calibration

The model is calibrated at an annual frequency and with the aim to represent the US economy in the years surrounding the Global Financial Crisis of 2008-2009. The calibration proceeds in two steps. For a first group of parameters, we fix values commonly used in the literature or equal to their directly observable empirical counterparts. The remaining ones are simultaneously set so as to match key targets concerning the economy's stochastic steady state (SSS) and its response to the realization of a systemic banking crisis ($\xi_t = 1$).[40]

Table 1 reports all parameter values and their calibration sources or targets. Table 2 compares the values of the six targeted moments in the data and in the model.

Pre-set parameters. The subjective discount rate, β, is set to a standard 0.98, delivering a risk-free rate around 2%. The output share α of the physical capital composite K is set to a standard 0.3 and the depreciation rates for both classes of physical capital, δ_h and δ_b, are set equal to a standard 0.1 per year.

The probability of a systemic event π is set at 4% which is the frequency of financial crises after 1971 reported by Schularick and Taylor (2012) based on evidence in Bordo et al. (2001) and coincides with the target for the unconditional probability of a crisis set by Krishnamurthy and Li (2024) based on several other sources. The value of the systemic risk-taking loss parameter λ is consistent with the combination of the loss-given-default (LGD) parameter of 45% that the foundation approach of Basel II (BCBS, 2004 paragraph 287) fixed for senior corporate loans without specific collateral, and the 30% average discounted total resolution cost per unit of assets estimated by Bennett and Unal (2015) using FDIC data from failed banks in the period 1986-2007. The minimum capital requirement γ is set to 8%, consistent with the general requirement under Basel II (BCBS, 2004; part 2.I, paragraph 40) as well as its Basel I predecessor.

[40] Since the only source of aggregate risk is the binary systemic shock ξ_t, we define the SSS as the invariant equilibrium allocation attained after sufficiently many periods without the shock taking value one.

Table 1
Calibration: pre-set and calibrated parameters

Parameter		Value	Source/Target
Subjective discount rate	β	0.98	Standard
Output share of physical capital composite	α	0.3	Standard
Depreciation rate of physical capital	δ_h, δ_b	0.10	Standard
Probability of systemic event	π	0.04	Schularick&Taylor (2012)
Risk-taking losses	λ	0.615	BCBS (2004), Bennet&Unal (2015)
Capital requirement	γ	0.08	BCBS (2004)
Deposit insurance coverage	η	1	Full deposit insurance
Risk-taking gains	μ	0.012	Crisis fall in credit/GDP ratio
Retained wealth-under-management	ψ	0.85	Return on bank equity
Non-bank-dependent share in capital	ϕ	0.53	Bank/non-bank ratio
Substitution parameter capital composite	σ	0.65	Crisis fall in bank/non-bank ratio
Equity issuance cost, scale parameter	κ_0	125	Bank equity issuance
Equity issuance cost, elasticity parameter	κ_1	10	Crisis bank equity issuance

This table reports the values of the parameters in the baseline calibration. The first block of the table contains parameter sets following convention or direct empirical estimates. The second block contains parameters set to match some target moments further described in Table 2.

Calibrated parameters. The second set of parameters are calibrated so as to simultaneously match the targets listed in Table 2. Each parameter can be mainly associated with one target, as a indicated in the last column of Table 1. Several parameters are set so that some variables in the SSS of the model match sample averages for the (non-crisis) period 1993-2006, while others are calibrated so that the model replicates variations observed in systemic banking crises relative to normal times. Following the convention in the empirical literature on banking crises, we define the moments concerning these crisis-related variations, by defining a crisis period as the four-year window that starts when a systemic shocks hits (Laeven and Valencia, 2018).

The risk taking gains parameter μ is set to match the average fall of about 30 percentage points in the credit to GDP ratio during a crisis. In the data, the pre-crisis year is chosen to be 2008, while the four-year crisis period covers years 2009-2012. In the model, the pre-crisis year value is taken to be the SSS value of the corresponding variable, while the four-year crisis period value is the mean of the values obtained in the four years following the realization of a systemic shock when the economy is in such a SSS.

Bankers' wealth retention rate ψ is set to 0.85 to match the about 12% average real return on average equity for US banks in the period 1993-2006.[41] The share of non-bank-dependent physical capital in the physical capital aggregator defined in (30), ϕ, is fixed to match the about 70% bank to non-bank financing ratio in the economy, which is obtained following the

[41] We compute the return on average equity for each year as the ratio of Net Income (call item RIAD4340) to Average of Total Equity Capital (call item RCFD3210) in the FFIEC Reports of Condition and Income for All Insured U.S. Commercial Banks (https://fred.stlouisfed.org/series/USROE) and adjust it for inflation using the GDP deflator reported by the US Bureau of Economic Analysis (https://fred.stlouisfed.org/series/GDPDEF).

same procedure as in De Fiore and Uhlig (2011).[42] The value of the elasticity of substitution parameter in the physical capital aggregator, σ, is set to replicate the about 35% fall in the bank to non-bank ratio during crises.

Finally, to calibrate the parameters related to the cost of equity issuance, κ_0 and κ_1, we target banks' equity issuance ratio in the SSS (4.6% of pre-existing equity) and during crises (7.6%), respectively. We estimate US banks' equity issuance using aggregate balance sheet and income and expense data for FDIC-insured commercial banks and savings institutions for the period 1993-2012.[43] We assimilate the equity issuance in the SSS to the average equity issuance in the period 1993-2006, and "crisis bank equity issuance" to the average issuance observed in 2009-2012.

Table 2
Calibration: targeted moments
Stochastic steady state (SSS) values, in % (unless indicated)

Variable	Data	Model
Crisis fall in credit/GDP ratio (4-year average, % of SSS value)	30.3	30.9
Return on bank equity	12.44	12.97
Bank/non-bank ratio	69.9	69.9
Crisis fall in bank/non-bank ratio (4-year average, % of SSS value)	35.4	31.3
Bank equity issuance (% of pre-issuance equity)	4.61	4.14
Crisis bank equity issuance (4-year average, % of pre-issuance equity)	7.61	8.03

This table reports data and model values of moments targeted to calibrate the second block of parameters in Table 1. In model terms, moments with the label "crisis" are defined as the mean of the corresponding variable (or fall in a variable) in the four years following the realization of a systemic shock (relative to its SSS value).

4.2 Systemic risk taking and crises in the baseline economy

The different panels of Figure 1 provide an account of the co-movement between three key endogenous variables. In columns, the panels depict the expected intermediation margin of the non-systemic bank ($E_t(R^b_{t+1}) - R^d_t$), the marginal value of bank equity (v_t), and the fraction of bank equity invested in systemic banks (x_t, denoted "systemic exposure" in figures and tables throughout the paper). Panels in the first row show these variables as functions of the wealth under bankers' management n^b_t (with the variation in the other state variable captured by the differently colored curves in each panel). The second row is symmetrically constructed with the wealth of the representative household n^h_t in the horizontal axis (and

[42] In particular, we identify such a ratio with the ratio of corporate loans to corporate securities, which is calculated using the balance sheet of nonfinancial corporate businesses reported in the US Flow of Funds Accounts (Table B.103). Securities are the sum of commercial paper, municipal securities and corporate bonds. Loans are the sum of bank loans, mortgages and other loans and advances.

[43] Using data reported in the FDIC Quarterly Banking Profile (https://www.fdic.gov/analysis/quarterly-banking-profile/), we define Before-issuance Equity in period t as Total Equity Capital in period t-1 plus Retained Earnings in period t (which is the difference between Net Income and Cash Dividends on Common and Preferred Stock). Then we estimate Equity Issuance as the difference between Total Equity Capital in period t and Before-issuance Equity.

the variation in n_t^b captured by the different curves in each panel). The first row shows how as bank equity becomes more abundant, banks' intermediation margin declines, the marginal value of bank equity declines, and systemic risk taking increases.[44] This happens because banks expand their investment in bank-dependent assets whose marginal return is decreasing at the aggregate level (a general equilibrium effect). The declining profitability of intermediation pushes the marginal value of bank equity down and both static (limited liability) and dynamic (equity preservation) considerations encourage bankers to take greater systemic risk.

In contrast to what would happen in a static version of our model, the aggregate systemic risk taking is not bang-bang but interior. This is due to the scarce-equity-preservation incentive and its dependence on x_t. The larger the fraction of bank equity exposed to the systemic shock, the larger the value of protecting equity against the shock since its realization would cause a larger decline in bank equity n_{t+1}^b and hence a larger increase in its shadow value v_{t+1}.[45] Due to to the convexity of $v_{t+1} = v(n_{t+1}^b)$ in n_{t+1}^b, the rise in the shadow value v_{t+1} implied by the realization of the systemic shock at date $t+1$ declines with the abundance of equity at date t, n_t^b. Thus maintaining the incentives for some equity to be invested in a non-systemic manner at t requires systemic risk taking x_t to increase with n_t^b.

One implication of this result is that the systemic shock will tend to cause a more severe damage the longer the economy has been in expansion (and thus the closest n_t^b is to its SSS level). The endogenous buildup of vulnerabilities that we quantify is sizeable. In the SSS, where the value of n_t^b is approximately 0.095, more than 75% of bank equity is invested in a systemic manner. In contrast, if the systemic shock realizes at that point, n_{t+1}^b declines to about 0.04 and systemic exposure declines to about 60%.

The second row in Figure 1 shows that household wealth n_t^h also decreases banks' intermediation margins since it contributes to expand the investment in non-bank-dependent physical capital, pushing down the overall returns on physical capital. However, n_t^h does not reduce but actually slightly increases the marginal value of bankers' wealth (as it implies a lower discount rate). All in all, n_t^h has a small negative effect on systemic risk taking.

Altogether, the results from both rows in Figure 1 imply that systemic risk taking increases when the wealth ratio n_t^b/n_t^h (an endogenous driver of the empirically observable bank-to-non-bank ratio) increases, as it is the case when the economy spends time without experiencing a systemic shock. Higher systemic risk taking contributes to inflate standard indicators of economic activity (output, consumption, investment, wages, etc.) as well as bank dividends as long as the systemic shock does not realize. However, it also increases the exposure to systemic shocks (and the costs not fully internalized by the risk taking banks).

[44] While the intermediation margin turns negative for some combinations of state variables, these combinations are never visited in the ergodic distribution of possible states.

[45] The scarce-equity-preservation incentive resembles the "last-bank-standing effect" obtained by Perotti and Suarez (2002) in a partial equilibrium duopolistic setup when the failure of one bank allows the survivor to gain market power, thus implicitly rewarding prudence.

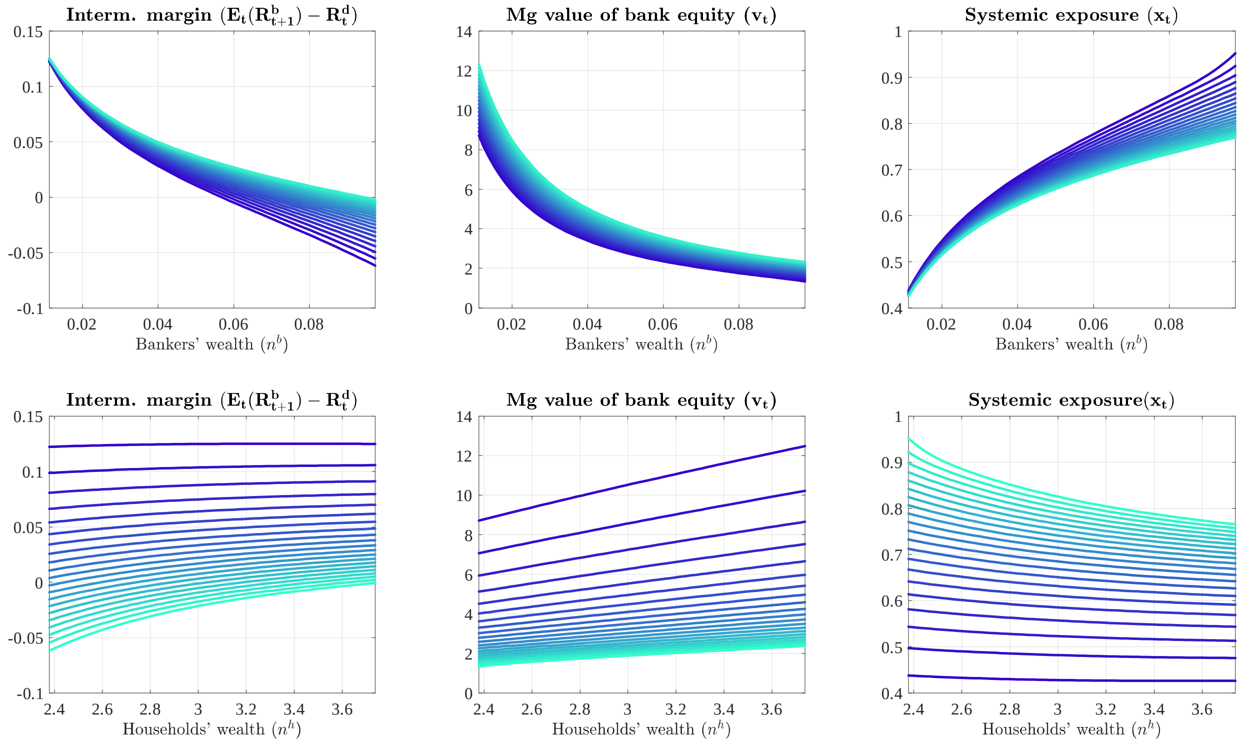

Figure 1. Equilibrium values of selected variables

Vertical axes: variable values (in levels). Horizontal axes: state variable values (in levels), where n^b is wealth under bankers' management and n^h is aggregate household wealth. Each line keeps fixed the value of the other state variable, with lighter shades of blue representing larger values.

Figure 2 shows the response of key aggregate variables to the realization of a systemic shock in the SSS (assuming the shock arrives at $t = 0$ and then not again during the subsequent periods). In the baseline economy (solid lines), the shock causes, on impact, a loss of about 45% of bank-dependent assets, a fall in output of 7%, and bank equity losses of about 75% (since the equity invested in systemic banks is fully wiped out). While equity issuance partly offsets these losses, the wealth under bankers' management falls by about 65% on impact. This provokes a similar reduction in bank credit (bank dependent investment), which largely explains the fall in output also in the second year (with the fall at $t = 1$ exceeding that at $t = 0$).[46]

The wealth under bankers' management and, thus, bank equity, bank credit, and output gradually recover from $t = 1$ onwards. The "scarce equity preservation effect" explains a (gradually diminishing) reduction in systemic risk taking after the systemic shock. The fall in consumption is very significant and persistent, exceeding the fall in output because of the wealth destruction effect of the shock. The representative household also suffers the taxes needed to cover the deposit insurance costs as well as the consequences of the credit crunch

[46] This decline of output at $t = 1$ occurs in spite of the partly compensating rise in non-bank dependent investment, which makes the bank-to-non-bank ratio first decline and then gradually recover after the shock.

(including, below normal wage income throughout the recovery path). Until banks fully recover their pre-crisis equity levels, the economy features reduced leverage (a low credit to GDP ratio) and a low bank to non-bank ratio.

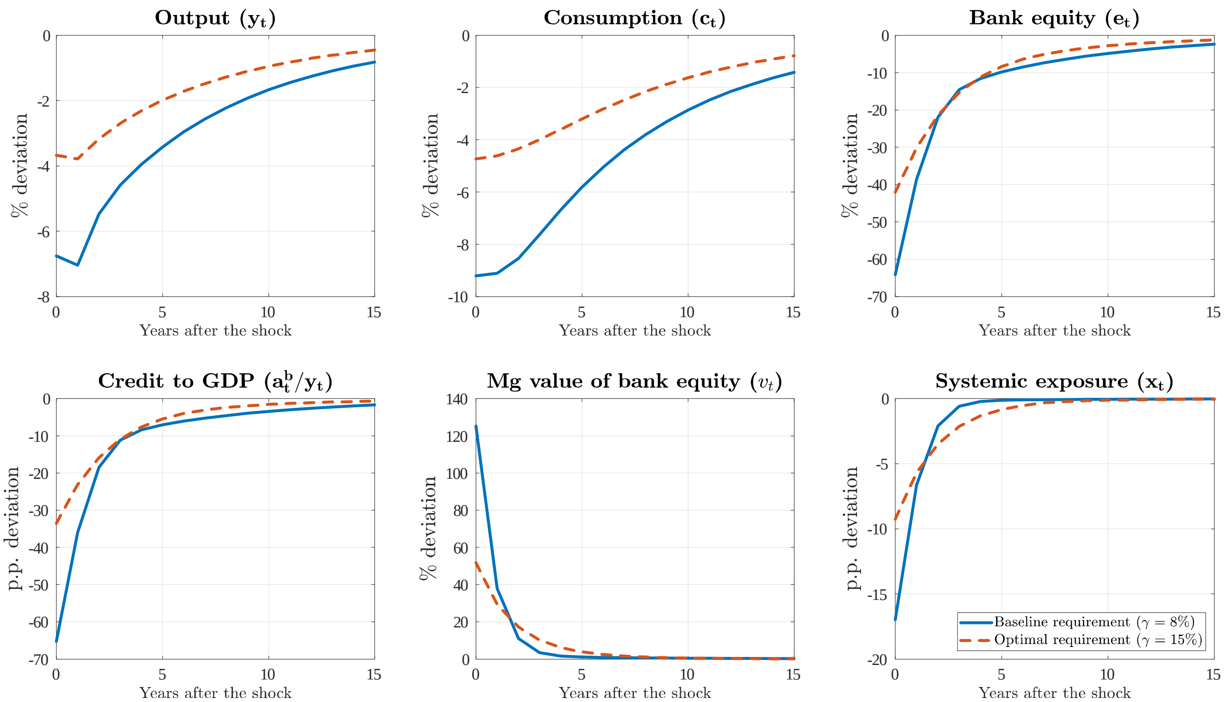

Figure 2. Endogenous responses to a systemic shock

Vertical axes: deviations from the stochastic steady state (units as indicated). Horizontal axes: years since the realization of the shock. The realization of the systemic shock is set to zero for a sufficiently large number of years before t=0, set to one at t=0, and again to zero for the remaining number of displayed years. Solid blue lines: baseline capital requirement (8%). Dashed red lines: optimal capital requirement (15%).

To provide a more systematic description of the baseline economy and its vulnerability to systemic shocks, Table 3 describes the means of key macroeconomic and banking aggregates and ratios, as well as their average deviation during crisis periods (the four-year window that starts with the realization of a systemic shock).

Table 3
Endogenous variables under baseline and optimal capital requirements
Unconditional means and variation during crises

	Unconditional means			Crisis variation (4-year average)		
	Baseline CR	Optimal CR		Baseline CR	Optimal CR	
Level variables	$\gamma = 8\%$	$\gamma = 15\%$	% diff.	$\gamma = 8\%$	$\gamma = 15\%$	p.p. diff.
Welfare (certainty-equivalent permanent-consumption units)	0.8127	0.8143	0.19	-1.18	-0.64	0.54
Consumption	0.8134	0.8144	0.13	-7.60	-3.91	3.68
Output (= GDP)	1.0968	1.0787	-1.65	-5.31	-2.99	2.32
Non-bank-dependent assets	1.6432	1.7237	4.90	-1.13	1.47	2.60
Bank-dependent assets (= Credit)	1.0886	0.8608	-20.92	-29.01	-24.34	4.67
Bank deposits	1.0015	0.7317	-26.94	-29.01	-24.34	4.67
Bank equity	0.0871	0.1291	48.27	-29.01	-24.34	4.67
Marginal value of bank equity	2.6247	3.3404	27.27	41.40	25.19	-16.21
Ratios (%)	$\gamma = 8\%$	$\gamma = 15\%$	p.p. diff.	$\gamma = 8\%$	$\gamma = 15\%$	p.p. diff.
Physical capital/GDP ratio	249.07	239.59	-9.48	-21.64	-11.08	10.56
Investment/GDP ratio	25.81	24.42	-1.39	1.76	0.69	-1.07
Credit/GDP ratio	98.93	79.69	-19.24	-28.20	-18.38	9.81
Deposit insurance cost / GDP ratio.	1.68	0.73	-0.95	9.52	4.16	-5.36
Bank/non-bank ratio	66.46	50.00	-16.46	-19.31	-13.03	6.28
Systemic exposure (% of bank equity)	74.87	47.98	-26.88	-6.03	-4.76	1.27
Intermediation margin (non-systemic bank)	1.39	2.23	0.84	2.14	1.67	-0.48
Return on bank equity (for crisis variations, geometric mean)	14.81	14.62	-0.18	-11.81	-8.75	3.06
Bank equity issuance (% of pre-issuance equity)	4.91	3.25	-1.66	3.67	1.35	-2.32
Cost of equity issuance (% of equity issued)	14.64	22.07	7.43	9.83	8.07	-1.75

This table reports relevant model variables under the baseline capital requirement (CR) and the optimal CR, as well as their variation across the two scenarios. The first three columns of results describe unconditional mean values, while the last three columns describe the average deviation (relative to the pre-crisis period) during the 4-year crisis periods following the realization of a systemic shock.

5 The effects of capital requirements

Having quantified the extent and implications of systemic risk taking in the baseline economy, we now perform a first counterfactual exercise. We analyze the effects of setting the minimum bank capital requirement γ at different levels. In Figure 3, after solving for the equilibrium under each of the values of γ in a grid varying from 4% to 30%, we depict the SSS levels of the same key variables previously described in Figure 2. Complementarily, several columns in Table 3 compare these and other variables across the baseline economy with $\gamma = 8\%$ and an economy with $\gamma = 15\%$ (which is the capital requirement that maximizes unconditional expected welfare, as further explained in subsection 5).

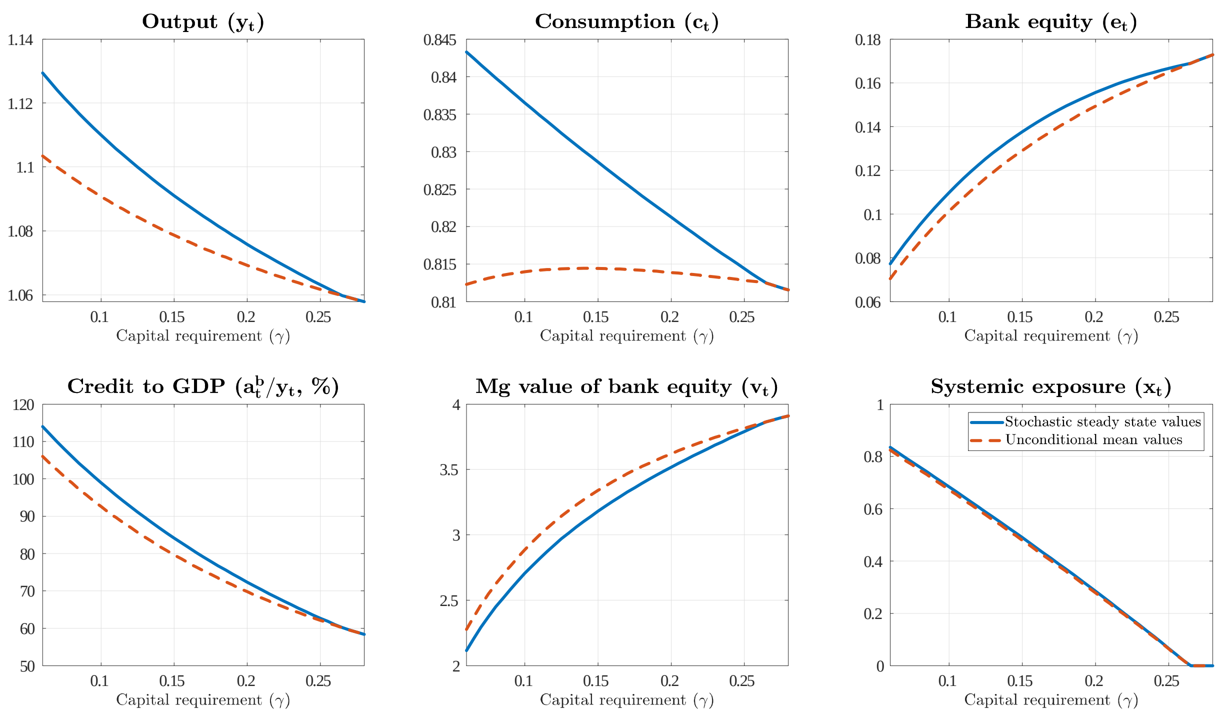

Figure 3. Effects of the capital requirement on selected equilibrium variables
Vertical axes: stochastic steady state values (solid blue lines) and unconditional mean values (dashed red lines); in levels, unless indicated otherwise. Horizontal axes: different values of the capital requirement γ (in levels).

The right bottom panel of Figure 3 shows the strong effect of the capital requirement on systemic risk taking (x_t). While with a requirement of 5% almost 90% of bank equity is invested in a systemic manner in the SSS, with 10% the fraction falls to below 70%, and with 15% to about 45%. In fact, inefficient systemic risk taking is fully eliminated (from the entire equilibrium path) with any requirement higher than 27%.

Since the model allows bankers to endogenously accumulate wealth under their management (via earnings retention and with discretionary equity issuance), higher capital requirements are associated with significantly higher aggregate levels of bank equity (e_t). However, bank equity becomes relatively more scarce as the capital requirement increases (e_t increases proportionally less than γ).[47] Thus, credit shrinks (the ratio of bank credit to GDP falls), while banks' intermediation margin (see Table 3) and, consequently, the marginal value of bank equity (v_t) increase.

As γ rises, non-bank-dependent physical capital partially substitutes for bank-dependent physical capital: the unconditional mean of the bank to non-bank ratio falls from 60% under γ=8% to 50% under γ=15%. However, this partial substitution does not prevent a significant negative impact on aggregate physical capital (see Table 3) and output. As shown in the left top panel of Figure 3, SSS output declines in a slightly convex manner as γ increases, implying a diminishing sacrifice ratio.[48]

The rise in γ has a smaller impact on SSS consumption than on SSS output, because imposing higher capital requirements on banks reduces the economy's overall savings rate (paralleling the fall in aggregate investment). In terms of the unconditional means reported in Table 3, moving to a capital requirement of 15% reduces output by 1.75% (25 basis points for each extra percentage point of the requirement) while leaving consumption virtually unchanged (actually it increases by about 13 basis points in total). This divergence between the impact of rises of γ on unconditional mean consumption (which slightly increases) and on SSS consumption (which falls) is explained by the reduction in systemic risk taking, which lowers the need to replenish lost wealth (via extra savings) every time the economy is hit by a systemic shock.

Welfare-maximizing capital requirements Figure 4 shows the impact of capital requirements on social welfare, which we define as the unconditional mean value of the lifetime utility of the representative household and report in certainty-equivalent permanent consumption terms.[49] Welfare is maximized for a capital requirement of 15%, almost twice the size of the 8% of the baseline calibration and higher than the average capital ratios with which US banks have operated in the period 2015-2019, after implementing the regulatory reforms that followed the Global Financial Crises (see Figure E.1 in Appendix E).[50]

[47] While γ multiplies by six when moving from 5% to 30%, bank equity only multiplies by three, implying that with γ=30% banks would only be able to finance half the bank-dependent investment than with γ=5%.

[48] Increasing γ from 5% to 10% reduces SSS output by about 2.2% (44 basis points of GDP for each extra percentage point of the requirement), while increasing it from 10% to 15% reduces output by a further 1.8% (36 basis points for each extra percentage point).

[49] For each depicted γ, we solve for equilibrium and simulate 10,000 paths of 1,000 periods, computing household's lifetime utility W using (4). After obtaining $E(W)$ by averaging W across the 10,000 paths, we compute the associated certainty-equivalent permanent consumption as $u^{-1}((1-\beta)E(W))$.

[50] Figure E.1 assimilates the ratio of Tier 1 Common Equity to risk weighted assets (RWA) of bank holding companies in the data to the capital ratio of banks in the model. In the model, we implicitly assume that bank-dependent assets carry a risk weight of 100% (which is the one stipulated for unrated corporate loans without specific collateral under the Standardized Approach). Using Tier 1 Common Equity as the counterpart of equity capital is coherent with the recent supervisory focus on capital components of the highest quality and, as shown in Figure E.1, makes the 8% capital ratio implied by the baseline calibration very close to its empirical counterpart in years 2001-2006.

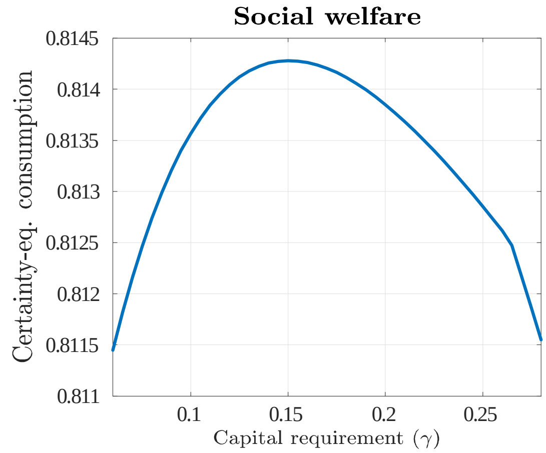

Figure 4. Effect of the capital requirement on social welfare

Vertical axis: welfare of the representative household expressed in terms of certainty-equivalent permanent consumption units. Horizontal axis: different values of the capital requirement γ. Social welfare is computed over 10,000 simulated paths, each comprised of 1,000 periods, for each different value of γ.

Relative to the baseline requirement of 8%, the optimal requirement of 15% reduces systemic risk taking from 75% to 46%. In terms of unconditional mean values, the implied difference in welfare is of 19 basis points of certainty-equivalent permanent consumption. To put the size of this gain into perspective, one has to take into account that systemic shocks are infrequent (occur with an annual frequency of 4%) and that the large direct and indirect losses that are avoided conditional on the realization of such shocks are traded off with the negative effects on SSS consumption and average output explained above.

Under the welfare maximizing capital requirement of 15%, economic performance during crisis periods is significantly better than in the baseline economy. As shown in Table 3, the decline in lifetime utility relative to its unconditional mean value is of 64 basis points rather than 118. The falls in consumption and output get reduced in 3.68 and 2.32 percentage points, respectively. Deposit insurance costs decline by 5.36 percentage points of GDP. The falls in the bank credit to GDP ratio and the bank-to-non-bank ratio decline by 9.81 and 6.28 percentage points, respectively. The milder effects of the arrival of a systemic shock can also be seen in the dashed red curves of Figure 2.

6 Removing deposit insurance

In this section we consider the counterfactual scenario without deposit insurance. Comparing the results with those of the baseline scenario with full deposit insurance allows us to explore the connection between deposit insurance, systemic risk taking, and the socially optimal level of the capital requirements. Formally, we analyze the same economy as in Section 4 but without deposit insurance or any implicit government bailout guarantee on deposits ($\eta = 0$). We solve for a separating equilibrium in which the non-systemic bank credibly commits to its risk profile by choosing a strictly positive voluntary capital buffer, that is, a capital ratio g_{0t}

above the minimum capital requirement γ. Incurring the cost of additional equity funding allows this bank to obtain deposit funding at a lower deposit rate than the systemic bank (which operates with no voluntary buffer).

Figure 5 has the same structure as Figure 1, describing equilibrium spreads, the marginal value of bank equity, and banks' systemic exposure as functions of the state variables of the model, and adding a fourth column with the capital ratio of the non-systemic bank g_{0t}. As with full deposit insurance, the most relevant variation in the endogenous variables is that associated with bank equity n_t^b (panels in the first row). The capital ratio g_{0t} increases strongly with n_t^b, ranging from slightly below 10% at the lower tail of the ergodic distribution of bank equity to above 25% at the upper tail (while the minimum requirement remains fixed at 8%). This means that the voluntary buffer of the non-systemic bank is positive and strongly procyclical (since, as long as the systemic shock does not realize, n_t^b grows until it reaches its SSS level). The explanation for this is that, when bank equity is less scarce, bank dependent capital is higher and its return is lower, implying lower intermediation margins which, ceteris paribus, would make systemic risk taking ($s = 1$) more tempting. Thus, maintaining the commitment to $s = 0$ requires the capital ratio g_{0t} to increase with n_t^b.[51]

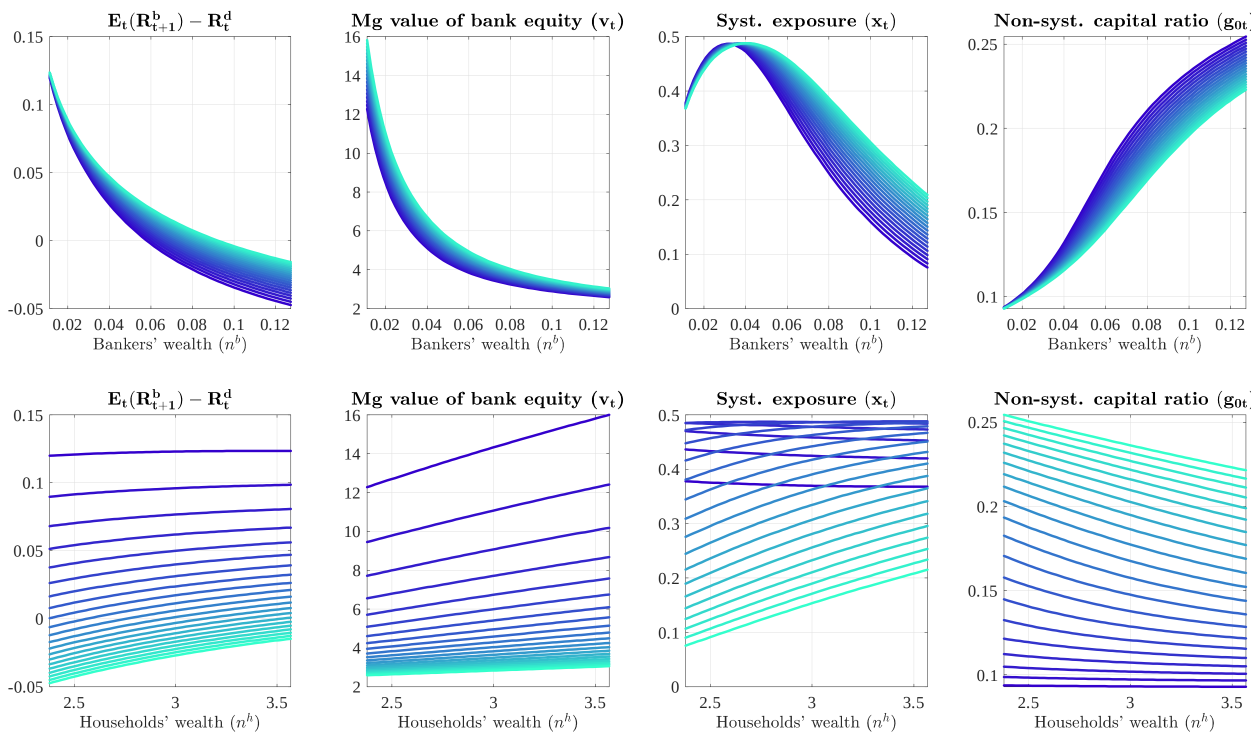

Figure 5. Equilibrium values of selected variables without deposit insurance
Vertical axes: variable values. Horizontal axes: state variable values, where n^b is wealth under bankers' management and n^h is aggregate household wealth. Each line keeps fixed the value of the other state variable, with lighter shades of blue representing larger values.

[51] The finding that the capital ratio needed to preserve the incentives to choose a low-risk profile increases with the abundance of bank equity extends to our dynamic general equilibrium setup a related insight obtained by Holmström and Tirole (1997) in a static partial equilibrium formulation.

In contrast with what we found for the case with full deposit insurance, the wealth under bankers' management n_t^b has a non-monotonic effect on systemic exposure. With full deposit insurance, all banks operate with the same leverage and an increase in bank equity has the primary effect of reducing intermediation margins and the continuation value of bank equity, thus increasing bankers' incentives to take risk. Restoring indifference via scarce-equity-preservation incentives requires x_t to increase as n_t^b increases.

Without deposit insurance, the systemic bank is more levered than the non-systemic bank and the discrepancy in leverage increases with n_t^b. Higher leverage makes the return on equity of the systemic bank more sensitive to changes in asset returns.[52] So, other things equal, a decline in asset returns reduces the equity returns of the systemic bank more than those of the non-systemic bank. In isolation, this novel force would push x_t down as n_t^b increases.[53] However, as already discussed, when n_t^b increases, the leverage of the non-systemic bank declines. This damages the return on equity that this bank can obtain for any given asset return and introduces a second force that operates on x_t in the exactly the opposite direction. Since the first force is weaker when the discrepancy in leverage across the banks is smaller and this discrepancy increases with n_t^b, the result is the inverted-U shape of x_t as a function of n_t^b shown in the third column of the first row of Figure 5.

Figure 6 shows the effects of varying the capital requirement γ across the economies with (solid blue lines) and without (dashed red lines) deposit insurance. The economy without deposit insurance goes through three regimes as γ increases. In the first, both the non-systemic bank and the systemic bank operate in equilibrium. A higher capital requirement imposes a larger burden mainly on the systemic bank (for which the requirement is binding), while making bank equity effectively more scarce, reducing bank-dependent investment and output. This imposed lower leverage and the rise in the marginal value of bank equity makes the attractiveness of systemic risk taking decreasing in γ up to a point (with $\gamma \simeq$16%) in which the systemic bank ceases to operate ($x_t = 0$). This leads to the second regime, where higher values of the minimum requirement do not alter any equilibrium variable because the only operating bank, the non-systemic bank, sticks to the endogenous capital ratio $g_{0t} > \gamma$ that satisfies its incentive compatibility constraint.[54] A third regime arises when the minimum requirement exceeds such a ratio, thus becoming binding for the non-systemic bank. At those levels of γ, the economy without deposit insurance performs exactly as with full deposit insurance, because at those levels of γ the latter also features $x_t = 0$.

[52] See Appendix B for analytical details based on a simplified variation of our model without aggregate uncertainty.

[53] Recall that in an equilibrium with $x_t \in (0, 1)$, the indifference condition in (13) requires the properly discounted expected equity returns generated under both risk profiles to be equalized. This means that, for the systemic bank, the risk taking gains and the lower use of expensive equity must exactly offset the impact of the higher cost of its deposits on its equity returns.

[54] If $x_t = 0$ at some t, the economy is no longer exposed to aggregate uncertainty, so g_{0t+s} is just the same constant for all $s \geq 0$. Interestingly, all bank deposits are riskless in this regime but the absence of deposit insurance still plays a role in making the non-systemic bank interested in committing to its risk profile by having a capital ratio above the regulatory minimum.

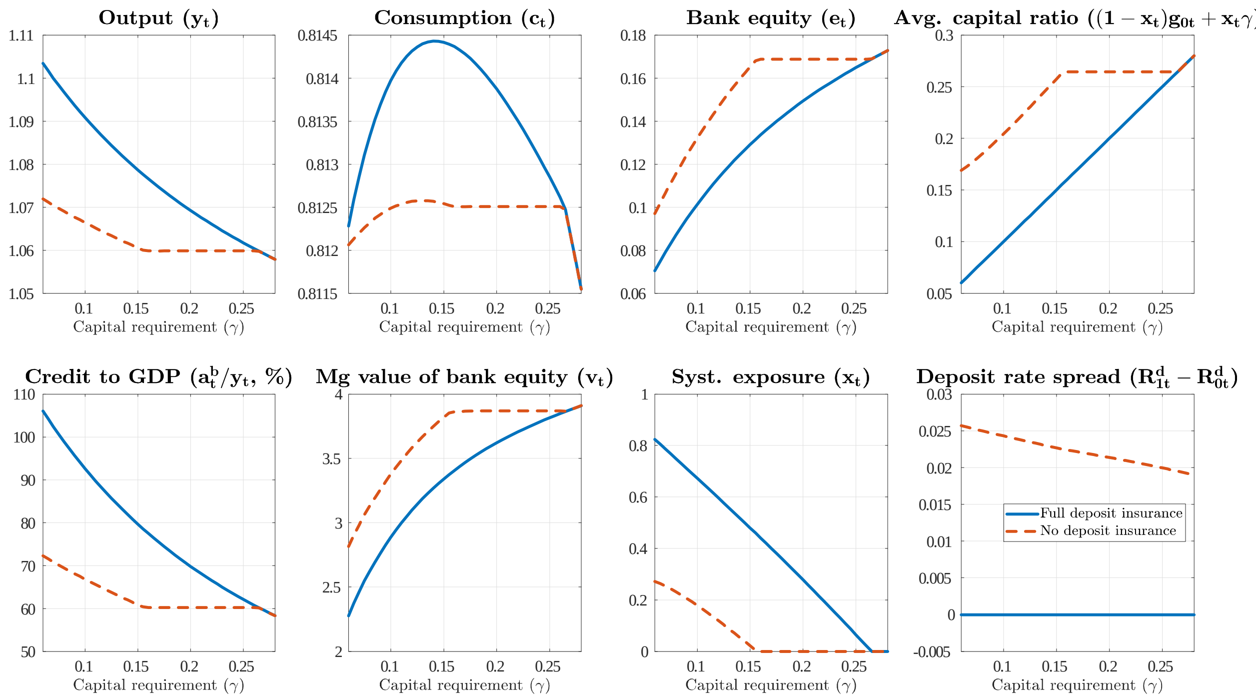

Figure 6. Key endogenous variables with and without deposit insurance

Vertical axes: variable values in levels (unless indicated). Horizontal axes: Different values of the capital requirement γ. Solid blue lines: baseline full-deposit-insurance economy. Dashed red lines: no-deposit-insurance economy.

The evolution of mean consumption in Figure 6 anticipates the effects on welfare depicted in Figure 7. As in the case with full deposit insurance, at low values of γ, imposing a higher capital requirement increases mean consumption and welfare because the beneficial effects of the reduction in the losses associated with the realization of systemic shocks offset the contractive effects (on investment and output) of making bank equity (and hence bank credit) effectively scarcer. Clearly, the net marginal welfare gains of increasing γ are negative once $x_t = 0$ but in our economy, both with and without deposit insurance, those marginal gains become zero before reaching that point. So the economy without deposit insurance also features an optimal capital requirement under which systemic risk taking is not zero.

Despite these elements in common, the differences between the two economies are noteworthy: the optimal capital requirement in the absence of deposit insurance is of about 13.5% (rather than the 15% of the economy with full deposit insurance) and leaves about 10% of bank equity exposed to systemic shocks (rather than the 50% of the economy with full deposit insurance). Without deposit insurance, for each given value of γ, systemic risk taking is lower. However, output and consumption are also lower because non-systemic banks absorb significantly more equity per unit of lending in order to remain committed to their risk profile. This depresses banks' capacity to sustain the investment in bank-dependent physical capital and explains why the economy without deposit insurance is only superior in welfare terms to the economy with full deposit insurance when γ is very low (lower than about 7%), that is, when risk taking under full deposit insurance is extremely high.

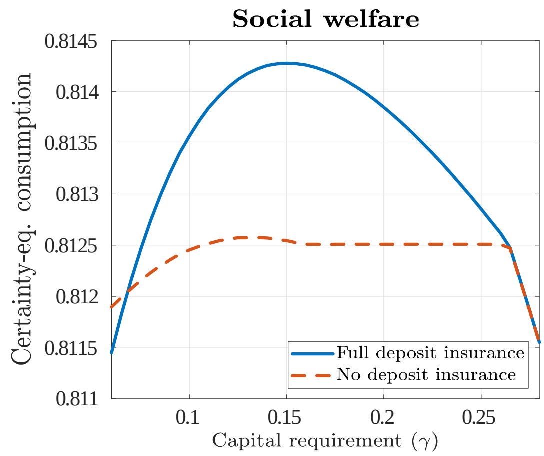

Figure 7. Wefare and capital requirements with and without deposit insurance
Vertical axis: welfare of the representative household expressed in terms of certainty-equivalent permanent consumption units. Horizontal axis: different values of the capital requirement γ. Solid blue lines: baseline full-deposit-insurance economy. Dashed red lines: no-deposit-insurance economy (separating equilibrium).

These welfare results reflect the interaction of several frictions. The unobservability of banks' risk profiles creates, with limited liability and sufficiently high leverage, the temptation to operate under the inefficient systemic profile. This can be mitigated by reducing bank leverage and making bankers more interested in preserving their (scarcer) equity. But making bank equity scarcer comes at the cost of lower bank-dependent investment. This takes us to the important and novel result that the welfare reached with full deposit insurance and sufficiently high minimum capital requirements exceeds the welfare reached without deposit insurance under any minimum capital requirement. This result suggests that without deposit insurance non-systemic banks, effectively devote "too much" equity to remaining committed to their risk profile since they do not internalize how their demand for bank equity contributes to its overall scarcity and, hence, to reduce the aggregate investment in bank-dependent physical capital.

Another important result from this analysis is that, even in the absence of deposit insurance, the optimal capital requirement is positive. The reason for this result is to be found in the coexistence of the non-systemic and the systemic bank at low levels of γ, although the presence of the systemic bank is not due to any implicit subsidy (since its risky deposits are fairly priced in the separating equilibrium that we analyze). In this case the inefficiency caused by the unobservability of risk taking decisions operates as an externality: the presence of the relatively highly levered systemic bank contributes to depress the equilibrium return on bank-dependent investment which, ceteris paribus, increases the capital ratio needed to preserve the incentives of the non-systemic bank. Imposing a higher capital requirement (only binding for the systemic bank) indirectly reduces the hurdle for bank-dependent investment to occur in the overall more efficient non-systemic mode.

7 Gradualism and counter-cyclicality

This section completes the analysis with two additional policy-relevant quantitative exercises. First, we analyze the dynamics associated with the transition to a higher capital requirement, assessing the advantages and disadvantages of introducing it gradually over several years rather than in an abrupt manner. Second, we examine the pros and cons of introducing a dynamic countercyclical adjustment (akin to the Countercyclical Capital Buffer of Basel III) in the capital requirement.

7.1 Transitional dynamics and the value of gradualism

In this first exercise, we consider the transitional dynamics associated with (gradually) moving from some initial low capital requirement γ_0 in some initial state of the economy to a new higher capital requirement γ^*. This allows us to assess the transitional implications of capital requirement reforms and to analyze how they depend on both the gradualism with which the targeted higher requirement is reached and the state of the economy when the reform starts to be implemented. For simplicity, we consider reforms that consist in linear increases from γ_0 to γ^* over T periods, that is, with

$$\gamma_t = \gamma_0 + \frac{(\gamma^* - \gamma_0)}{T} t, \tag{31}$$

for $t = 1, ..., T-1$ and $\gamma_t = \gamma^*$ for $t \geq T$. All the transitions described below assume that right before $t = 0$ the economy is at the SSS reached under the constant 8% capital requirement of our baseline results. The (unanticipated) gradual introduction of the new requirement γ^* is announced at $t = 0$.

Figure 8 compares the trajectories of key macroeconomic variables in two different scenarios where the capital requirement increases to $\gamma^* = 15\%$. Panel A considers reforms announced and started when the economy has not been hit by a systemic shock (a normal period), while panel B considers reforms announced and started in the same period in which the economy is hit by a systemic shock (a financial crisis). All trajectories are described in terms of deviations from the initial SSS values of each variable. The solid blue lines describe the implications of a non-gradual introduction of the new requirement ($T = 1$), while the dashed red lines consider a gradual introduction over $T = 6$ years.

The trajectories in panel A correspond to those where the economy does not experience a systemic shock over the entire depicted horizon. Upon the announcement of the reform, the marginal value of bank equity jumps up anticipating the greater effective scarcity of bank equity from $t = 1$ onwards. The fall in bank-dependent investment from $t = 1$ onwards (not fully offset by a rise in non-bank-dependent investment) produces a temporary rise in consumption, which is smoothed over time starting at $t = 0$.[55] The fall in output starts at $t = 1$ (due to lower investment at $t = 0$) and is specially strong at $t = 2$ (due to the drastic fall in bank-dependent investment after $t = 1$).

[55] The rise in consumption is the other side of the coin of the fall savings, which happens mainly via the reduction in bank deposits and is the response to lower deposit rates.

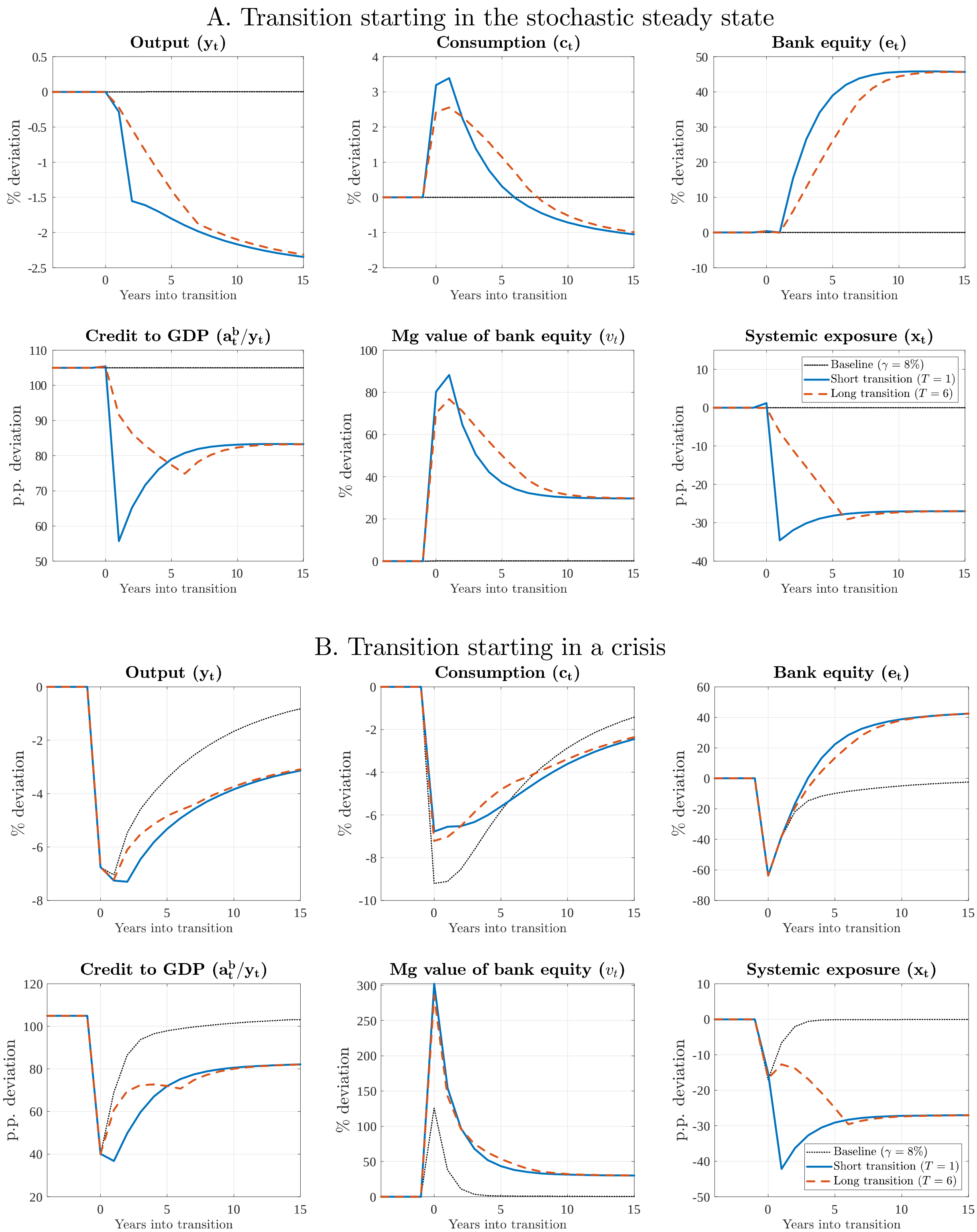

Figure 8. Gradualism and the response to a change in capital requirements

Vertical axes: deviations from stochastic steady state of baseline economy (units indicated). Horizontal axes: years since start of transition from capital requirement γ_0=8% to γ_T=15%, with $T = 1$ (blue solid lines) and $T = 6$ (red dashed lines) and/or realization of systemic shock (as applicable); otherwise no shock before or after $t = 0$ for sufficiently many years. Black dotted lines represent the baseline economy with γ_t=8% for all t.

When the new requirement is introduced at once ($T = 1$), the marginal value of bank equity, the bank to non-bank ratio, and systemic exposure strongly overshoot at $t = 1$, reverting to their new SSS levels as bank equity gradually reaches its new (higher) SSS levels.[56] With a gradual introduction of the new requirement ($T = 6$), all the trajectories are smoother and the overshooting of the bank to non-bank ratio and systemic exposure occur later and are more moderate. On the negative side, gradualism makes the decline in systemic risk taking delayed and more moderate during the transition path. Additionally, the rise in consumption is less front-loaded and bank equity accumulates at a slower pace during the transition—the resulting welfare implications will be analyzed below.

The trajectories in panel B of Figure 8 show the results when the reforms are announced and started in the same period in which the economy is hit by a systemic shock.[57] The goal is to explore what happens when the transition to the higher requirement γ^* starts during a systemic crisis. The rise in capital requirements adds to the decline in output and the effective scarcity of bank capital during the crisis but mitigates the impact of the crisis on consumption (since the decline in bank-dependent investment frees savings, as seen above) and brings significant additional reductions in risk taking (compared to that happening after a crisis in the economy with a constant capital requirement).

Figure 9 displays social welfare for reforms like the ones analyzed in each of the parts of Figure 8 (all started when the economy is at the SSS reached under γ_0=8%) and taking into account the possible realization of the systemic shock at any period after $t = 0$. Average welfare at $t = 0$ is computed by discounting the realized utility of the representative household from period $t = 0$ onwards and reported, on the vertical axis, in permanent certainty-equivalent net consumption terms. The horizontal axis shows different implementation horizons T for the gradual introduction of the new requirement γ^*. The various curves correspond to selected values of γ^* from 15% to 21%.

For transitions started in normal times (left panel), for every target requirement γ^* there is an optimal implementation horizon T. Lower targets call for shorter horizons. Intuitively, lower values of γ^* provoke lower scarcity of bank equity (and hence lower negative impact on investment and output) during the transition, reducing the opportunity cost of grasping the gains from the reduction in risk taking and the transitional consumption gains from the freeing of household savings. Welfare is maximized with γ^*=20% and T=6. Thus, the optimal level of the capital requirement when taking transitional dynamics into account is significantly higher than the 15% that maximizes the unconditional expected welfare (Figure 4). This means that the transition from low to high requirements actually features benefits rather than costs in spite of its contractive effects on investment and output. The reason for this is, again, the temporary rise in consumption associated with the freeing of resources previously absorbed by the investment in bank-dependent physical capital.

[56] Output does not overshoot because in the first years of the transition non-bank dependent investment absorbs part of the savings freed by the fall in bank-dependent investment, moderating the increase in consumption (and the fall in output) that would have otherwise occurred.

[57] As a reference, the solid black lines show the trajectories obtained in the baseline economy with a constant $\gamma = 8\%$ when its is hit by the systemic shock at $t = 0$.

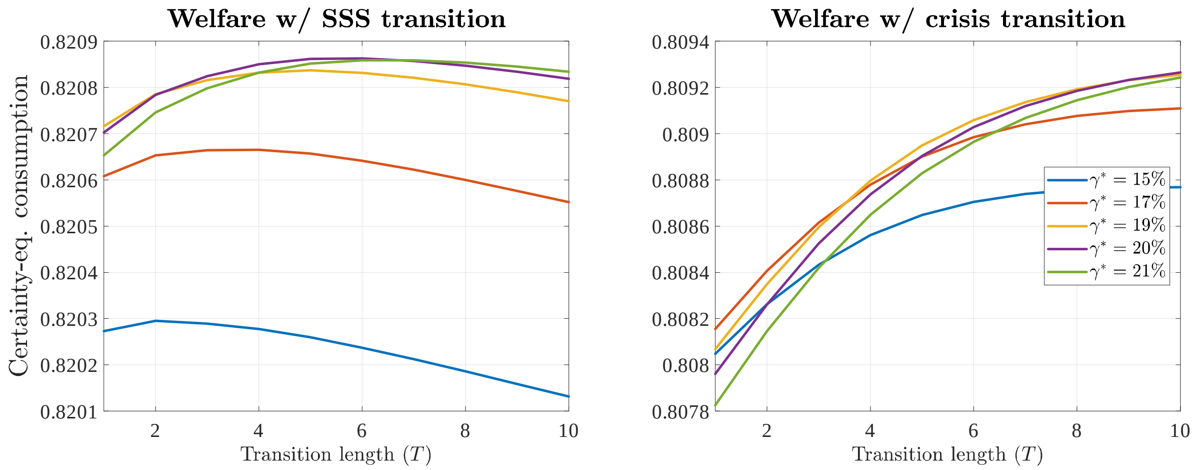

Figure 9. Social welfare as a function of the gradualism of the reform

Vertical axes: welfare of the representative household expressed in terms of certainty-equivalent permanent consumption units. Horizontal axes: Implementation horizons T (in years) for the rise of the capital requirement from γ_0=8% to the target values γ^* indicated for each depicted curve.

For transitions started in crisis times (right panel), the optimal implementation horizons are longer for all the explored values of γ^* and the optimal values of γ^* are lower at every horizon up to T=10. Welfare is maximized with an implementation horizon of ten years (or more) and a target requirement similar to that found when starting in normal times, thus suggesting that the key differences between normal and crisis times refer to the balance of costs and benefits that determine the optimal gradualism of the reform.

Summing up, this section unveils several important implications for the analysis of capital requirement reforms: (i) increasing capital requirements is more beneficial that what would be inferred from the comparison of welfare across the ergodic distributions of each capital regime, (ii) reforms that can be gradually implemented can be optimally made more ambitious (with a higher target requirement γ^*), and (iii) reforms undertaken in crisis times call for longer implementation horizons (and, if horizons are fixed short, for less ambitious targets) than reforms started in normal times.

7.2 Cyclically-adjusted capital requirements

As a final quantitative exercise, we analyze the potential value of a cyclically-adjusted capital requirement. In general terms, a potentially time-varying capital requirement γ_t could be expressed as a generic function of the state variables of the model, $\Gamma(n_t^b, n_t^h)$. Following the terms of the regulatory debate and for computational tractability, we consider here a parametric specification of Γ under which the capital requirement increases or decreases relative to a benchmark value γ depending on how the wealth available for bankers to invest as bank equity, n_t^b, deviates from its stochastic steady state value $\overline{n}^b$. In particular, we consider

$$\Gamma(n_t^b) = \min\{\max\{\gamma[1 + \tau(n_t^b/\overline{n}^b - 1)], 0\}, 1\}, \tag{32}$$

where $\tau \in \mathbb{R}$ measures the sign and intensity of cyclical adjustment. With $\tau > 0$ (< 0) the cyclical adjustment would imply higher (lower) values of γ_t in periods in which bank equity and, other things equal, bank credit are more abundant (scarcer). For $\tau > 0$, these dynamics conform to the logic of operation of the Countercyclical Capital Buffer" (CCyB) introduced by Basel III.

Figure 10 shows the welfare implications of setting alternative (both negative and positive) values of τ under two relevant values of γ: the baseline 8% of the calibrated economy and 15%, which is the optimal level of the capital requirement both without any cyclical adjustment ($\tau = 0$) and under a simultaneously optimized value of τ. Under both values of γ, the welfare maximizing value of τ is positive, although the very flat welfare curves for each given γ (compared to the distance between the two curves) mean that the degree of cyclical adjustment is much less important for welfare than the level of the capital requirement γ.

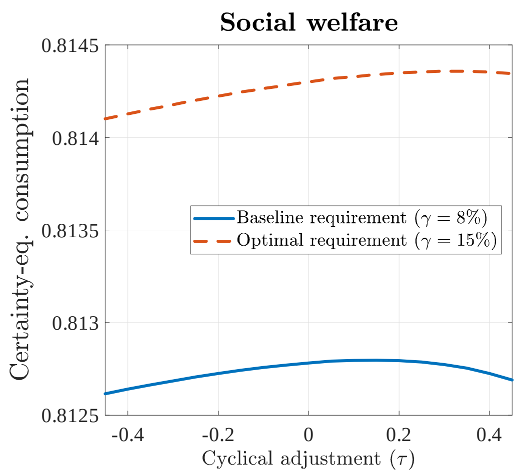

Figure 10. Social welfare for different degrees of cyclical adjustment

Vertical axis: welfare of the representative household expressed in terms of certainty-equivalent permanent consumption units. Horizontal axis: degree of cyclical adjustment (τ). Each line represents a different benchmark capital requirement level (γ): 8% (blue solid line) and 15% (dash red line).

The results in Figure 10 also imply that the optimal cyclical adjustment under $\gamma = 15\%$ is stronger than under $\gamma = 8\%$. Having an optimal τ of around 0.4 when $\gamma = 15\%$ implies that if the wealth under bankers' management declines by 40% (as happens when the economy is hit by a systemic shock in the stochastic steady state reached under $\gamma = 15\%$, see Figure 2) the capital requirement declines in 2.4 percentage points ($0.15 \times 0.4 \times 0.4 = 0.024$). This is a non-negligible decline close to the indicative 2.5% size considered in the guidance of the CCyB in Basel III. In contrast, the optimal τ of about 0.15 when $\gamma = 8\%$ implies that if bankers' wealth declines 65% (as when the economy is hit by a systemic shock in the stochastic steady state reached under $\gamma = 8\%$) the cyclical adjustment is of only 0.8 percentage points ($0.08 \times 0.15 \times 0.65 = 0.0078$). These results suggest that having a larger benchmark capital requirement reduces the negative side effects of aiming to reduce the credit supply effects caused by the aggregate loss of bank equity when a systemic shock realizes.

To explore the drivers of these results, Figures 11 and 12 describe the implications of a cyclically-adjusted capital requirement in the economy with a baseline requirement of 15%. Figure 11 shows the time-varying capital requirement implied by the capital requirement rule in (32) in the years around the realization of a systemic shock. The depicted paths correspond to the fully stochastic economy in the case in which a shock arrives at year $t = 0$ when the economy was at its SSS at $t = -1$, and does not realize again during the remaining depicted years. The three lines compare the scenario with no dynamic adjustment (solid blue line), the optimal dynamic adjustment (dashed red line), and a twice-as-big dynamic adjustment (dotted yellow line). With the same conventions, Figure 12 shows the paths of key equilibrium variables around the arrival of a systemic shock under each of the three degrees of cyclical adjustment. Variables are measured in differences with respect to their SSS levels in the economy with the constant 15% requirement.

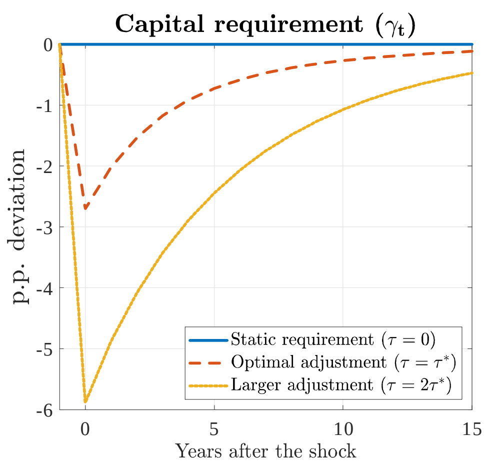

Figure 11. Capital requirement for different degrees of cyclical adjustment
Vertical axis: percentage points deviation from the 15% optimal static capital requirement. Horizontal axis: years since the realization of a systemic shock. The realization of the systemic shock is set to zero for a sufficiently large number of years before t=0, set to one at t=0, and again to zero for the remaining displayed years. Solid blue lines: optimal static capital requirement (15%). Dashed red lines: optimal cyclical adjustment. Dotted yellow lines: twice as large cyclical adjustment.

The credit smoothing effects implied by a more intense cyclical adjustment are clear in the left bottom panel of Figure 12 and translate into a more rapid recovery of output levels (left top panel).[58] However, lowering the capital requirement after the shock also implies reducing the effective scarcity of bank equity and, hence, its marginal value (middle bottom panel), which is detrimental to the equity-preservation-incentives that keep systemic risk taking under control both before and after the systemic shock. Thus, as shown in the right bottom panel, the higher the intensity of the cyclical adjustment, the higher the systemic

[58] Notice that consumption falls by more on impact (and for the first few years after the shock) when the cyclical adjustment of the requirements is more intense. This partly reflects that investment falls by less on impact (and for the first few years after the shock).

exposure both at the pre-shock SSS ($t = -1$) and along the trajectories after the shock ($t = 0, 1, ..$). This explains why, on impact, there are bigger aggregate bank equity losses under the more intense adjustment (right top panel); in addition, the lower equity returns after a more intense adjustment induce a slower recovery of aggregate bank equity. The counterproductive effects on systemic risk taking and on the speed of accumulation of bank equity explain the small net welfare gains from playing with the degree of cyclical adjustment of the capital requirement shown in Figure 10.

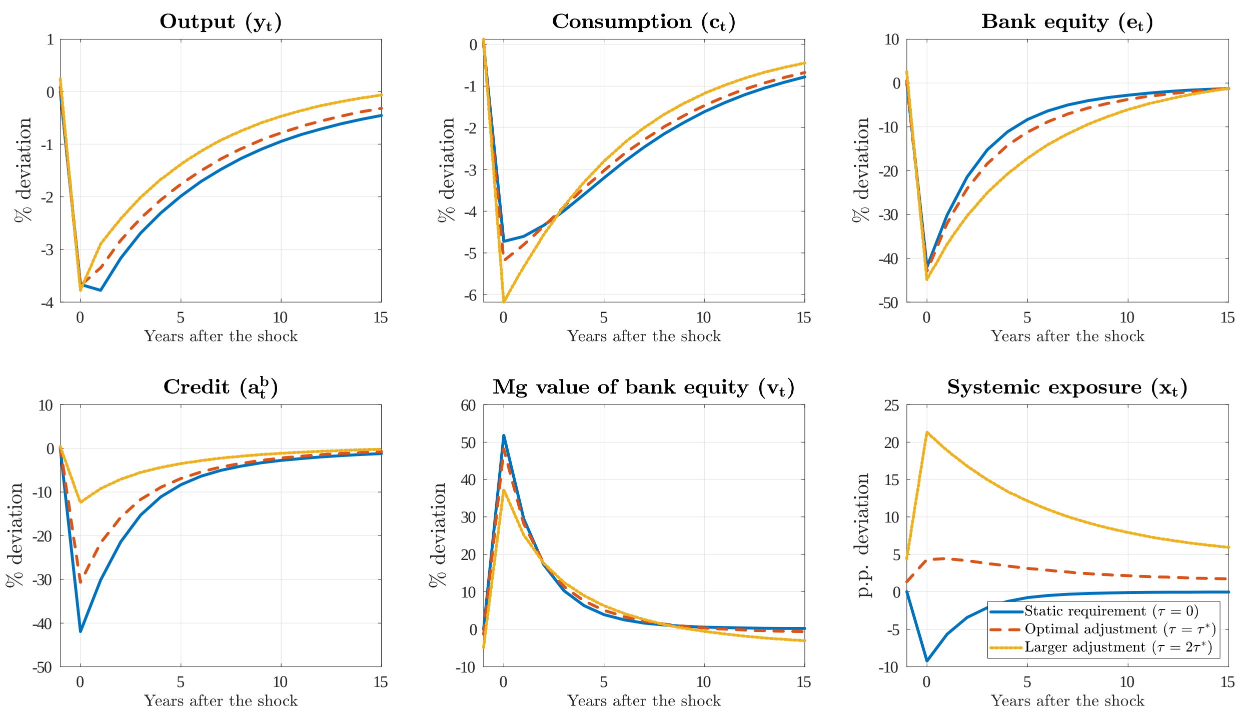

Figure 12. Crisis dynamics under different degrees of cyclical adjustment

Vertical axes: deviations from the stochastic steady state of the economy with a static requirement (units as indicated). Horizontal axes: years since the realization of the shock. The realization of the systemic shock is set to zero for a sufficiently large number of years before t=0, set to one at t=0, and again to zero for the remaining number of displayed periods. Solid blue lines: optimal static capital requirement (15%). Dashed red lines: optimal cyclical adjustment. Dotted yellow lines: twice as large cyclical adjustment.

8 Conclusions

We have developed a dynamic general equilibrium model with banks that features endogenous systemic risk taking. The main friction in the model is the unobservability of banks' decisions regarding their exposure to systemic shocks. The analysis accommodates the consideration of scenarios both with and without deposit insurance. Starting with a baseline calibration intended to capture the normal- versus crisis-times performance of the US economy in the years around the 2008-2009 financial crisis, we have run a number of counterfactual exercises exploring the effects of setting capital requirements at different levels, as well as other relevant design features of capital regulation. This includes assessing the implications of introducing higher capital requirements in a gradual manner or adding cyclical adjustments to their baseline level. We also analyze the effects of removing deposit insurance and its interaction with capital requirements. The analysis provides novel insights on each of these fronts.

First, we find that, both with and without deposit insurance, the optimal bank capital requirement level is positive, but substantially lower than the level that reduces systemic risk taking to zero. This is because, in both scenarios, further reductions in systemic risk taking would bring marginal gains offset by the cost of the implied contraction in bank-dependent investment. Second, gradualism reduces the sacrifice of bank-dependent investment during the transition to a higher requirement but also delays the reduction in systemic risk taking. We find that regulatory reforms that take transitional effects into account and optimally incorporate some gradualism would target higher long-term capital requirements than reforms focused on maximizing long-term welfare without considering the transitional effects. Third, lowering capital requirements in a transitory manner after a systemic shock can soften the resulting decline in bank-dependent investment, at the cost of increasing systemic risk taking both ex ante and ex post. These counterproductive effects explain why the optimal degree of cyclical adjustment carries very modest net welfare gains and grows with the baseline level of the capital requirement (which reduces the negative effects on risk taking).

The results that we obtain for the scenario without deposit insurance are novel and interesting not just in quantitative but also in qualitative terms. In the equilibrium that we explore in this scenario, banks investing in a non-systemic manner implicitly commit to do so by operating with higher capital ratios than the other banks. This allows depositors to recognize these banks' commitment to be non-systemic and to accept cheaper deposit rates from these banks. As commonly expected, market discipline works in the sense that the fraction of bank equity invested in systemic banks is lower without deposit insurance than with full deposit insurance under any given level of the capital requirement. However, capital requirements still have a role to play: increasing the minimum capital requirement (which in equilibrium is binding for the systemic banks only) reduces the extra voluntary buffer that non-systemic banks choose to guarantee the incentive compatibility of their risk profile. As a result, the optimal capital requirement without deposit insurance is lower than with deposit insurance, but far from zero. Interestingly, we find that, unless the capital requirement is very low, the economy with full deposit insurance can generate greater social welfare than the economy without deposit insurance. This is due to the credit-contraction effects associated with non-systemic banks' large reliance on equity funding in the absence of deposit insurance and challenges common wisdom on the welfare cost of deposit insurance in the presence of risk shifting problems.

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Appendices

A Proof of Proposition 1

Plugging (7) into (6) yields the following compact version of a banker's value function:

$$\begin{aligned} V_t(n_{it}) &= \max_{\substack{m_{it}\geq -n_{it} \\ x_{it}\in[0,1]}} \Big(-m_{it} - C(m_{it}^+) + \mathbb{E}_t\left\{\Lambda_{t+1}(1-\psi)[(1-x_{it})R^e_{0t+1} + x_{it}R^e_{1t+1}]\right\}(n_{it}+m_{it}) \\ &\quad + \mathbb{E}_t\left\{\Lambda_{t+1}V_{t+1}\left(\psi[(1-x_{it})R^e_{0t+1}+x_{it}R^e_{1t+1}](n_{it}+m_{it})\right)\right\}\Big) \end{aligned} \tag{A.1}$$

Let us guess and verify that this value function is affine, namely, can be expressed as

$$V_t(n_{it}) = v_t n_{it} + v_t^0, \tag{A.2}$$

where both v_t and v_t^0 do not depend on the wealth n_{it} under the management of banker i at the beginning of period t. Under the conjectured expression for $V_t(n_{it})$, (A.1) can be written as

$$\begin{aligned} v_t n_{it} + v_t^0 &= \max_{\substack{m_{it}\geq -n_{it} \\ x_{it}\in[0,1]}} \Big(-m_{it} - C(m_{it}^+) + \mathbb{E}_t\left\{\Lambda^b_{t+1}[(1-x_{it})R^e_{0t+1}+x_{it}R^e_{1t+1}](n_{it}+m_{it})\right\} \\ &\quad + \mathbb{E}_t\left(\Lambda_{t+1}v^0_{t+1}\right)\Big), \end{aligned} \tag{A.3}$$

with $\Lambda^b_{t+1} = \Lambda_{t+1}(1-\psi+\psi v_{t+1})$. Moreover, given the linearity in $x_t \in [0,1]$ of the expression optimized in the right hand side of this equation and the non-negativity of $n_{it}+m_{it}$, we can express it as

$$\begin{aligned} v_t n_{it} + v_t^0 &= \max_{m_{it}\geq -n_{it}} \Big[-m_{it} - C(m_{it}^+) + \max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\}(n_{it}+m_{it}), \\ &\quad + \mathbb{E}_t\left(\Lambda_{t+1}v^0_{t+1}\right)\Big] \end{aligned} \tag{A.4}$$

Grouping the terms in n_{it}, this becomes:

$$\begin{aligned} v_t n_{it} + v_t^0 &= \left[\max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\}\right] n_{it} + \max_{m_{it}\geq -n_{it}} \Big[-m_{it} - C(m_{it}^+) \\ &\quad + \max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\}m_{it} + \mathbb{E}_t\left(\Lambda_{t+1}v^0_{t+1}\right)\Big], \end{aligned} \tag{A.5}$$

where the first term in the right hand side is linear in n_{it} and the second is independent of n_{it} unless, perhaps, when the lower bound for the choice of m_{it} is binding in any period, that is, if the banker faces a situation in which paying out the whole wealth under management is strictly preferred to any other choice.

Let us first deal with the special case in which $\max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\} \leq 1$. In this case, choosing $m_{it} = -n_{it} < 0$ is optimal and the RHS of (A.5) simplifies to $n_{it} + \mathbb{E}_t\Lambda_{t+1}v^0_{t+1}$, which is consistent with the conjectured affine form of the value function under $v_t = 1$ and $v_t^0 = \mathbb{E}_t\Lambda_{t+1}v^0_{t+1}$. This also says that the marginal value of the wealth with which bankers enter a period can never be lower than one since bankers can always return the wealth to the household (for whom the marginal value of wealth is one). Meanwhile, the term $v_t^0 = \mathbb{E}_t\Lambda_{t+1}v^0_{t+1}$ would account for the option value of raising wealth from the household in future periods.

Let us now turn to the case with $\max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\} > 1$. In this case, it is optimal to choose the $m_{it} > 0$ that satisfies the first order condition

$$-1 - C'(m^+_{it}) + \max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\} = 0, \tag{A.6}$$

which does not depend on n_{it}. So the validity of (A.5) gets confirmed with

$$v_t = \max\{\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right), \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right)\}, \tag{A.7}$$

and

$$v^0_t = \max_{m_{it}\in\mathbb{R}}\left[-m_{it} - C(m^+_{it}) + v_t m_{it} + \mathbb{E}_t\Lambda_{t+1}v^0_{t+1}\right]. \tag{A.8}$$

Putting the two cases together, we conclude that the marginal value of a unit of wealth under bankers' management satisfies (12), a banker's optimal portfolio decision is

$$x_{it} = \begin{cases} 0, & \text{if } \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right) > \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right), \\ \text{any } x \in [0,1], & \text{if } \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right) = \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right), \\ 1, & \text{if } \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right) < \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right), \end{cases} \tag{A.9}$$

and her optimal policy for m_{it} is

$$m_{it} = \begin{cases} \text{any } m \in [-n_{it}, 0] & \text{if } v_t = 1, \\ (C')^{-1}(v_t - 1), & \text{if } v_t > 1, \end{cases} \tag{A.10}$$

meaning that the banker raises additional wealth $(C')^{-1}(v_t - 1)$ from the household if the marginal value of having it under her management, v_t, is greater than one and is indifferent between no distribution ($m = 0$) and any positive dividend ($m < 0$) if $v_t = 1$.

Finally, since the optimal policies for x_{it} and m_{it} are independent of the individual banker's wealth n_{it} (except for the lower bound to m_{it} if $v_t = 1$), we can drop the individual subscript i and use their aggregate counterparts (13) and (14) as equilibrium conditions for the aggregate portfolio and distribution decisions of the whole continuum of existing bankers.■

B The influence of banks' leverage on risk taking

To understand how capital requirements affect banks' risk taking incentives, in this appendix we consider a variation of the model without aggregate uncertainty in which aggregate variables such as the returns on bank-dependent physical capital, aggregate consumption, the shadow marginal value of bank equity, and other equilibrium variables linked to them remain constant at their non-stochastic steady state values, that is,

$$R^b_{t+1} = R^b, \tag{A.11}$$
$$\Lambda_{t+1} = \beta, \text{ and} \tag{A.12}$$
$$v_t = v \geq 1, \text{ implying } \Lambda^b_{t`+1} = \beta(1-\psi+\psi v). \tag{A.13}$$

Yet assume that any risk-taking bank ($s = 1$) is solvent (for idiosyncratic reasons, in this case) with probability π and fails with probability $1 - \pi$, while any non-risk-taking bank ($s = 0$) is solvent with probability one.

B.1 The case with full deposit insurance

As established in (13), in an equilibrium with $x_t > 0$, we must have $\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right) \geq \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right)$. With full deposit insurance, this condition particularizes to

$$\frac{\mathbb{E}_t\left[\Lambda^b_{t+1}\max\{R^b_{t+1}\Delta_{t+1}(1) - R^d_t(1-\gamma), 0\}\right]}{\gamma} \geq \frac{\mathbb{E}_t\left[\Lambda^b_{t+1}\max\{R^b_{t+1}\Delta_{t+1}(0) - R^d_t(1-\gamma), 0\}\right]}{\gamma}, \tag{A.14}$$

where R^d_t is the common deposit rate promised by both the non-systemic and the systemic bank. Under the conditions stated in (A.11)-(A.13), the prior inequality becomes

$$\beta(1-\psi+\psi v)\pi[R^b(1+\mu)-(1/\beta)(1-\gamma)] \geq \beta(1-\psi+\psi v)\left[R^b-(1/\beta)(1-\gamma)\right], \tag{A.15}$$

since the deposit rate is $R^d_t = 1/\beta$. This condition simplifies to

$$1-\gamma \geq \frac{\beta R^b[1-\pi(1+\mu)]}{1-\pi}. \tag{A.16}$$

Since, $1-\pi(1+\mu) > 0$ by (2), condition (A.16) does not hold when $\gamma = 1$ and, hence, when the capital requirement γ is sufficiently large. In contrast, for $\gamma = 0$ it holds provided that

$$\beta R^b \leq \frac{1-\pi}{1-\pi(1+\mu)}, \tag{A.17}$$

that is, the profitability of bank assets (as determined by the gross return on bank-dependent physical capital R^b) is not too large.

So risk taking is easier to sustain when the capital requirement γ, the return on bank assets R^b, and the implied risk of failure $1-\pi$ are small, and when the risk taking gain μ is large. These implications are consistent with the quantitative results we obtain for the model with aggregate uncertainty, in which risk taking x_t declines with γ and increases with total bank capital n^b_t (which, other things equal, reduces R^b_{t+1}).[59]

[59] The residual equilibrating force in the full model (that prevents bang-bang solutions for x_t) is the (positive) impact of x_t on the importance of the "scarce equity preservation incentive" for non-systemic banks. As x_t increases (decreases), other things equal, the relatively larger (lower) scarcity of bank equity after a systemic shock decreases (increases) the marginal attractiveness of risk taking.

B.2 The case without full deposit insurance

Conditions for the systemic bank to be active As established in (13), in an equilibrium with $x_t > 0$, we must have $\mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{1t+1}\right) \geq \mathbb{E}_t\left(\Lambda^b_{t+1}R^e_{0t+1}\right)$. Without deposit insurance, in a separating equilibrium, this condition particularizes to

$$\frac{\mathbb{E}_t\left[\Lambda^b_{t+1}\max\{R^b_{t+1}\Delta_{t+1}(1) - R^d_{1t}(1-\gamma), 0\}\right]}{\gamma} \geq \frac{\mathbb{E}_t\left[\Lambda^b_{t+1}\max\{R^b_{t+1}\Delta_{t+1}(0) - R^d_{0t}(1-g_{0t}), 0\}\right]}{g_{0t}}. \tag{A.18}$$

Under the conditions stated in (A.11)-(A.13) and the further simplifying assumption that $\lambda = 1$ (so that the systemic bank has zero asset value when it fails), the deposit rates that each bank must pay to attract deposits are $R^d_{0t} = 1/\beta$ and $R^d_{1t} = 1/(\pi\beta)$, and the inequality above becomes

$$\beta(1-\psi+\psi v)\pi\{R^b(1+\mu) - [1/(\pi\beta)](1-\gamma)\}/\gamma \geq \beta(1-\psi+\psi v)\left[R^b - (1/\beta)(1-g_0)\right]/g_0. \tag{A.19}$$

The inequality simplifies to

$$\beta R^b \geq \frac{(g_0/\gamma) - 1}{\pi(1+\mu)(g_0/\gamma) - 1}, \tag{A.20}$$

whose right hand side is decreasing in $g_0/\gamma > 1$ (since $\pi(1+\mu) < 1$ by (2)). This implies that risk taking is easier to sustain when the capital buffer of the non-systemic bank g_0/γ is high, the return on bank assets R^b is high, the implied risk of failure $1-\pi$ is small, and the risk taking gain μ is large.

The main qualitative difference with respect to the case with full deposit insurance is the different sign of the effect of R^b (for a given g_0). With deposit insurance, the profitability of risk taking hinges less on asset returns and more on the opportunity to fund the bank with deposits that do not price in the risk of failure. Without deposit insurance, in a separating equilibrium, the latter subsidy disappears and the only possible advantage of risk taking is its association with relatively larger leverage (a higher g_0/γ). However, as R^b declines, the advantages of operating with higher leverage diminish. In the limit case with $\beta R^b = 1$ (which would arise in general equilibrium if bank equity were sufficiently abundant), (A.20) cannot hold for any $g_0/\gamma > 1$.

Incentive compatibility conditions for systemic and non-systemic banks In the setup with no aggregate uncertainty considered in this appendix, the incentive compatibility condition (24) for the non-systemic bank, operating under some $g_{0t} = g_0 \geq \gamma$ and paying the gross deposit rate $R^d_{0t} = 1/\beta$ to prefer the risk profile $s = 0$ to $s = 1$ simplifies to

$$[R^b - (1/\beta)(1-g_0)] \geq \pi[R^b(1+\mu) - (1/\beta)(1-g_0)] \tag{A.21}$$

or

$$g_0 \geq \bar{g}_0 \equiv 1 - \frac{\beta R^b[1-\pi(1+\mu)]}{1-\pi}, \tag{A.22}$$

where $\bar{g}_0 < 1$ under (2) and having $\bar{g}_0 > 0$ requires $\beta R^b < (1-\pi)/[1-\pi(1+\mu)]$.

Likewise, the incentive compatibility condition (25) for the systemic bank, operating under some $g_{1t} = g_1 \geq \gamma$ and paying the gross deposit rate $R^d_{1t} = 1/(\pi\beta)$ to prefer the risk profile $s = 1$ to $s = 0$ simplifies to

$$\pi\{R^b(1+\mu) - [1/(\pi\beta)](1-g_1)\} \geq \{R^b - [1/(\pi\beta)](1-g_1)\} \tag{A.23}$$

or

$$g_1 \leq \bar{g}_1 \equiv 1 - \frac{\pi\beta R^b[1-\pi(1+\mu)]}{1-\pi}, \tag{A.24}$$

where $\bar{g}_1 < 1$ under (2) and $\bar{g}_1 > \bar{g}_0$ so that having $\bar{g}_0 > 0$ also implies $\bar{g}_1 > 0$.

Thus if $\beta R^b < (1-\pi)/[1-\pi(1+\mu)]$, the intervals $[\bar{g}_0, 1]$ and $[0, \bar{g}_1]$ are non-empty and their intersection $[\bar{g}_0, \bar{g}_1]$ is non-empty. In this case, depending on the position of the capital requirement γ relative to $\bar{g}_1$ and $\bar{g}_0$, the following possibilities arise:

1. If $\gamma < \bar{g}_0$, then (A.23) is satisfied for $g_1 = \gamma$, and the separating equilibrium involves $g_0 = \bar{g}_0 > g_1 = \gamma$.

2. If $\gamma \in [\bar{g}_0, \bar{g}_1]$, then both (A.21) and (A.23) can be satisfied for $g_0 = g_1 = \gamma$.

3. If $\gamma > \bar{g}_1$, then (A.23) cannot be satisfied by any $g_1 \geq \gamma$, while (A.21) can be satisfied by just choosing $g_0 = \gamma$.

Thus, for $\gamma > \bar{g}_{1t}$ the "separating equilibrium" would degenerate in an equilibrium in which only the non-systemic bank is active. However, the situation in which the systemic bank is not active in equilibrium also arises in the two other cases where, even if each bank could be separated through a proper capital structure choice, the investment in the systemic bank is simply not attractive enough to bankers. To see this, notice that the condition for $x_t > 0$ in (A.20) requires g_0/γ to be sufficiently larger than one, and hence cannot be satisfied when $\gamma \in [\bar{g}_0, \bar{g}_1]$ and, by continuity, cannot be satisfied either in an interval of values of γ strictly below but sufficiently close to $\bar{g}_0$.

Summing up, a "separating equilibrium" in which the non-systemic bank chooses $g_0 = \max\{\bar{g}_0, \gamma\}$ and the systemic bank chooses $g_1 = \gamma$ or does not operate can always be sustained; moreover, the systemic bank will cease to operate if γ exceeds the critical value $\bar{\gamma} < \bar{g}_0$ for which (A.20) holds with equality under $\gamma = \bar{\gamma}$ and $g_0 = \bar{g}_0$.

Net impact of asset returns on risk taking In a separating equilibrium with $x_t > 0$, both (A.20) and (A.21) must be satisfied. If (A.21) is satisfied with equality (as it will be the case if $g_0 \geq \gamma$), then setting $g_0 = \bar{g}_0$ in (A.20) reveals that the final effect of R^b on risk taking incentives is non-monotonic. For low values of R^b, the effect operating through the lowering g_0 dominates, making the attractiveness of risk taking decline with R^b. However, at larger values of R^b, the direct effect dominates, making risk taking increase with R^b. This is consistent with what we find in our quantitative analysis of the case without deposit insurance, where increases in bank equity n_t^b push R_{t+1}^b down and make systemic risk taking x_t first increasing and then decreasing in n_t^b.

C Equilibrium conditions

State variables: wealth under bankers management n_t^b and household wealth n_t^h.
Value and policy functions (to be found numerically): shadow value of bankers' wealth v_t, household's investment in non-bank-dependent physical capital a_t^h, promised deposit rates of the non-systemic bank R_{0t}^d and the systemic bank R_{1t}^d, capital ratio of the non-systemic bank g_{0t}, bankers' equity issuance m_t, share of bank equity invested in the systemic bank x_t.
Equilibrium conditions (referred to date t unless otherwise indicated):

- Bank equity:
$$e_t = n_t^b + m_t. \tag{A.25}$$
- Bank equity allocation:
$$e_{0t} = (1 - x_t)e_t, \tag{A.26}$$
$$e_{1t} = x_t e_t. \tag{A.27}$$
- Banks assets implied by the capital ratio decisions of each bank:
$$a_{0t}^b = e_{0t}/g_{0t}, \tag{A.28}$$
$$a_{1t}^b = e_{1t}/\gamma. \tag{A.29}$$
- Deposits implied by balance sheet constraint of each bank:
$$d_{st} = a_{st}^b - e_{st} \text{ for } s = 0, 1. \tag{A.30}$$
- Bank-dependent physical capital at $t + 1$:
$$k_{t+1}^b = \Delta_{t+1}(0)a_{0t}^b + \Delta_{t+1}(1)a_{1t}^b. \tag{A.31}$$
- Total physical capital at $t + 1$:
$$k_{t+1} = \left[\phi(k_{t+1}^h)^\sigma + (1 - \phi)(k_{t+1}^b)^\sigma\right]^{\frac{1}{\sigma}}. \tag{A.32}$$
- Final output (GDP) at $t + 1$:
$$y_{t+1} = k_{t+1}^\alpha. \tag{A.33}$$
- Labor market equilibrium at $t + 1$:
$$l_{t+1} = 1, \tag{A.34}$$
$$w_{t+1} = (1 - \alpha)y_{t+1}. \tag{A.35}$$
- Equilibrium in the markets for physical capital at $t + 1$:
$$R_{t+1}^h = \phi\alpha(k_{t+1}^h)^{\sigma-1}y_{t+1}/k_{t+1}^\sigma + 1 - \delta^h, \tag{A.36}$$
$$R_{t+1}^b = (1 - \phi)\alpha(k_{t+1}^b)^{\sigma-1}y_{t+1}/k_{t+1}^\sigma + 1 - \delta^b. \tag{A.37}$$

- Return on equity of each bank at $t+1$:

$$R^e_{0,t+1} = \max\{0, (1/g_{0t})[\Delta_{t+1}(0)R^b_{t+1} - (1-g_{0t})R^d_t]\}, \tag{A.38}$$

$$R^e_{1,t+1} = \max\{0, (1/\gamma)[\Delta_{t+1}(1)R^b_{t+1} - (1-\gamma)R^d_t]\}. \tag{A.39}$$

- Non-discretionary bank dividends at $t+1$:

$$\overline{M}_{t+1} = (1-\psi)(R^e_{0,t+1}e_{0,t} + R^e_{1,t+1}e_{1,t})$$

(where the notation $\overline{M}_{t+1}$ is introduced to distinguish the non-discretionary component from the total net payments that bankers make to the household at $t+1$, $M_{t+1} = \overline{M}_{t+1} - m_{t+1} - C(m^+_{t+1})$).

- Deposit insurance costs at $t+1$:

$$\begin{aligned} DI_{t+1} &= \eta \max\{0, (1/g_{0t})[(1-\gamma)R^d_{0t} - \Delta_{t+1}(0)R^b_{t+1}]e_{0,t}\} \\ &\quad + \max\{0, (1/\gamma)[(1-\gamma)R^d_{1t} - \Delta_{t+1}(1)R^b_{t+1}]e_{1,t}\}. \end{aligned} \tag{A.40}$$

- Lump-sum taxes to finance DI_{t+1} at $t+1$:

$$T_{t+1} = DI_{t+1}. \tag{A.41}$$

- Laws of motion of n^b_t and n^h_t:

$$n^b_{t+1} = \psi(R^e_{0,t+1}e_{0,t} + R^e_{1,t+1}e_{1,t}), \tag{A.42}$$

$$n^h_{t+1} = R^d_t d_t + R^h_{t+1}a^h_t + w_{t+1} + \overline{M}_{t+1} - T_{t+1}. \tag{A.43}$$

- Consumption implied by the household's budget constraint:

$$c_t = n^h_t - a^h_t - d_{0t} - d_{1t} - m_t - C(m^+_t). \tag{A.44}$$

- Household's stochastic discount factor (Euler equation for consumption):

$$\Lambda_{t+1} = \beta u'(c_{t+1})/u'(c_t). \tag{A.45}$$

- Household's first order condition for a^h_t:

$$\mathbb{E}_t[\Lambda_{t+1}R^h_{t+1}] = 1. \tag{A.46}$$

- Household's first order condition for d_{0t} and d_{1t}:

$$\mathbb{E}_t[\Lambda_{t+1}\tilde{R}^d_{st+1}] = 1 \text{ for } s = 0, 1, \tag{A.47}$$

with

$$\tilde{R}^d_{st+1} = \eta R^d_{st} + (1-\eta)\min\{R^d_{st}, R^b_{t+1}\Delta_{t+1}(s)/(1-g_{st})\} \tag{A.48}$$

and $g_{1t} = \gamma$.

- Bankers' stochastic discount factor:

$$\Lambda_{t+1}^b = \Lambda_{t+1}(1 - \psi + \psi v_{t+1}). \tag{A.49}$$

- Bankers' value function:[60]

$$v_t = \max\{\mathbb{E}_t[\Lambda_{t+1}^b R_{0,t+1}^e], \mathbb{E}_t[\Lambda_{t+1}^b R_{1,t+1}^e]\}. \tag{A.50}$$

- Bankers' first order condition for net equity issuance m_t:

$$v_t = 1 + C'(m_t^+). \tag{A.51}$$

- Bankers' equity allocation indifference condition:

$$\mathbb{E}_t[\Lambda_{t+1}^b R_{0,t+1}^e] = \mathbb{E}_t[\Lambda_{t+1}^b R_{1,t+1}^e].$$

  If this condition results in $x_t < 0$ (or $x_t > 1$), we fix $x_t = 0$ (or $x_t = 1$, respectively) and solve the of equilibrium equations excluding this indifference condition.

- Capital ratio decision of the non-systemic bank:

  - In the pooling equilibrium with full deposit insurance ($\eta = 1$), the capital requirement γ is also binding for the non-systemic bank:

$$g_{0t} = \gamma. \tag{A.52}$$

  - In the separating equilibrium without full deposit insurance ($\eta < 1$), the capital ratio of the non-systemic bank satisfies (24) with equality:

$$\begin{aligned} & \mathbb{E}_t\left[\Lambda_{t+1}^b \max\{R_{t+1}^b \Delta_{t+1}(0) - R_{0t}^d(1 - g_{0t}), 0\}\right] - v_t g_{0t} \\ = \; & \mathbb{E}_t\left[\Lambda_{t+1}^b \max\{R_{t+1}^b \Delta_{t+1}(1) - R_{0t}^d(1 - g_{0t}), 0\}\right] - v_t g_{0t}. \end{aligned} \tag{A.53}$$

[60] Relative to (12), we have removed the term 1 within the max operator below, since (A.51) already guarantees $v_t \geq 1$.

D Other variables used in the quantitative analysis

In the description of quantitative results, we also refer to derived variables whose definition in terms of previously defined equilibrium variables is as follows (in alphabetical order, all dated at t):

- Bank deposits:
$$d_t = d_{0t} + d_{1t}. \tag{A.54}$$

- Bank equity issuance (as share of pre-existing equity):
$$\frac{m_t^+}{n_t^b}. \tag{A.55}$$

- Bank to non-bank ratio:
$$\frac{a_t^b}{a_t^h}. \tag{A.56}$$

- Cost of equity issuance (as share of issued equity):
$$\frac{C(m_t^+)}{m_t^+}. \tag{A.57}$$

- (Expected) intermediation margin (non-systemic bank):
$$E_t(R_{t+1}^b) - R_{0t}^d. \tag{A.58}$$

- Investment:
$$I_t = [a_t^h - (1-\delta^h)k_t^h] + [a_t^b - (1-\delta^b)k_t^b]. \tag{A.59}$$

- Return on bank equity:
$$R_t^e = (1 - x_{t-1})R_{0,t}^e + x_{t-1}R_{1,t}^e. \tag{A.60}$$

E Supplementary figures

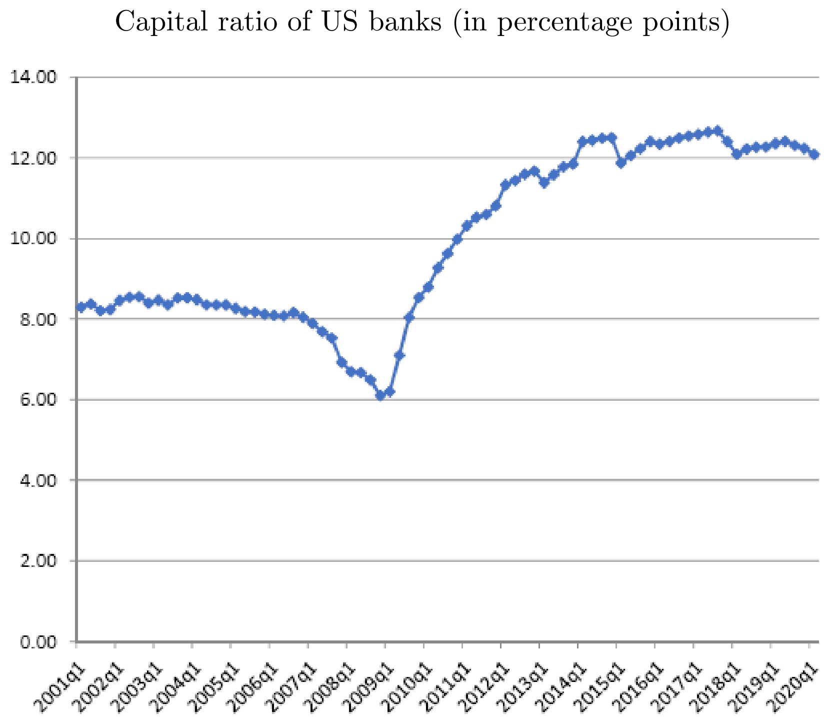

Figure E.1. Tier Common Equity Ratio of US banks
Vertical axis: CET1 and Tier 1 common equity as percentage of risk-weighted assets; all US bank holding companies. Horizontal axis: quarters between 2001q1 and 2021q1. Source: Quarterly Trends for Consolidated US Banking Organizations, Federal Reserve Bank of New York.