Entwined Risks: Sovereign Default, Bank Failures and Economic Activity*

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Premilinary and Incomplete

Abstract

This paper examines the two-way feedback loop between bank failure risk and sovereign default risk in a setup in which both risks are endogenous and amplify each other. The risk of bank insolvency increases sovereign spreads, and vice versa, heightened sovereign risk increases the risk of bank failures. Both channels increase the cost of capital to firms, reducing investment and GDP with amplification effects resulting from CES complementarity in capital and labor. Quantitative results calibrated to Spain illustrate these entwined risk effects in response to increased risk of default or bank failures. The effects strengthen nonlinearly as sovereign debt or the exposure of banks to sovereign debt rise, and they weaken with stricter capital requirements.

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1 Introduction

Historically, banking crises have often predated or accompanied sovereign defaults and have been associated with severe economic downturns (see Reinhart & Rogoff 2011, Balteanu et al. 2021, Borensztein & Panizza 2009, Bocola 2016, Perez 2018). The recent experience of the European debt crisis, the rapid growth of sovereign debt globally fueled by the global financial crisis and the COVID crisis, and concerns for the fragility of banking systems have raised further awareness and interest in understanding this phenomenon.

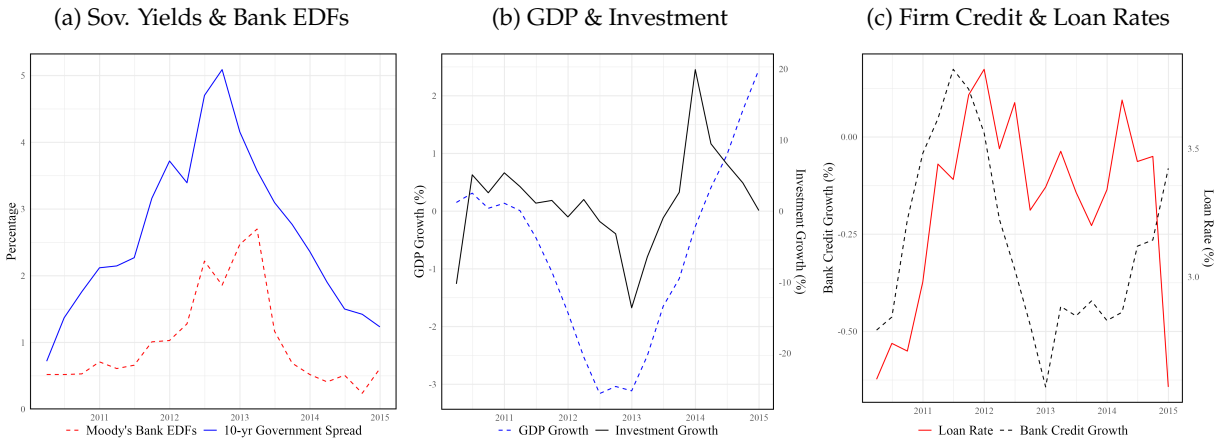
The European debt crisis was characterized by a rapid increase in sovereign and bank default risk, a deep recession and a severe credit crunch. The two-way links by which sovereign and bank risk affect each other became dramatically evident in this episode. In one direction, bank bailouts significantly contributed to rising sovereign credit risk across Eurozone countries, as was the case with the 2008 Irish bailout (see Acharya et al. 2014, Hur et al. 2021). In the opposite direction, heightened sovereign risk in GIIPS countries (i.e. Greece, Ireland, Italy, Portugal and Spain) inflicted losses on European banks' sovereign bond portfolios, raising serious concerns about their solvency (see Altavilla et al. 2017, Gennaioli et al. 2018, Arellano et al. 2024).

Consider the case of Spain as an example. Data for the 2010-2015 period plotted in Figure 1 illustrate clearly the feedback loop between sovereign and banking risks, deteriorating credit conditions, and sharp economic contraction in Spain during the European debt crisis. Panel (a) shows that the 10-year government bond spreads (red dashed line) and Moody's Expected Default Frequencies (EDFs) for banks (blue solid line) increased significantly, peaking around 2012, highlighting the close co-movement between sovereign and bank risks. Firm credit growth plummeted, reflecting tightened lending conditions, while loan rates spiked, further exacerbating financing constraints for firms (see Panel (c)). These developments in financial markets coincided with sharp decelerations in GDP growth and investment growth, as shown in Panel (b).

This paper studies the two-way feedback links between the risk of bank failures and sovereign risk focusing on three closely related questions. First, what is the transmission mechanism driving the effects of bank (sovereign) risk on sovereign (bank) risk? Second, how does this mechanism induce financial amplification of macroeconomic outcomes, leading to sharp recessions? Third what role does bank regulation (specifically capital requirements and deposit insurance) play in mitigating this sovereign-bank nexus and its macro effects?

We provide answers to these questions by examining the theoretical and quantitative implications of

Figure 1: 2010-2012 Sovereign Debt Crisis - Spain



a dynamic general equilibrium macro model in which both bank failures and sovereign default (and the risks attached to them) are endogenous. We show that the entwined risks of sovereign default and bank failures amplify each other and yield large endogenous output costs. On the one hand, sovereign default risk increases the probability of bank failures. On the other, the risk of bank failures reduces the price of sovereign debt and increases the spreads. Both effects increase firms' cost of capital and reduce the demand for both capital and labor (via CES complementarity), depressing economic activity. We also show that these effects strengthen nonlinearly as sovereign debt and/or the banks' holdings of that debt grow, and weaken with tighter capital requirements.

The model builds on elements from the sovereign default literature based on the setup proposed by Eaton & Gersovitzh (1981) and the bank default models that follow Gertler & Kiyotaki (2015). We consider households that transition randomly between being consumer-workers and bankers (or financiers). Consumer-workers make decisions about consumption, saving via bank deposits, and labor supply. Bankers choose equity financing for banks, pay dividends to the consumer-workers, and accumulate net worth. There is also a representative final-goods producer that operates a CES technology using capital and labor and is subject to productivity shocks. This producer participates in competitive markets. We also have banks that raise equity from financiers and deposits from households to invest in capital claims from the producer and government bonds, face idiosyncratic risks on the returns to their capital claims, limited liability, and costly defaults as in Mendicino et al. (2020). These features lead to a risk premium on capital returns.

On the side of the government, we consider a sovereign issuing debt but unable to commit to repay. The sovereign defaults strategically when the default payoff exceeds the repayment payoff. As a result,

sovereign debt carries a risk premium. The government also provides a partial guarantee for bank deposits. Government activities, including deposit insurance and regular spending, are funded through income taxes and debt issuance. In addition, the government imposes capital requirements by which banks must maintain equity proportional to their capital holdings.

Analytic results illustrate the feedback mechanism connecting bank failures and sovereign default. In one direction, sovereign default affects the banks' balance sheet and cash flow. The resulting income loss increases the threshold return on private capital investments needed for a bank to stay solvent, which increases the probability of bank failures. In the opposite direction, higher probability of bank failures reduces the price of sovereign debt and increases the spread of the sovereign debt yield relative to the mean return on deposits. The classic Eaton-Gersovitz effect of default risk lowering sovereign debt prices is augmented by a risk component driven by the endogenous covariance between sovereign default and the probability of bank failures. The spread on sovereign yields relative to deposits reflects this risk component too, and it also captures an extra endogenous premium due to expected losses on the fraction of deposits not covered by insurance. Both sides of this feedback linkages increase financing costs to firms, which respond by reducing demand for capital and labor. This is the transmission mechanism by which the connected risks of sovereign default and bank failures have real effects.

To examine the model's quantitative implications, we start by calibrating the model to match key macro and financial moments of the Spanish economy. Then, we produce a set of results designed to illustrate the strength of the feedback links connecting sovereign default and banking fragility and their macro effects.

First, we study the long-run effects of sovereign and bank stress by comparing unconditional moments with moments conditional on high sovereign stress (sovereign spreads greater than 2%) and on both high sovereign and bank stress (probability of bank failures above 1.1%). Periods of sovereign stress are marked by countercyclical government debt-to-GDP ratios (e.g. Bocola 2016) and higher probability of bank failures (1.4% instead of 1.1%). Sovereign spreads rise about 300 basis points, and both sovereign debt as a share of GDP and the share of bank assets invested in sovereign debt are higher. Investment as a share of GDP falls from 22% to 20%. Banking stress further amplifies the effects of sovereign stress. In these states of the world, banks demand a higher premium to hold government debt (spreads rise 450 basis points), which leads to a smaller increase in the debt-to-GDP ratio and in the bank holdings of sovereign debt. Still, the probability of bank failures rises more (to 1.9%) and the investment rate falls significantly more (to 15%).

Second, we examine dynamics around a typical episode of sovereign stress using 20-period event windows centered on the date of a peak in the sovereign spread at a value one standard deviation above its

mean. The spread rises from 2% 10 periods earlier to 6.5% at the peak, and 10 periods after the peak it remains high at 4/5%, showing that episodes of sovereign stress are persistent. This pattern is associated with a sequence of negative TFP shocks, with TFP in the period when the spread peaks falling to a level 3% lower than 10 periods earlier. Output drops by about 5% when the spread peaks relative to 10 periods earlier, and 10 periods after it only recovers by 2 percentage points. The probability of bank failures peaks with the sovereign spread, rising to 1.4% from about 1% 10 periods earlier, and bank equity also hits bottom when the spread peaks at about 0.66, from 0.75 10 periods earlier. Like GDP, 10 periods after the spread peaks, bank equity recovers only slightly, reaching 0.67 10 periods later.

A counterfactual in which we allow banks to fully and costlessly hedge sovereign risk (with the same sequence of TFP and the same spread dynamics) shows that GDP falls less and the effects on the probability of bank defaults and equity losses are much weaker. This underscores the critical role of the sovereign-bank nexus in amplifying and prolonging economic stress during sovereign debt crises.

Third, we study dynamic spillovers between bank risk and sovereign risk by analyzing impulse responses to shocks that directly increase either the risk of bank failures (an MIT innovation to the variance of the shocks to idiosyncratic bank returns on capital) or the risk of sovereign default (an MIT shock to the disutility of default). In the first experiment, larger variance of banks's asset returns causes the probability of bank failures to rise to near 7% and bank equity falls about 2% below its mean. The feedback with sovereign risk causes the sovereign spread to rise by 65 basis points. Government debt increases to support the financial sector and output falls by 4%. These movements are persistent, taking about 10 periods for them to dissipate. Interestingly, all these effects are significantly stronger and more persistent when we repeat the experiment with an initial ratio of sovereign debt to GDP of 60% instead of 55. This is also indicative of a strong feedback relationship between sovereign risk and bank failure risk (i.e., the effects of higher bank risk are non-linearly larger at higher levels of sovereign debt).

In a counterfactual we study the role that capital requirements play in the above findings. Tighter capital requirements (10% vs. 8%) weaken significantly the effects of the MIT shock to the variance of the banks' idiosyncratic returns on capital. Hence, tighter capital requirements make the banking system more resilient, although this does not necessarily imply they result in welfare or efficiency gains.

In the experiment exploring the effects of higher sovereign risk (induced by a surprise reduction in the disutility of sovereign default), we find large spillovers from sovereign risk to banking fragility that are significantly larger when the banks' exposure to sovereign debt is high. At a 9.5% exposure ratio, similar to the data, the spread rises 180 basis point and then falls quickly to vanish in about 4 periods. Bank equity

falls 5%, the probability of bank failures rises 50 basis points, and GDP falls 2%, with all these effects dissipating relatively fast. At a 19% exposure ratio, close to the model's long run average, the spread rises 250 basis points, bank equity falls 10%, the probability of bank failures reaches 2.5% and GDP falls 4%, and all of these effects are more persistent. Also in this case, tighter bank capital requirements (10% instead of 8%) enhance the banks' resilience, resulting in weaker effects of the same shock to sovereign risk.

Literature Review. This paper contributes to the literature on quantitative models of sovereign default initiated by Arellano (2008) and Aguiar & Gopinath (2006). Specifically, it contributes to the recent work on the sovereign-to-bank nexus and the interplay between sovereign default, bank credit and output. In the earlier literature on this topic, Bocola (2016) investigates how exogenous sovereign risk shocks are transmitted to bank credit provision by eroding the net worth of banks through losses on sovereign debt holdings, thereby constraining credit supply. Sosa-Padilla (2018) and Perez (2018) examine the government's incentive to service its debt, highlighting how sovereign defaults can trigger sharp contractions in bank credit and economic activity. These models generally abstract from bank defaults and their impact on government finances through bailout guarantees. Hence, we contributed to this early literature on the credit effects of the sovereign-bank nexus by fully exploring the two-way feedback loop between bank and sovereign risk in model in which both sovereign default and bank failures are endogenous.

Our works is also related to theoretical and quantitative studies that examine the foundations of the bank-to-sovereign nexus. The theoretical branch of this literature derives important findings from elegant theoretical frameworks of the "doom-loop" often in environments that consider simplified time horizons and abstracting from general equilibrium interaction (see e.g. Acharya et al. 2014, Cooper & Kalin 2018, Fahri & Tirole 2018). Our paper builds on these contributions by incorporating some of the key mechanisms from the theoretical research into a quantitative dynamic general equilibrium model. The model captures the two-way sovereign-bank nexus and serves as a tool for evaluating the effectiveness of capital regulation in mitigating its adverse effects.

In the recent quantitative literature, Hur et al. (2021) consider the transmission of exogenous bank capital losses that trigger costly government interventions modeled as contingent guarantees on bank capital. Like in our paper, in their model the pricing condition of sovereign debt is affected by private credit-market conditions, but via the effect of sovereign debt on the supply of working capital and its interest rate: Under repayment, higher debt issuance lowers the cost of working capital and reduces the price of sovereign debt. They model banking crises as exogenous shows to the banks' equity. Our analysis differs in that we model endogenously bank insolvency risk and in that the effect of bank risk on sovereign debt pricing is driven by

the covariance between sovereign default and the endogenous probability of bank failures. In addition, we consider standard government guarantees on deposits financed via a combination of taxes and debt. These features allow us to examine both the impact of bank bailouts on sovereign risk and the transmission of sovereign risk to bank fragility, and the adverse financial amplification that these feedback effects have on the real economy. In this respect, our paper introduces a new mechanism driving endogenous sovereign default costs via the entwined risks of bank and sovereign default risk, instead of the working capital channel widely used in the literature (see e.g. Sosa-Padilla 2018, Mendoza & Yue 2012, Arellano et al. 2024). Our analysis differs from Arellano et al. (2024) which shows that an increase in sovereign risk propagates to the real sector via interest rate effects required by financial intermediaries holding sovereign debt on loans granted to firms to finance their working capital expenses. A distinguishing feature of our model is the possibility of bank default which amplifies sovereign risk and vice versa, endogenously triggering sovereign default costs.

Finally, this paper also contributes to the literature that evaluates capital requirements in quantitative macro-banking models (see e.g. Van Den Heuvel 2008, Mendicino et al. 2020, Begenau 2020, Corbae & D'Erasmo 2021, Elenev et al. 2021, Begenau & Landvoigt 2022, Mendicino et al. 2024). These models typically focus on the role of bank default risk, abstracting from the interaction with sovereign risk. We study the role of bank capital requirements in weakening the sovereign-bank nexus. Our analysis differs from Abad (2019) which examines bank capital regulation in a model of the sovereign-to-bank nexus with exogenous sovereign default. A distinguishing feature of our approach is the endogenous choice of borrowing and default by both banks and the government. This contribution of our work is key to capture the two-way feedback loop between bank failure and sovereign default and the role of bank capital requirement in mitigating the bank-sovereign nexus.

The remainder of the paper is structured as follows: Section 2 presents the model and Section 3 discusses the calibration. Section 4 examines the model performance during periods of sovereign stress. Section 5 examines how the economy behaves around episodes of high sovereign risk. Section 6 studies the transmission of risk from sovereign to banks and vice-versa. Section 7 concludes.

2 Model

Environment. Figure 2 provides a visual representation of the agents in the model and their interactions through their balance sheets. The model features a household sector, a banking system, final goods pro-

ducers and a government.

We study an economy populated by households of two types (with a unitary measure each), consumer-workers and bankers-financiers. The former consume, save by holding bank deposits and supply labor. The latter provide equity to banks and pay dividends to the consumer-workers. Each period, a fraction of bankers survives and a fraction retires with an equal fraction starting as new bankers. Each new banker receives an initial endowment of net worth from the consumer-workers.[1]

Competitive banks raise equity from bankers and deposits from households to invest in productive capital and government bonds. Banks face idiosyncratic shocks to capital returns, operate under limited liability, and default when the returns on their holdings of capital and government debt are insufficient to repay their depositors. Bankruptcy is costly and imposes dead weight losses on society.[2] The risk of bank failures yields a risk premium on capital returns relative to deposit rates.

A representative final goods producer operates a CES technology that uses capital and labor to produce final goods. Factor and goods markets are competitive, so that factor demands equalize marginal products with factor prices.

The government issues sovereign debt sold to banks so as to maximize utility from government expenditures, but is unable to commit to repay and thus sovereign default is possible and sovereign debt carries a risk premium. The government also provides guarantees for banks modeled in the form of (partially) insured deposits. Governmentconsumption and deposit insurance are financed by income taxes and debt issuance. The government also imposes a capital requirement by which the banks' equity cannot be lower than a fraction of their capital holdings.

2.1 Consumer-workers

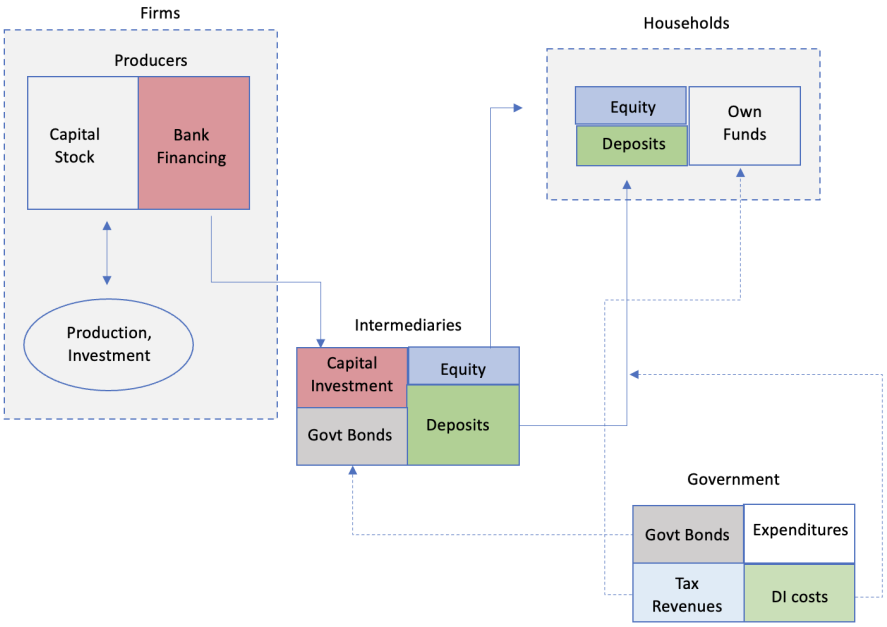
The representative consumer worker chooses consumption, C_t, labor supply, L_t, and non-state-contingent deposits with the banking sector, D_t so as to solve the followingoptimization problem:

$$\max_{C_t, L_t, D_t} \mathbb{E} \sum_{t=0}^{\infty} \beta^t \left(C_t - \chi \frac{L_t^{1+\eta}}{1+\eta} \right) \tag{1}$$

[1] As in Gertler & Kiyotaki (2010), each period some consumer-workers become bankers and an equal number of bankers retire and become consumer-workers again. This assumption ensures that bankers do not accumulate enough net worth for banks to be financed entirely by internal funds.

[2] Upon default, a fraction of the bank assets value is lost in repossession (Bernanke & Gertler 1989, see e.g.).

Figure 2: Model Sketch



subject to the budget constraint:

$$(1-\tau)W_t L_t + \widetilde{R}^d_{t-1} D_{t-1} + \Pi_t = C_t + D_t \tag{2}$$

We use a standard time-separable expected utility function (1), with β as the subjective discount rate. Period utility is linear in consumption, so that consumer-workers are risk-neutral, and separable in consumption and the disutility from labor supply. Labor disutility is an exponential function with scale parameter and Frisch elasticity parameter η. These preferences are in the class that neutralizes the wealth effect on labor supply by making the marginal rate of substitution between C_t and L_t independent of the former.

In the budget constraint (37), τ is the tax rate on labor income, $W_t L_t$, where W_t is the wage rate, and Π_t denotes dividend payments from bankers. We assume that households do not directly own capital and do not hold government debt. $\widetilde{R}^d_{t-1}$ denotes the *realized* gross return paid at date t on the deposits carried over from the previous period D_{t-1}. This realized return can differ from the contracted return because in the event of bank failures, deposit insurance does not cover all deposits In particular,

$$\widetilde{R}^d_{t-1} = R^d_{t-1} - (1-\kappa)\Omega_t,$$

where R^d_{t-1} is the non-state-contingent contract ("promised") gross interest rate when the deposits were made at $t-1$ and $(1-\kappa)\Omega_t$ are the uninsured losses realized in case of bank failures at date t. A fraction κ of deposits is covered by insurance and pays the contracted return R^d_{t-1}. A fraction $1-\kappa$ is uninsured. For these, solvent banks pay the contracted return, while deposits with banks that default yield losses in the amount Ω_t per unit of deposits.[3]

The optimality conditions of the household's problem are:

$$\mathbb{E}[\widetilde{R}^d_t] = \frac{1}{\beta}, \tag{3}$$

$$(1-\tau)W_t = \chi L^\eta_t. \tag{4}$$

Condition (3) implies that, due to the risk-neutrality of consumer-workers, the *expected* gross return on deposits must be constant and equal to the gross rate of time preference ($1/\beta$). Notice that, since $\widetilde{R}^d_t \leq R^d_t$ this result also implies that $R^d_t \geq \mathbb{E}_t[\widetilde{R}^d_t] = 1/\beta$. Hence, there is a premium in the contract rate on deposits (i.e., deposits are risky because of the existence of uninsured deposits). Condition (4) sets labor supply so as to equate the after-tax wage rate with the marginal disutility of labor.

2.2 Production

Producers of final goods operate a constant-elasticity-of-substitution (CES) production function that uses of capital and labor. Goods and factor markets are competitive.

Firms finance their capital purchases through banks.[4] This is central to the transmission mechanism connecting the sovereign-bank risk nexus to economic activity: When the banking sector suffers losses on its holdings of sovereign debt (either through outright default or fluctuations in the price of sovereign debt), its intermediation capacity shrinks.[5] This also happens when the probability of bank failures raises. In both instances, the reduced supply of bank funds increases the rental rate of capital and reduces the demand

[3] $\widetilde{R}^d_{t-1} = R^d_{t-1} - (1-\kappa)\Omega_t$ follows from adding up κR^d_{t-1} for the fraction of insured deposits,$(1-\kappa)R^d_{t-1}$ for uninsured deposits in ex-post solvent banks, and $-(1-\kappa)\Omega_t$ for uninsured deposits in ex-post defaulting banks. Note also that $0 < \Omega_t < R^d_{t-1}/(1-\kappa)$, because uninsured deposits of ex-post insolvent banks cannot make negative losses, otherwise the realized return would exceed the contracted return, and the loss in these deposits cannot exceed the amount that would make the realized return negative (keeping $\widetilde{R}^d_{t-1} > 0$ requires $\Omega_t < R^d_{t-1}/(1-\kappa)$).

[4] It is assumed that firms are penniless and finance all their capital purchase through banks. At the end of the period t the firms issue claims Z_t to acquire K_t units of productive capital. The price of each claim is set equal to the price of capital, $q_{k,t}$, that is, as if banks own capital and rent it to firms. Indeed, due to the absence of financial frictions between firms and banks, firms repay bank financing at the realized return on capital. See Gertler & Kiyotaki (2010).

[5] Sosa-Padilla (2018) uses a similar mechanism assuming that banks provide working capital financing to producers. Sovereign default hurts the balance sheet of banks and forces them to tighten working capital credit. In his setup however, banks do not take deposits and are not exposed to the risk of failure.

for capital from firms, thereby imposing output losses from sovereign risk and/or banking-system risk. As inMendoza & Yue (2012), this output cost depends on the functional form of the production function and the elasticity of substitution of factors of production. The CES formulation is important to deliver a convex sovereign default cost in line with the qualitative features of exogenous defaults costs that the literature typically assumes. With capital and labor as gross substitutes, the higher cost of capital induced by either sovereign risk or higher risk of bank failures induces also a reduction in labor demand, and hence wages (at equilibrium). This mechanism amplifies the resulting output drop.

The firm's profit-maximization problem is given by:

$$\max_{K_t, L_t} z_t \left[\alpha K_t^{\epsilon} + (1-\alpha) L_t^{\epsilon}\right]^{\frac{1}{\epsilon}} - W_t L_t - r_t^k K_t$$

where, z_t is a productivity shock, α is the capital share parameter, and $\frac{1}{1-\epsilon}$ is the elasticity of substitution between capital and labor.

The firms' optimality conditions are standard. They equate the marginal costs of labor and capital with their corresponding marginal products:

$$r_t^k = z_t \alpha K_t^{\epsilon-1} \left[\alpha K_t^{\epsilon} + (1-\alpha) L_t^{\epsilon}\right]^{\frac{1}{\epsilon}-1}, \tag{5}$$

$$W_t = z_t (1-\alpha) L_t^{\epsilon-1} \left[\alpha K_t^{\epsilon} + (1-\alpha) L_t^{\epsilon}\right]^{\frac{1}{\epsilon}-1}. \tag{6}$$

The productivity shock z_t follows a standard AR(1) process:

$$z_t = \rho_z z_{t-1} + \epsilon_t^z \quad \text{where} \quad \epsilon_t^z \sim \mathcal{N}(\bar{z}, \sigma_z). \tag{7}$$

2.3 Banking Sector

We characterize the banking sector as separated into "bankers" (or financiers) who use their net worth to invest in bank equity and pay dividends to households, and a continuum of competitive banks (see e.g. Mendicino et al. 2018). Banks in our model intermediates funds by using bank equity and deposits raised from households to finance lending to firms and investing in sovereign debt.

Bankers. In each period, some bankers return to the households and some household members become bankers. Each period can be divided into three stages: payment, surviving, and investment stages. In the payment stage, previously active bankers get paid on their previous-period investments. In the surviving

stage, each banker stays active with probability θ and retires with probability $1-\theta$. Retiring bankers return to the households again and transfer any accumulated net worth to the household sector. At the same time, a mass $(1-\theta)$ of households become new bankers, guaranteeing that the bankers' population remains constant and equal to 1. This new cohort of bankers receives net worth equal to a fraction $(1-\theta)\chi$ of the net worth of retiring bankers from households. In the investment stage, bankers provide equity financing to banks and pay dividends to households div_t.

Bankers invest their net worth N_t by funding the equity position of banks. Their recursive optimization problem is given by:

$$V_{b,t}(N_{t-1}) = \max_{E_t, div_t} \left\{ div_t + \mathbb{E}_t \left[\Lambda_{t+1} \left((1-\theta) N_t + \theta V_{b,t+1}(N_t) \right) \right] \right\}$$

$$s.t. \begin{cases} E_t + div_t = N_{t-1} \\ div_t \geq 0 \end{cases}$$

where N_t is given by $N_t = \rho_{b,t} E_t$, E_t is the diversified equity investment in the continuum of banks, $\rho_{b,t} = \int_0^\infty \rho_{b,t}(\omega) dF(\omega)$ is the rate of return on the equity invested in banks living in period t (to be characterized in more detail later), div_t is the dividend paid to households, and Λ_{t+1} is the stochastic discount factor of households (which equals β at equilibrium because the utility is linear in consumption). Note that from the point of view of an individual banker $\rho_{b,t}$ is exogenous, but at equilibrium it equals the gross rate of return of the portfolio of banker equity.

We guess that the bankers' value function is linear in net worth so that $V_{b,t}(N_{t-1}) = \nu_{b,t} N_{t-1}$, where $\nu_{b,t}$ is an endogenous undetermined coefficient solved for in the model's equilibrium. This coefficient represents the shadow value of a unit of a banker's wealth as in Gertler & Kiyotaki (2010). Hence, we can rewrite the banker's Bellman equation as

$$\nu_{b,t} N_{t-1} = \max_{E_t, div_t} \left\{ div_t + \mathbb{E}_t \left[\Lambda_{t+1} \left((1-\theta) + \theta \nu_{b,t+1} \right) N_t \right] \right\}. \tag{8}$$

Insofar as $\nu_{b,t} > 1$ (which we verify quantitatively for our solutions based on particular parameter values), it is optimal for bankers not to pay dividends prior to retirement (i.e., $div_t = 0$ for "surviving" bankers). When bankers retire, they pay dividends for the full amount of their net worth ($div_t = N_{t-1}$). It follows from (8), that an interior equilibrium in which banks receive a strictly positive amount of equity from

bankers ($E_t > 0$) requires that the properly discounted gross expected return on equity be equal to $\nu_{b,t}$:

$$\mathbb{E}_t \left[\Lambda_{b,t+1}\rho_{b,t+1}\right] = \nu_{b,t} \tag{9}$$

where $\rho_{b,t+1}$ is derived from the banks' optimization problem that we examine below, and $\Lambda_{b,t+1} \equiv \Lambda_{t+1}\left((1-\theta) + \theta\nu_{b,t+1}\right)$ is the bankers' stochastic discount factor. Note that this condition holds trivially from the binding participation constraint of the banks.

Since each period a fraction θ of bankers survives, and a fraction $1-\theta$ of new bankers receives a fraction χ of the wealth that retiring bankers gave to households ($(1-\theta)\,N_{t-1}$), the aggregate net worth of active bankers evolves as follows:

$$N_t = \theta N_{t-1} + \chi\,(1-\theta)\,N_{t-1}. \tag{10}$$

The profits from bankers paid to households are:

$$\Pi_t = (1-\chi)(1-\theta)N_{t-1}.$$

Banks. A continuum of banks operate across two consecutive dates so that the intertemporal decision about net worth accumulation in the financial system is carried out by the bankers. Banks raise funds in the form of equity from bankers and deposits from households, and use these funds to "rent out" capital to final goods producers at rental rate r_t^k and to purchase government bonds B_t at price q_t.[6]

We assume that banks are identical ex-ante but bank-specific shocks ω_t affect the return of their individual capital holdings, resulting in ex-post heterogeneous performance across banks, as in the classical Merton (1974) approach to corporate default (e.g. Mendicino et al. 2020, Elenev et al. 2021). This captures the idea that ex-post some banks hold high-quality assets while others hold low-quality assets. These shocks follow a log-normal distribution:

$$\omega_t \sim \log\mathcal{N}(-\frac{\sigma^2}{2}, \sigma^2).$$

The corresponding CDF and PDF are denoted $F(\omega)$ and $f(\omega)$, respectively.

Once the shock hits, a bank's realized date-$t+1$ gross return on capital investments (or loans) is

[6] As explained earlier, we can think of the bank as purchasing claims from final goods producers and this can be represented as if capital was being rented out.

$\omega_{t+1}R^k_{t+1}$, where

$$R^k_{t+1} = r^k_{t+1} + (1-\delta) \tag{11}$$

denotes the average gross return on capital.

The realized return on a bank's holdings of government debt at $t+1$ is defined as

$$R^b_{t+1} \equiv \frac{(1-\lambda)q_{t+1} + \lambda(1-\Delta_{t+1})}{q_t}, \tag{12}$$

where $\Delta_{t+1} \in \{0,1\}$ is the default decision of the government at time $t+1$ (with $\Delta_{t+1} = 1$ indicating defaut) and λ is the fraction of government debt maturing each period.[7]

The objective function of an individual bank is to maximize the net present value of the bankers' stake at the bank

$$NPV_{b,t} = \mathbb{E}_t\Big\{\Lambda_{b,t+1}\max\Big[\omega_{t+1}R^k_{t+1}K_t + R^b_{t+1}q_tB_t - R^d_tD_t, 0\Big]\Big\} - \nu_{b,t}E_t$$

where the equity investment E_t is valued at its equilibrium opportunity cost $\nu_{b,t}$, and the max operator reflects shareholders' limited liability (i.e., the pay zero in the event of a default, which occurs when the total return on their assets cannot cover the principal and interest on their deposit liabilities).

Banks face the following budget and capital-requirement constraints:

$$K_t + q_tB_t = D_t + E_t \tag{13}$$

$$E_t \geq \phi(K_t + \iota q_tB_t) \tag{14}$$

In our baseline case, we set $\iota = 0$ to reflect the zero-risk weight applied to government debt.

Banks that draw a value of ω_{t+1} below the threshold $\overline{\omega}_{t+1}$ will have negative net worth and hence default at $t+1$. The threshold $\overline{\omega}_{t+1}$ is defined by the following condition:

$$(\overline{\omega}_{t+1}R^k_{t+1} - R^d_t)\frac{E_t}{\phi} + (R^b_{t+1} - R^d_t)q_tB_t + R^d_tE_t = 0 \iff \overline{\omega}_{t+1} = \frac{(1-\phi)R^d_t - (R^b_{t+1} - R^d_t)\frac{\phi}{E_t}q_tB_t}{R^k_{t+1}}. \tag{15}$$

[7] Note that we are assuming partial default, because the portion of the debt maturing at $t+1$ is not considered defaulted on and continues to trade at price q_{t+1}.

The bank's problem can then be rewritten as:

$$NPV_{b,t} = \mathbb{E}_t \left[\Lambda_{b,t+1} \int_{\overline{\omega}_{t+1}}^{\infty} \left\{ (\omega_{t+1} - \overline{\omega}_{t+1}) \frac{R^k_{t+1}}{\phi} E_t \right\} dF(\omega_{t+1}) \right] - \nu_{b,t} E_t$$
$$= \mathbb{E}_t \left[\Lambda_{b,t+1} (1 - \Gamma(\overline{\omega}_{t+1})) \frac{R^k_{t+1}}{\phi} - \nu_{b,t} \right] E_t \tag{16}$$

where

$$\Gamma(\overline{\omega}_t) \equiv \int_0^{\overline{\omega}_t} \omega dF(\omega) + \overline{\omega}_t \int_{\overline{\omega}_t}^{\infty} dF(\omega).$$

Since this payoff is linear in E_t, the requirement that banks are willing to invest in capital (subject to the capital requirement) only if $NPV_{b,t} \geq 0$ implies:

$$\mathbb{E}_t \left[\Lambda_{b,t+1} (1 - \Gamma(\overline{\omega}_{t+1})) R^k_{t+1} \right] \geq \phi \nu_{b,t}$$

which holds with equality since it is not in a bank's interest to pay more for capital than strictly needed. In fact, any pricing of capital leading to $NPV_{b,t} > 0$ would make banks wish to expand E_t to infinity, which cannot be an equilibrium. The aggregate (gross) return on a portofolio of equity symmetrically invested in all banks is then

$$\rho_{b,t+1} = (1 - \Gamma(\overline{\omega}_{t+1})) \frac{R^k_{t+1}}{\phi}. \tag{17}$$

The first-order condition with respect to B_t can be expressed as:

$$\mathbb{E}_t \left[\Lambda_{b,t+1} (1 - F(\overline{\omega}_{t+1})) (R^b_{t+1} - R^d_t) \right] = 0, \tag{18}$$

where $F(\overline{\omega}_{t+1}) = \int_0^{\overline{\omega}_t} dF(\omega)$ is the default probability of the bank. Recalling that $\Lambda_{b,t+1}$ is the bankers' SDF and that the limited liability of banks implies that they pay zero in case of default, it follows from this expression that the expected spread of the returns on public debt relative to deposits risk-adjusted by weighing by the bankers' SDF must be zero (i.e., it is akin to a no-arbitrage condition on a risky asset). Debt is risky because of sovereign default risk. In periods of stress in sovereign debt, limited liability makes investing in high-yield, risky sovereign debt attractive for banks' shareholders: they can enjoy high profits insofar as the government does not default, while their losses are limited to their initial equity contribution otherwise.

The banks' optimality conditions yield two important results that characterize the nexus between sovereign default risk and the risk of bank failures. First, by manipulating the banks' first order-condition (18) using also the optimality condition for deposits from the consumer-workers, we find that there is an excess expected return on sovereign debt relative to the expected return on bank deposits:

$$\mathbb{E}_t[R^b_{t+1}] - \beta^{-1} = (1-\kappa)E_t[\Omega_{t+1}] - \text{cov}_t\left(\frac{\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))}{\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\right]}, R^b_{t+1}\right) \tag{19}$$

The right-hand-side of this expression indicates that this excess expected return has two components: The first term (in red) is the premium due to the uninsured losses of the banks, and the second term (in blue) is an additional premium due to the covariance of the SDF-weighted probability of non-failure of and the realized return on public debt (the premium is positive because the covariance is negative). Note that the bankers' SDF differs from the consumer-workers' intertemporal marginal rate of substitution (i.e., the SDF of bankers in a friction-less model) because it also a function of the banker's marginal value of wealth, which is turn affected by the probability of default of banks.

The second result follows from substituting the expression for the realized return on government debt in (12) into (18) and solving for q_t to obtain

$$q_t = \frac{\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))((1-\lambda)q_{t+1} + \lambda(1-\Delta_{t+1}))\right]}{R^d_t\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\right]}. \tag{20}$$

Manipulating this condition, we derive the banks' condition for the price of newly issued government debt:

$$q_t = \frac{1}{R^d_t}\Bigg[\mathbb{E}_t[(1-\lambda)q_{t+1} + \lambda(1-\Delta_{t+1})] + \text{cov}_t\left(\frac{\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))}{\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\right]}, (1-\lambda)q_{t+1} + \lambda(1-\Delta_{t+1})\right)\Bigg] \tag{21}$$

This expression is analogous to the standard pricing condition of Eaton-Gersovitz models of sovereign default: Sovereign debt subject to default risk is sold at a discount relative to the inverse of the interest rate on deposits (i.e., the implied price of non-state-contingent deposits). The discount has two components. The first term (in red) is the standard Eaton-Gersovitz term reflecting the fact that the probability of repayment is less than 1 (if all the debt matures in one period, we obtain the standard risk-neutral premium

$(1/\mathbb{E}_t[1-\Delta_{t+1}])$. The second term (in blue) arises from two effects: (i) a risk premium channel arising from the relationship between the bank's stochastic discount factor and the return on sovereign debt. This channel would tend to lower the price the bank is willing to pay for sovereign debt relative to the standard Eaton-Gersovitz benchmark. (ii) a risk-shifting channel arising from the positive correlation between the return on sovereign debt and the probability of the bank surviving. If this channel dominates it would push banks to value government debt more highly than the risk-neutral case. Intuitively, this arises because the bank faces truncated losses in the event of sovereign debt crises due to its limited liability.

2.4 Government

We follow Arellano et al. (2024) in formulating the government's payoff assuming that the government derives utility only from it's own expenditures and that the government may have a subjective discount factor ($\beta^G < \beta$) different from that of consumer-workers. In addition, we assume a period utility function of the Stone-Geary type, with a "subsistence level" of government expenditures $\bar{G}$ We characterize the government's problem in recursive form. The state variables are $S_t = \{z_t, S_t^e\}$, where the endogenous aggregate states are given by $S_t^e \equiv \{B_{t-1}, N_{t-1}, D_{t-1}\}$. As in Arellano et al. (2024) and Mendoza & Yue (2012), the government internalizes the effect of its choices on the private-sector actions, which we indicate by denoting allocations and prices determined in private markets as functions of the current state S_t, the endogenous states S_{t+1}^e and the current default decision Δ_1. The government views these allocations and prices as a schedule that depends on its choices.

The government's optimization problem is characterized as follows. First, the government decides whether to default or not by choosing the action with the highest payoff,

$$V(S_t) = \max_{\Delta_t \in \{0,1\}} \{(1-\Delta_t)V^G(S_t) + \Delta_t V^D(S_t)\}, \tag{22}$$

where $V^G(S_t)$ and $V^D(S_t)$ are the payoffs under repayment (good standing) and default, respectively.

Repayment payoff (government in good standing). If the government repays, it has full access to the bond market and it's optimization problem is:

$$V^G(S_t) = \max_{G_t, B_t} \frac{(G_t - \bar{G})^{1-\gamma}}{1-\gamma} + \beta^G \mathbb{E}_t[V(S_{t+1})] \tag{23}$$

subject to the budget constraint:

$$\tau W_t(S_t, S^e_{t+1}, \Delta_t) L_t(S_t, S^e_{t+1}, \Delta_t) + q_t(z_t, S^e_{t+1})(B_t - (1-\lambda)B_{t-1}) - \lambda B_{t-1} = G_t + DI_t(S_t, S^e_{t+1}, \Delta_t) \quad (24)$$

where fraction λ of government debt matures each period. Preferences are taken from Bocola & Dovis (2019). $\bar{G} \geq 0$ represents a minimum threshold for public good consumption. In their same way, we view $\bar{G}$ as reflecting elements of public spending that are relatively inflexible in the short term, such as wages for public employees and pensions. The inclusion of $\bar{G}$ disrupts the homotheticity of government preferences, a feature that is essential for aligning sovereign spread and bond issuance dynamics in advanced economies (Bocola & Dovis 2019, Bocola et al. 2019).

Default. If the government chooses to default on the fraction of maturing debt λB_t, then there are no further choices to make. The government simply maintains a balanced budget. It's value function is:

$$V^D(S_t) = \frac{(G^D_t - \bar{G})^{1-\gamma}}{1-\gamma} + \beta^G \mathbb{E}_t[V(S_{t+1})]$$

where $G^D_t = \tau W_t(S_t, S^e_{t+1}, \Delta_t) L_t(S_t, S^e_{t+1}, \Delta_t) - DI_t(S_t, S^e_{t+1}, \Delta_t)$ and government debt now evolves according to $B_t = (1-\lambda)B_{t-1}$. Note that while a government defaulting in a given period must run a balanced budget we do not impose exclusion in any subsequent periods. Non-defaulted government debt continues to be traded and a government that default in t must decide whether or not to default again in period $t+1$.

Deposit Insurance. The average loss rate per unit of bank debt realized at t due to bank default is defined by $\Omega_t = \frac{TC_t}{D_{t-1}}$, where the total cost of default from banks in equilibrium writes:

$$\begin{aligned} TC_t &= \int_0^{\overline{\omega}_t} \left\{ R^d_{t-1} D_{t-1} - (1-\mu)(\omega_t R^K_t K_{t-1} + R^b_t q_{t-1} B_{t-1}) \right\} \mathrm{d}F(\omega_t) \\ &= \left[\overline{\omega}_t - \Gamma(\overline{\omega}_t) + \mu G(\overline{\omega}_t) \right] R^K_t K_{t-1} + \mu F(\overline{\omega}_t) R^b_t q_{t-1} B_{t-1}, \end{aligned} \quad (25)$$

where $G(\overline{\omega}_t) = \int_0^{\overline{\omega}_t} \omega dF(\omega)$.

We assume that bankruptcy involves deadweight losses. The bankruptcy cost is assumed to equal a proportion μ of the realized gross payoff to the bank's capital and sovereign holdings, i.e. $\mu(\omega_t R^K_t K_{t-1} + R^b_t q_{t-1} B_{t-1})$. The deposit insurance scheme covers κ of this, e.g. $DI_t = \kappa TC_t$. We can rewrite (3) explicitly

using the expected loss on deposits:

$$R_t^d - (1-\kappa)\mathbb{E}_t\left[\frac{[\overline{\omega}_{t+1} - \Gamma(\overline{\omega}_{t+1}) + \mu G(\overline{\omega}_{t+1})]\, R_{t+1}^k K_t + \mu F(\overline{\omega}_{t+1}) R_{t+1}^b q_t B_t}{D_t}\right] = \frac{1}{\beta} \tag{26}$$

where κ is given.

2.5 Equilibrium

We focus on Markov equilibria in which government policies are functions of payoff-relevant state variables $S = \{z, S^e\}$, with $S^e = \{B, N, D\}$ where z denotes the TFP shock processes, B is the government's stock of debt, N is the aggregate equity of banks and D is households' deposits.

Definition 1. *The Markov Recursive Equilibrium for this economy consists of government borrowing policy $B'(S)$, default policy $\Delta(S)$, spending $G(S)$, value functions $\mathcal{V}(S) \equiv \{V(S), V^G(S), V^D(S)\}$ and pricing function for the sovereign bond $q\left(z, S^{e\prime}\right)$such that*

1. *Given the price $q\left(z, S^{e,\prime}\right)$, the borrowing $B'(S)$, default rule $\Delta(S)$, spending $G(S)$ and value functions $\mathcal{V}(S)$ satisfy the sovereign's maximization problem.*

2. *The set of policy functions $\mathbf{\Gamma}(S) \equiv \{K'(S), C(S), L(S), D'(S), E(S), div(S)\}$ and prices $\mathcal{P}(S) \equiv \{w(S), r^K(S), R^d(S)\}$ is consistent with the private competitive equilibrium.*

3. *The equilibrium bond price function is consistent with future policies and satisfy the condition (20).*

3 Calibration

We solve the model using value function iteration.[8] Then, we parameterize our model economy to try to capture some key features of the banking sector, the fiscal problems of the government, and the interaction between them. As is standard, we proceed in two steps by first setting the values for a number of externally calibrated or preset values, which we draw from the literature. With these in hand, we then parameterise another set of parameters by internally calibrating them with the objective of minimizing the distance between a collection of data and model moments. The model is calibrated quarterly using data for Spain during the 1999:Q1 - 2019:Q4 period. Results are reported in 1- 3.

[8] See Online Appendix for details.

Externally Calibrated Parameters

The quarterly depreciation rate δ is set to the typical value of 0.025, while the capital share in production α is set at 0.4. The TFP process is parametrised with persistence ρ_z set at 0.92 and standard deviation σ_z at 0.006 which is in the range of estimated TFP processes for Spain. The deadweight losses from bankruptcy are set as in Mendicino et al. (2020) at 0.3. The government risk aversion γ is set at typical values for this parameter and as set in Arellano et al. (2024) at 2. For the Frisch elasticity of labor, we again rely on the common value in the literature and set it 0.75 implying an η of 1.33. The parameter governing the disutility of labor χ is essentially a scaling parameter, and we set it such that the steady-state labour supply is equal to $1/3$. The discount factor of households is set such that $1/\beta$ equals the risk-free rate which we take as the yield on German bunds over 2000-2019. Finally, the capital requirements for banks are set according to current rules under Basel III at 8%.

Table 1: Model Parameters

Preset parameters					
Banks bankruptcy cost	μ	0.3	STD for TFP	σ_z	0.006
Depreciation rate of capital	δ	0.025	Frisch elasticity of labor	$1/\eta$	0.75
Government risk aversion	γ	2	Capital share in production	α	0.4
AR parameter TFP	ρ_z	0.92	Disutility of labor	χ	6.8587
Discount factor of consumers	β	0.994	Capital requirement for banks	ϕ	0.08
Calibrated parameters					
mean STD iid risk for banks	σ	0.0301	Share of insured deposits	κ	0.401
Discount factor of government	β^G	0.992	Survival rate of bankers	θ	0.910
Labor income tax	τ	0.280	Transfer from HH to bankers	χ	0.781
Maturing debt	λ	0.039	Elasticity of Substitution	ϵ	-0.151
Habit in government consumption	$\bar{G}$	0.102			

Internally Calibrated Parameters

For the remaining parameters, we set them to minimize the weighted sum of the squared distance between the simulated model moments and the corresponding data moments summarized in Table 3. Loosely speaking the standard deviation of the i.i.d shock to banks σ and the share of insured deposits κ are targeting the bank funding spread and real equity return of banks. The discount factor of the government β^G and the minimum level of government spending $\overline{G}$ are set to match government indebtedness, as summarised by the debt-to-GDP ratio and ratio of government bonds to total bank assets. The tax rate on labour τ is set to match the government's revenue as a share of GDP. The elasticity of substitution between capital and labour in the production function ϵ helps to calibrate default costs and so helps in matching the mean

and standard deviation of sovereign spreads. The parameters θ and χ enter into the law of motion of bank equity and so pin down the steady-state level of equity. As such, they also determine the overall level of capital in the economy and, hence, the credit spread. Finally, λ is chosen so that the implied average maturity of debt in the model matches the average maturity of Spanish government debt.

Table 3: Data targets used to calibrate the model as well as the corresponding model values. Asset returns are reported in annualized levels. We define $R^* = 1/\Lambda$ as the risk-free interest rate.

Table 2: Model fit

Targets	Definition	Data	Model
Real equity return of banks	$(\rho - 1)$	0.05203	0.081367
Gov't bond as % bank assets	$\frac{qB}{qB+K}$	0.0661	0.1855
Gov't Debt to GDP ratio	$\frac{B}{GDP}$	0.5359	0.5878
Gov't Revenue to GDP ratio	$\frac{\tau w L}{GDP}$	0.2155	0.2035
Gov't Debt Spread	$R^b - R^*$	0.0099	0.0186
Bank Net Interest Margin	$R^K - R^d$	0.007	0.004
Bank Funding Spread	$R^d - R^*$	0.008	0.002
Avg. Gov't Debt Maturity	$\frac{1}{4\lambda}$	6.47	6.47
STD Gov't Debt Spread	$\sigma(R^b - R^d)$	0.016	0.015

4 Sovereign-Bank Nexus: Long-run Effects

We use our calibrated model to examine the properties of the model in periods of sovereign stress. Table 4 reports the model's implied moments conditional on being in a state of sovereign stress, defined as a period of sovereign spreads higher than 2.2%, which approximately represents the level of the spreads in the run-up to the European sovereign debt crisis. For comparison, the table also reports the unconditional moments (column A). In addition, we also consider an additional state of high sovereign stress coupled with a probability that the bank default to be greater than its baseline level (column C).

On average, sovereign stress in the model is associated with an increased risk of insolvency in the banking sector. When conditioning on sovereign stress alone (column B), the probability of banking default increases by almost 30%, resulting in an increase in the deposit insurance costs as a fraction of GDP by 6%. The economy shows a 9% lower investment-to-GDP ratio. On the government side, the conditional mean of the sovereign spread rises to almost 5%, approximately the value reached by 10-year Spanish sovereign spread at the peak of the crisis. The sovereign stress scenarios in our model are characterized by countercyclical government debt-to-GDP ratios (Bocola et al. 2019) and by increased exposure of banks to sovereign bonds. The high volatility of the spreads and the procyclicality of government debt issuance

Table 4: Sovereign-Bank Nexus: Implied Moments

	(A) Unconditional (%)	(B) Sov. Stress	(C) Sov. Stress P.D. Bank >1.1
GDP	1	0.95 (-5%)	0.95 (-5%)
Inv. to GDP	22	20 (-9%)	15 (-32%)
Gov. Debt to GDP	58.8	64.1 (+9%)	63.1 (+7%)
Gov. Rev. to GDP	21.5	20.3 (-6%)	20.2 (-7%)
Gov. Bond to Bank Assets	18	19.4 (+5%)	18.8 (+2%)
Gov. Debt Spread	1.8	4.9 (+151%)	6.3 (+222%)
P.D. Bank	1.1	1.4 (+27%)	1.9 (+73%)
D.I. to GDP	0.32	0.34 (+6%)	0.38 (+19%)

Note: Results based on model simulation over 5,000 periods.
Sovereign Stress defined as sovereign spreads higher than 2.2%.

are due to the government's cautious behavior and its limited incentives to front-load consumption. In our parameterization, the government uses debt mostly for consumption smoothing (as indicated by the almost constant revenue-to-GDP ratio across scenarios), so it optimally keeps debt low in high-output states while borrowing in the face of adverse output shocks.

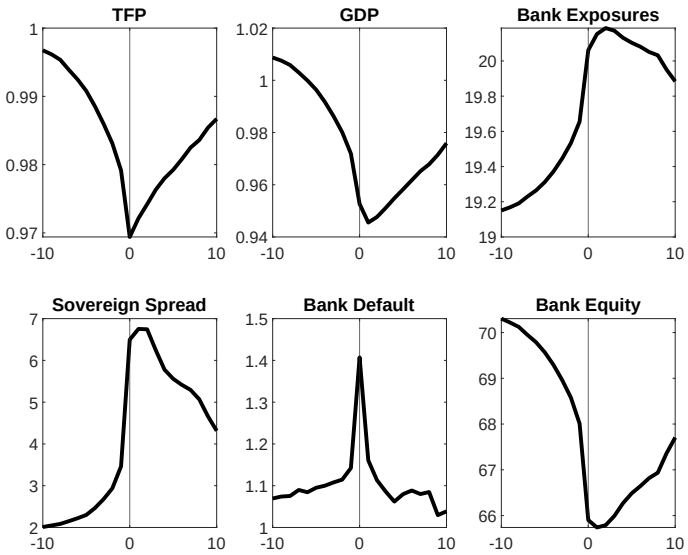
These patterns are exacerbated when sovereign stress is associated with a higher probability of bank default, as shown in column (C). In particular, the drop in investment to GDP is dramatic (32%), and there are substantial increases in sovereign spreads and bank default probabilities relative to their unconditional levels. In these states of the world, banks demand a higher premium to hold government debt (given their very low net worth), which curbs the government's precautionary savings motive. This is reflected in the smaller increase in government debt-to-GDP compared to the sovereign stress-only scenario and in the lower revenue-to-GDP ratio (a 7% decrease).

5 Spread Event

We now examine how the dynamics of the economy around episodes of high sovereign risk. We define such stress events as episodes of sovereign spread that goes above 1 standard deviation of its mean level.[9] Figure 3 plots the average path for key model variables for 10 quarters before and after the event. During

[9] We simulate the model for 50,000 periods and then select stress events.

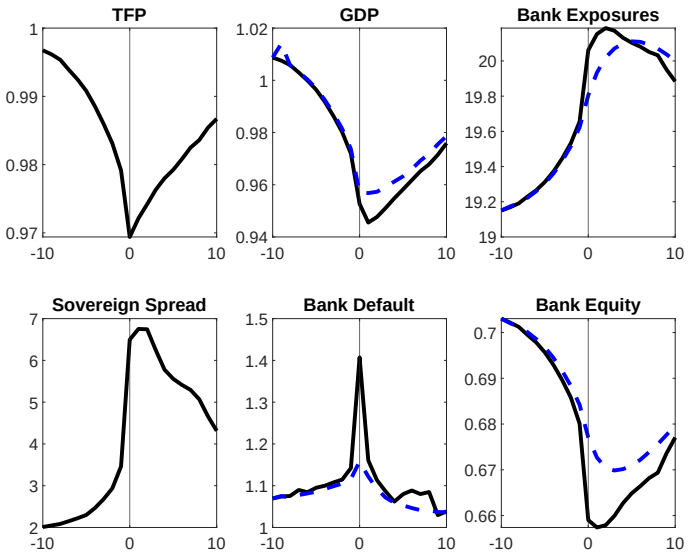
Figure 3: Heightened Sovereign Risk Event



these spread events, the economy experiences significant stress in multiple dimensions. Episodes of high sovereign risk in the model are endogenous generated as the result of a sharp and persistent deterioration in the economy fundamentals. Total factor productivity (TFP) decreases steadily in the leading up to the crisis, to then begin a slow and incomplete recovery. This drop in productivity is accompanied by a sharp contraction in GDP, which mirrors the TFP dynamics and fails to return to pre-crisis levels even 10 quarters after the peak of the crisis. Bank sovereign exposures rise steadily in the lead-up to the crisis, to then gradually declining but remaining elevated. At the same time, the sovereign spread spikes dramatically, marking the onset of the crisis, while bank default rates surge sharply, reflecting severe financial strain. Bank equity also experiences a steep decline leading into the crisis, bottoming out at the event before showing a modest recovery thereafter. These dynamics highlight the interconnected nature of economic activity, sovereign risk, and banking sector vulnerabilities during a sovereign debt crisis, with recovery proving slow and incomplete, underscoring the persistent adverse effects of such events on the economy

Next we examine the role of the sovereign-bank nexus. The blue line in Figure 4 plots the case where we switch off the spillovers from sovereign to bank. Specifically, we consider the case where banks are able to fully (and costlessly) hedge their risk to sovereign debt such that the return to holding debt is constant at the steady-state value. Since the banks now suffer no losses from drops in price of the bonds they hold, bank default does not spike and bank equity losses are more contained. The drop in GDP is, consequently, less pronounced. Banks how

Figure 4: No Sovereign to Bank Nexus



6 Short-run Dynamics

In what follows, we examine the spillovers from banks to sovereign and vice versa, by introducing shocks that originate purely in one sector or the other, rather than a common shock like TFP. For banks, we choose to bank risk shock, i.e. a shock the standard deviation of the i.i.d. shocks to their returns to capital. For the government, we assume an exogenous shock to the government's disutility of default. Both shocks are implemented by means of a standard MIT shock.[10]

6.1 Financial Stress

We start by exploring the transmission of a sudden increase to the standard deviation of the bank iid shock to capital returns. This implies higher probability that banks draw a shock below the threshold for insolvency. Figure 5 (black line) shows the impulse responses to the shock in the baseline economy. A sudden increase in the standard deviation of bank-specific shocks bank default spikes. The default of a larger number of banks latter has an impact on the aggregate dynamics of bank equity which is key to determining the lending capacity of the whole banking sector. This deterioration in the banking sector

[10] At $t = 0$ all agents learn that the shock has suddenly hit the economy and they also learn the path it will take as the shock decays and returns to its baseline value. We solve the model backward from the end of the shock episode, where value functions, policy functions, and pricing functions have returned to steady-state. We move back through the periods, solving for a new set of value, policy and pricing functions with each prevailing value of the relevant parameter (i.e. σ for the shock to banks and σ for the shock to the government, respectively) until we reach $t = 0$. With this series of policy and pricing functions in hand, we can then forward simulate to generate the endogenous responses of all variables.

transmits to the real economy: GDP initially falls before gradually recovering. The heightened banking sector stress also pushes up sovereign spreads, further amplifying the recession. This reflects the fact that banks need to be compensated more in order to hold sovereign debt on their balance sheet exactly at the same time in which deposit insurance costs go up and the government needs to finance those expenses with debt. In response, government debt rises, as the sovereign borrows to smooth consumption and support the financial sector.

Figure 6 compares how these dynamics unfold under two different initial government debt positions. The black line represents the baseline scenario with a 55% debt-to-GDP ratio, while the blue line corresponds to the scenario with a 60% debt-to-GDP ratio. When the economy starts from a higher initial debt-to-GDP ratio (blue line) it experiences a more pronounced and persistent deterioration in macro-financial conditions. Sovereign spreads spike more sharply and remain elevated for longer, as higher fiscal vulnerabilities are perceived to last for longer.

Interestingly, the debt issuance response becomes pro-cyclical when debt to GDP is higher: This is because, despite the consumption smoothing motive being active, the pricing conditions become so tight (banks are very constrained) that the sovereign prefers to borrow less in order to increase the likelihood of repayment in the future and lower the spreads today. Consequently, bank default probability exhibits a more pronounced adverse response, and GDP takes longer to recover. In essence, a higher initial government debt amplifies and prolongs the real and financial consequences of the same underlying bank risk shock.

Figure 7 examines the role of bank capital requirements in taming the economy's reaction to the shock. The black line depicts the impulse responses under a baseline 8% capital requirement (CR), and the blue line shows the results for a 10% CR. When capital requirements are tighter at 10% (blue line), the banking system is more resilient to the initial shock. With higher initial capital buffers, the banking sector's net worth declines less sharply, and the probability of bank defaults rises less significantly. The milder banking stress pushes sovereign spreads up by less, leading to a smaller decline in GDP. Higher capital buffers thus weaken the transmission of financial distress originated in the banking sector to the sovereign and the broad economy.

6.2 Sovereign Stress

To isolate spillovers from sovereign risk to the banking sector, we assume that there is an exogenous increase in the risk of default. To operationalise this, we suppose - just for the purposes of this exercise - that

Figure 5: Shock to st.dev of bank idiosyncratic shocks

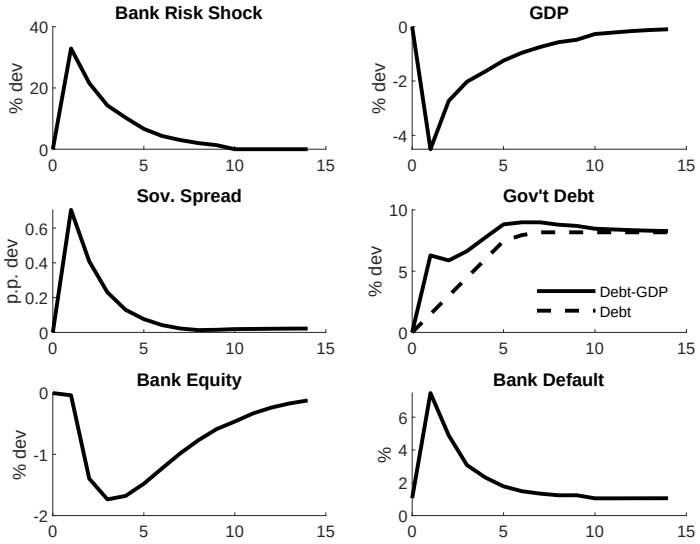


Figure 6: Black: 55% Debt to GDP; Blue: 60% Debt to GDP

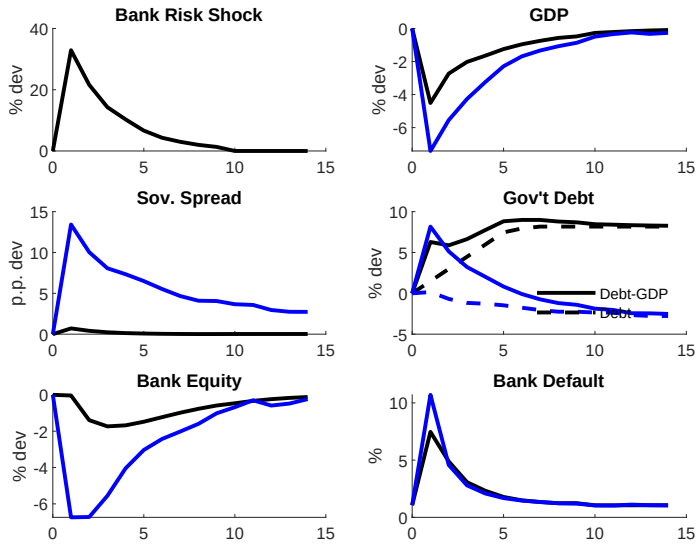
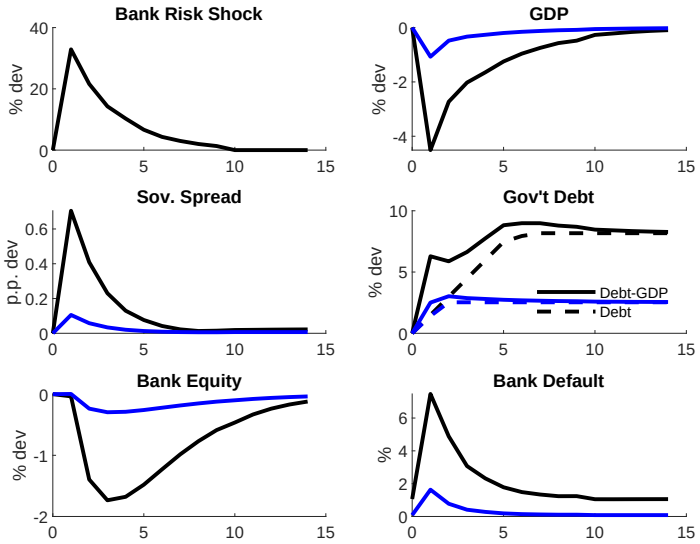


Figure 7: Black: CR 8%; Blue: CR 10%



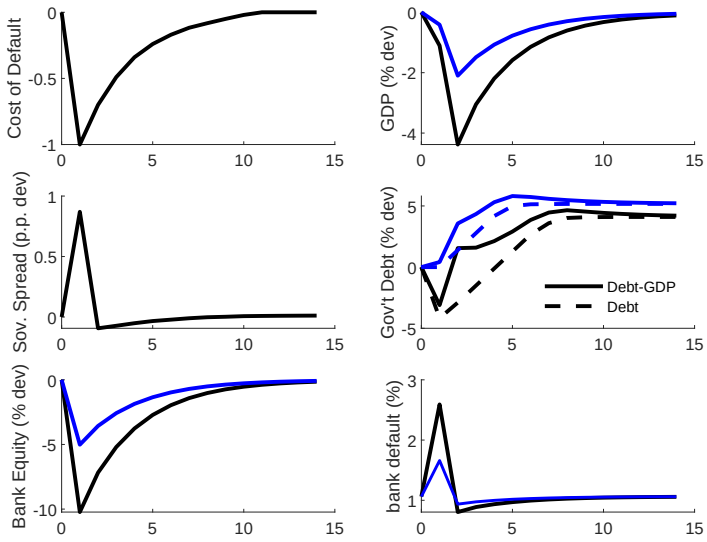
the value of being in the default state for the government is given by:

$$V^D(S_t) = v(\tau W_t L_t - DI_t) + \beta^G \mathbb{E}_t[V(S_{t+1})] - \xi_t$$

where ξ_t is an exogenous shock to the government's disutility of default (note that negative ξ_t implies the government find default relatively less costly). In the baseline, we have that ξ_t is identically 0. Here we are going to subject ξ_t to an MIT shock constructed in the same manner as the MIT shock to the banking sector detailed above.

Figure 8 shows the path for this shock that reduces the government's perceived cost of default, modeling a situation in which a newly elected policymaker attaches less importance to the consequences of reneging on its debt obligation. When the government becomes more inclined to consider default as a viable option, banks increase their assessment of sovereign risk. This shift leads to an increase in sovereign spreads as banks demand higher yields to compensate for the elevated likelihood of default. The resulting deterioration in financing conditions pressures government debt levels upward. Banks, which hold substantial amounts of sovereign bonds, suffer losses in their portfolios as spreads increase and bond values fall. These losses make banks less able to cover their debt, therefore increasing the probability of bank default and impairing the intermediation capacity of the whole banking sector. As a result, banks reduce their investment in productive assets, which depresses both aggregate investment and the price of capital. This further amplify the initial bank balance sheet losses, ultimately weakening GDP. In other words, a

Figure 8: Shock to Government Cost of Default



lower perceived cost of default sparks a feedback loop of deteriorating financial conditions, eroding market confidence, suppressing economic activity and triggering heightened riskiness in the banking sector.

In Figure 9 we compare the shock in the baseline in which banks have a high exposure to sovereign bonds (19%). In the blue-line scenario, their exposure is halved to 9.5%. When bank exposures are halved, the destabilizing sovereign-bank nexus is significantly mitigated. Although the cost-of-default shock still raises sovereign spreads and puts upward pressure on government debt, banks suffer smaller losses and face lower default probabilities. With a less impaired financial system, GDP experiences a milder decline and recovers more robustly.

Figure 10 compares how this same shock plays out under different bank capital requirements. The black lines represent the baseline scenario with an 8% CR, while the blue lines show the results for a stricter 10% CR. In both cases, the government's reduced aversion to default triggers an adverse chain reaction: sovereign spreads increase, fiscal strains mount, and the financial sector weakens. However, when banks are required to hold more capital (10%), they are better equipped to absorb losses from declining sovereign bond values. This resilience curbs the rise in bank default probabilities and mitigates the credit crunch, tempering the downturn in GDP.

Figure 9: Black: 19% Exposures; Blue: %9.5 Exposures

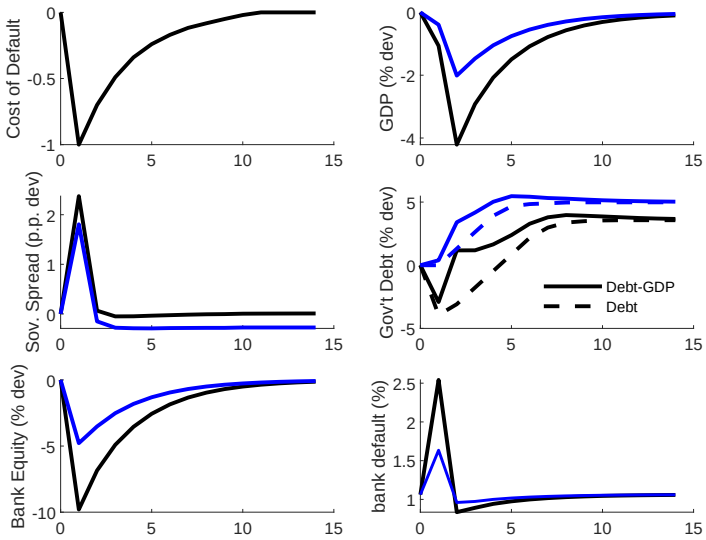
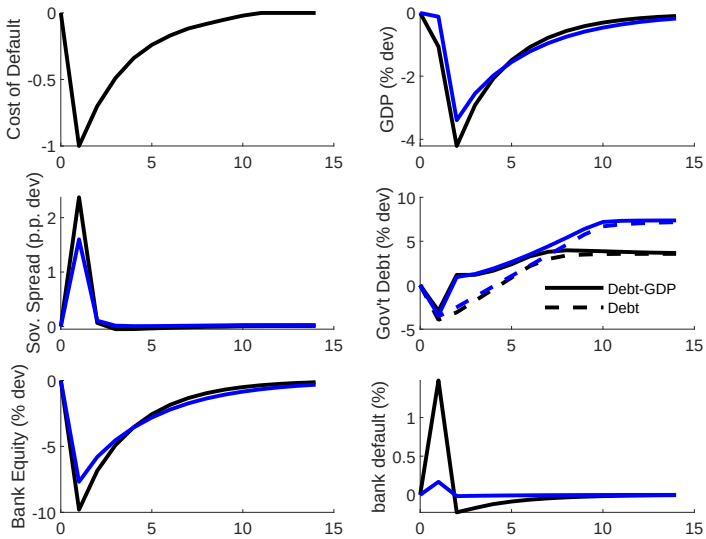


Figure 10: Black: CR 8%; Blue: CR 10%



7 Conclusions

This paper examines the interconnected risks of sovereign default and bank failures, highlighting how they amplify each other and generate significant economic downturns. Using a dynamic general equilibrium model of sovereign risk and bank default, we show that sovereign risk increases the probability of bank failures, while banking fragility leads to higher sovereign debt spreads, increasing firms' financing costs, and depressing investment and labor demand.

Through counterfactual exercises, we find that allowing banks to hedge sovereign risk significantly mitigates economic downturns. Additionally, tighter bank capital requirements reduce the severity of sovereign-bank feedback effects. Impulse response analysis further shows that shocks to bank risk or sovereign risk trigger persistent economic contractions, with stronger effects at higher sovereign debt levels. The findings underscore the critical role of financial regulation in mitigating the macroeconomic consequences of sovereign and banking crises.

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Appendices

A Model Derivations

Bank Problem

Starting from the objective function of the bank

$$NPV_{b,t} = \mathbb{E}_t\Big\{\Lambda_{b,t+1}\max\Big[\omega_{t+1}R^k_{t+1}K_t + R^b_{t+1}q_tB_t - R^d_tD_t, 0\Big]\Big\} - \nu_{b,t}E_t,$$

we substitute in $K_t = E_t/\phi$ from the capital requirement constraint (14) at equality (setting $\iota = 0$) and $D_t = q_tB_t + E_t(1-\phi)/\phi$ from the budget constraint (13) to get

$$NPV_{b,t} = \mathbb{E}_t\Big\{\Lambda_{b,t+1}\max\Big[\omega_{t+1}R^k_{t+1}\frac{E_t}{\phi} + R^b_{t+1}q_tB_t - R^d_t\left(q_tB_t + \frac{E_t(1-\phi)}{\phi}\right), 0\Big]\Big\} - \nu_{b,t}E_t, \tag{27}$$

Recall the definition of $\overline{\omega}_{t+1}$ from (15) and that bank default for $\omega_{t+1} < \overline{\omega}_{t+1}$. Taking first order condition with respect to B_t, we recover (18). Moreover using the definition of $\overline{\omega}_{t+1}$, we can rewrite the objective function (27) as

$$NPV_{b,t} = \mathbb{E}_t\left[\Lambda_{b,t+1}\int_{\overline{\omega}_{t+1}}^{\infty}\left\{(\omega_{t+1} - \overline{\omega}_{t+1})\frac{R^k_{t+1}}{\phi}E_t\right\}dF(\omega_{t+1})\right] - \nu_{b,t}E_t. \tag{28}$$

Expected Excess Return on Government Bonds

Starting from (18), rearranging the terms to express the difference in returns:

$$\mathbb{E}_t\Big[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))R^b_{t+1}\Big] = \mathbb{E}_t\Big[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))R^d_t\Big]. \tag{29}$$

Then normalize the marginal value of funds dividing through by $\mathbb{E}_t\big[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\big]$:

$$\mathbb{E}_t\left[\frac{\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))}{\mathbb{E}_t\big[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\big]}\cdot R^b_{t+1}\right] = R^d_t. \tag{30}$$

Using the decomposition of the expectation of a product:

$$\mathbb{E}_t[R^b_{t+1}] = R^d_t - \text{cov}_t\left(\frac{\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))}{\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\right]}, R^b_{t+1}\right). \tag{31}$$

This gives the final relationship:

$$\mathbb{E}_t[R^b_{t+1} - R^d_t] = \text{cov}_t\left(-\frac{\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))}{\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\right]}, R^b_{t+1}\right). \tag{32}$$

Adding and subtracting $E_t[\tilde{R}^d_t]$, using the result from the household's problem that $E_t[\tilde{R}^d_t] = 1/\beta$, and applying the definition of $E_t[\tilde{R}^d_t]$, we can rewrite the excess expected return government debt over the expected payout on bank deposits as:

$$\mathbb{E}_t[R^b_{t+1}] - \beta^{-1} = (1-\kappa)E_t[\Omega_{t+1}] - \text{cov}_t\left(\frac{\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))}{\mathbb{E}_t\left[\Lambda_{b,t+1}(1-F(\overline{\omega}_{t+1}))\right]}, R^b_{t+1}\right). \tag{33}$$

National Accounts

In this section we derive the relevant national accounts equation for GDP from the aggregation of the budget constraints of all agents and the equilibrium conditions. Start with the budget constraint of households:

$$(1-\tau)W_tL_t + \widetilde{R}^d_t D_{t-1} + \Pi_t = C_t + D_t \tag{34}$$

and use the government's budget constraint

$$\tau W_tL_t = G_t + DI_t - q_t(B_t - (1-\lambda)B_{t-1}) + (1-\Delta_t)\lambda B_{t-1} \tag{35}$$

to sub in for tax revenue τW_tL_t:

$$W_tL_t - (G_t + DI_t - q_t(B_t - (1-\lambda)B_{t-1}) + (1-\Delta_t)\lambda B_{t-1}) + \widetilde{R}^d_{t-1}D_{t-1} + \Pi_t = C_t + D_t \tag{36}$$

Now recognise that the per unit loss on bank deposits, Ω_t, which is account for in $\tilde{R}^d_t = R^d_{t-1} - (1-\kappa)\Omega_t$ is also related to the cost of deposit insurance in the government's budget constraint. Specifically, $DI_t =$

$\kappa\Omega_t D_{t-1}$. Subbing these in and rearranging we have:

$$W_t L_t + q_t B_t - D_t - ((1-\lambda)q_t - (1-\Delta_t)\lambda)B_{t-1} + -\Omega_t D_{t-1} + R^d_{t-1} D_{t-1} + \Pi_t = C_t + G_t \tag{37}$$

which accounts for the fact that households either pay for bank default through lower returns on deposits, through taxes, or through net issuance of government debt.

From the budget constraint of the bank, we have that

$$q_t B_t - D_t = N_t - K_t \tag{38}$$

Now, at time t the banks return to the bankers their net worth times the gross return on equity $\rho_t N_{t-1}$. A measure θ of this net worth will be kept by surviving bankers, and new bankers of measure $(1-\theta)$ will be given a fraction χ of the net worth of retiring bankers. This implies that (i) the net worth of banks in period t is $N_t = (\theta + \chi(1-\theta))\rho_t N_{t-1}$ and that $q_t B_t - D_t = (\theta + \chi(1-\theta))\rho_t N_{t-1} - K_t$; and (ii) the profits accruing to households is $\Pi_t = (1-\theta)(1-\chi)\rho_t N_{t-1}$. Subbing both of these results back into our equation gives us:

$$W_t L_t + (\theta + \chi(1-\theta))\rho_t N_{t-1} + (1-\theta)(1-\chi)\rho_t N_{t-1} - K_t - R^b_t q_{t-1} B_{t-1} + -\Omega_t D_{t-1} + R^d_{t-1} D_{t-1} = C_t + G_t \tag{39}$$

From this equation it is clear that the flows between households and bankers simply aggregate to $\rho_t N_{t-1}$.

$$W_t L_t + (\rho_t N_{t-1} + R^d_{t-1} D_{t-1} - R^b_t q_{t-1} B_{t-1} - \Omega_t D_{t-1}) = C_t + G_t + K_t \tag{40}$$

Focusing on the term in brackets above, we can use the definition of $\rho_t N_{t-1}$ to write:

$$\begin{aligned}
&\rho_t N_{t-1} + R^d_{t-1} D_{t-1} - R^b_t q_{t-1} B_{t-1} - \Omega_t D_{t-1} \\
&\quad = \int_{\overline{\omega}}^{\infty} (\omega R^k_t K_{t-1} + R^b_t q_{t-1} B_{t-1} - R^d_{t-1} D_{t-1}) dF(\omega) + R^d_{t-1} D_{t-1} - R^b_t q_{t-1} B_{t-1} - \Omega_t D_{t-1} \\
&\quad = \int_{\overline{\omega}}^{\infty} \omega R^k_t K_{t-1} dF(\omega) + (1 - F(\overline{\omega}))(R^b_t q_{t-1} B_{t-1} - R^d_{t-1} D_{t-1}) - (R^b_t q_{t-1} B_{t-1} - R^d_{t-1} D_{t-1}) - \Omega_t D_{t-1}
\end{aligned}$$

Canceling terms and using the expression for $\Omega_t D_{t-1}$ this can be expanded as:

$$= \int_{\overline{\omega}}^{\infty} \omega R_t^k K_{t-1} dF(\omega) - F(\overline{\omega})(R_t^b q_{t-1} B_{t-1} - R_{t-1}^d D_{t-1}) - \int_0^{\overline{\omega}_t} \left\{ R_{t-1}^d D_{t-1} - (1-\mu)(\omega_t R_t^K K_{t-1} + R_t^b q_{t-1} B_{t-1}) \right\} \mathrm{d}F(\omega_t)$$

The terms involving government debt and deposits cancel, the two parts of the integral over ω can be joined to form $R_t^k K_{t-1}$. So we are left with the return to capital and just the deadweight loss from bank default:

$$= R_t^k K_{t-1} - \mu[G(\overline{\omega}) R_t^k K_{t-1} + F(\overline{\omega}) R_t^b q_{t-1} B_{t-1}]$$

Putting this term back into our original equation for the expression in brackets gives us:

$$W_t L_t + R_t^k K_{t-1} - \mu[G(\overline{\omega}) R_t^k K_{t-1} + F(\overline{\omega}) R_t^b q_{t-1} B_{t-1}] = C_t + G_t + K_t$$

Using the definition of $R_t^k = r_t^k + 1 - \delta$ and rearranging:

$$W_t L_t + r_t^k K_{t-1} - \mu[G(\overline{\omega}) R_t^k K_{t-1} + F(\overline{\omega}) R_t^b q_{t-1} B_{t-1}] = C_t + G_t + K_t - (1-\delta) K_{t-1}$$

Finally, note that the definition of investment $I_t = K_t - (1-\delta) K_{t-1}$ and the zero profit condition of firms

$$\Pi_t^f = Y_t - r_t^k K_{t-1} - W_t L_t = 0 \tag{41}$$

can be used to achieve the final expression:

$$Y_t - \mu[G(\overline{\omega}) R_t^k K_{t-1} + F(\overline{\omega}) R_t^b q_{t-1} B_{t-1}] = C_t + G_t + I_t$$

Consequently, $GDP_t = Y_t - \mu[G(\overline{\omega}) R_t^k K_{t-1} + F(\overline{\omega}) R_t^b q_{t-1} B_{t-1}]$

B Data sources

- Gross domestic product: GDP chain-linked volume indices. Quarterly Spanish National Accounts (1999Q1 - 2018Q4). Instituto Nacional de Estadistica (Spanish Statistical Office).

- GDP deflator: Quarterly Spanish National Accounts (1999Q1 - 2018Q4). Instituto Nacional de Estadistica (Spanish Statistical Office).
- Government spending: Final consumption expenditure by general government. Quarterly Spanish National Accounts (1999Q1 - 2018Q4). Instituto Nacional de Estadistica (Spanish Statistical Office).
- Tax revenues: Taxes on production and imports (D.2), Current taxes on income, wealth, etc. (D.5), and Capital taxes (D.91). Spanish National Accounts. Quarterly non-financial accounts for the institutional sectors. General government (S.13): transactions and balancing items (1999Q1 - 2018Q4).
- Sovereign bond holdings/bank assets: ECB Statistical Data Warehouse.
- Sovereign spreads: difference between the yield on a 10Y bond and the yield on a German sovereign bond with the same maturity, obtained from Bloomberg
- Bank equity returns: obtained from the Bank of Spain financial institution statistics. Calculated as total after-tax bank book profit (Table 4.36) divided by total equity (Table 4.7).

C Sketch of Solution Method

1. Construct a grid for $S = \{z, N, D, B\}$ and create a Markov chain for the AR(1) process for z_t using Tauchen's method.
2. Guess policy functions for $B(\cdot)$, $\Delta(\cdot)$ and $N(\cdot)$ (equivalently $K(\cdot)$ in the baseline), pricing functions for $q(\cdot)$ and $R^d(\cdot)$, and value functions $V(\cdot)$, $V^G(\cdot)$, $V^S(\cdot)$ and the shadow cost of equity $\nu^b(\cdot)$.
3. For a given guess of the policy functions, solve for sovereign debt prices and bank funding costs using the guessed pricing functions $q(\cdot)$ and $R^d(\cdot)$. From these we can find deposits through the bank's budget constraint.
4. Given these, we can determine the outcomes in the goods and factor markets W, L, R^k and consequently government revenue, bank default and required deposit insurance. Given R^k we can derive ρ_t^b and so we also update our guess for policy function $N(\cdot)$ using the law of motion.
5. VFI step: With these outcomes in hand, we can compute government consumption for the repayment case for all feasible choices of government debt and for the default case. Using these and the guessed

value functions from before, we update the government's debt choice, default choice and value functions. Importantly, to aid convergence, we assume that the government is hit by extreme value i.i.d. default taste shocks such that $\Delta(\cdot) \in [0, 1]$ returns a probability of default.

6. Update prices: Given the computed outcomes for bank default, government debt and government default, we can update the pricing equations $q(\cdot)$ and $R^d(\cdot)$ as well as the shadow cost of bank equity $\nu^b(\cdot)$.

7. Check convergence: We check for convergence of all value functions and pricing functions. If the maximum difference between the old and new guessed functions is below a preset tolerance for all such functions, we finish, otherwise we return to step 3 and repeat.