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December 2022

Working Paper 2022-5

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Fiscal Multipliers with Sovereign Risk and Fragile Banks*

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October 31, 2022

Abstract

We quantify the size of fiscal multipliers in an economy with sovereign and bank default risk. We build a DSGE model with financial frictions for the euro area in which the interplay of corporate, bank and sovereign solvency risk affects the transmission of government spending. Sovereign bonds carry a credit risk premium that depends on government indebtedness. The banking system is fragile through its direct and indirect exposure to sovereign risk and limited loss absorption capacity. Calibrating the model on sovereign and bank riskiness reminiscent of the euro area sovereign debt crisis period, we show that adverse financial channels may significantly depress the fiscal multiplier. The trade-off for the fiscal authority, between the macroeconomic stabilization objective and solvency risks, continues to be relevant in the euro area. We also evaluate the scope for monetary and macro-prudential policy to mitigate the financial setbacks and help restore the effectiveness of fiscal stimulus.

Keywords: DSGE models, fiscal stabilization, sovereign risk, sovereign-bank nexus.

JEL classification: E44, E52, E62.

*We are grateful to three anonymous referees for valuable comments and suggestions. The views expressed are solely our own and do not necessarily reflect those of the European Central Bank, the Central Bank of Cyprus or the Eurosystem.

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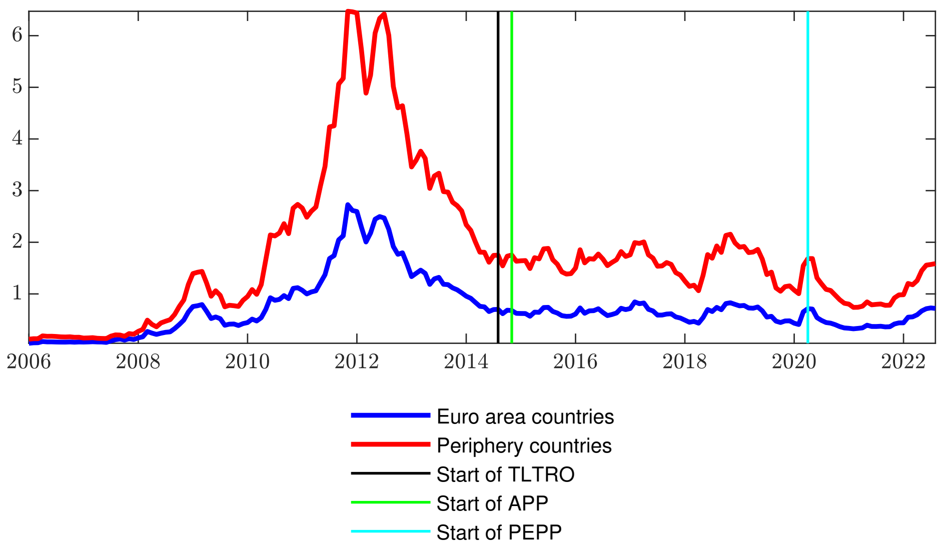
1 Introduction

The interaction of fiscal and monetary policy within the euro area is the subject of active research and policy debate. As Europe faces a succession of crises, the role of fiscal stabilization of the business cycle takes center stage. At the same time, the economies experience a rapidly changing interest rate environment - in which also country spreads again open up (see Figure 1). The challenges posed by these sovereign-financial dynamics today are reminiscent of those during the Great Financial Crisis (GFC) and the Sovereign Debt Crisis.

Figure 1: Country spreads of sovereign bonds



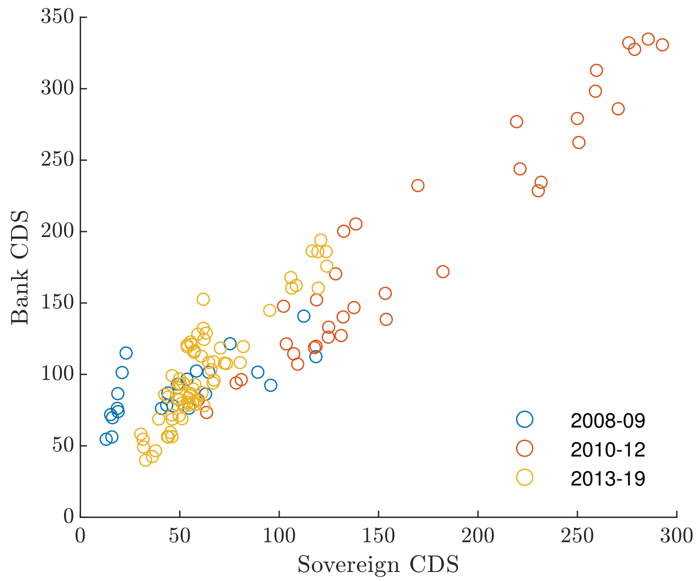
Notes: Spreads in annualized percentage point of the GDP-weighted 10-year government benchmark bond spread between area area countries and Germany. The German government bond rate serves as a proxy for a long-term risk-free rate. Periphery refers to a GDP-weighted aggregate across Greece, Italy, Portugal, Spain, and Ireland. TLTRO = Targeted longer-term refinancing operations, APP = Asset purchase program, PEPP = Pandemic emergency purchase program.

The Sovereign Debt Crisis has been especially severe for countries with high debt levels that struggled with the macro-financial fall-out from the financial crisis. Figure 1 shows that sovereign spreads have been particularly high for this group of countries. However, even on an aggregate level, there is sovereign riskiness. Furthermore, while the spreads normalized after the 2012 peak, they continue to stay above the near-zero level that was seen before the GFC. Sovereign risk pricing continues to matter as shown also in more recent episodes. Institutional innovations, but especially unconventional central bank actions influenced the spreads decisively. When the pandemic crisis erupted in early 2020, spreads started to rise again until the announcement of emergency asset purchases calmed the financial risk pricing again.

This paper sheds new light on understanding the constraints of fiscal stabilization in an economy where sovereign and financial risks interact. Our aim is to quantify the different layers of the sovereign-bank nexus using a macro-finance model for the area area. The sovereign debt crisis in Europe has shown that public sector solvency concerns have particularly adverse effects on the economy if they meet a strained financial sector.

Across area area countries, financial and government riskiness has been correlated. This is illustrated in Figure 2 which sets Credit Default Swap (CDS) prices for banks and sovereigns in relation to each other. During the height of the European sovereign debt crisis 2010-12, this connection was particularly pronounced and reflects the strong exposure of the banking system to their host country. Bank default risk after the crisis normalized to some extent, yet there continues to be a substantial relationship despite progress in financial integration during this period.

Figure 2: Sovereign vs bank default risk



Notes: GDP weighted area area countries' 5-year sovereign CDS in bps. 5-year bank CDS in bps, the median bank CDS in each available area area country is weighted by GDP to construct the aggregate.

Concretely, this paper investigates the following three main research questions. First, it quantifies to which extent an adverse interplay of sovereign and financial risk can depress the output multipliers of government spending. Second, it presents a detailed decomposition of the layers of the sovereign bank nexus thereby investigating the transmission channels of sovereign risk. And lastly, it quantifies the degree of (unconventional) monetary and macro-prudential policy intervention that is necessary to restore the fiscal multiplier to a benchmark case despite the presence of adverse sovereign-financial feedback loops.

It proposes a dynamic stochastic general equilibrium (DSGE) model which can account for feedback loops between risky banks and risky sovereign debt. DSGE models can deliver a wide range of government spending multipliers depending on exact model specification, policy regimes, the nature of sovereign debt, and the presence of the Effective Lower Bound (ELB) constraint (Leeper et al. (2017)). It highlights a specific source of multiplier variation that is due to the sovereign-bank-nexus. The work builds on the macro-finance models of Darracq Pariès and Papadopoulou (2020), Darracq Pariès et al. (2016) and Darracq Pariès et al. (2019) by introducing a government sector and by specifying an endogenous sovereign default risk function. In this model, the sovereign-bank nexus arises through two main channels (see also Dell'Ariccia et al. (2018) on what constitutes the nexus and for a definition of the associated technical terms). Through the sovereign-exposure channel, sovereign risk triggers adverse valuation effects on bank holdings of government bonds which weakens bank capital position and raises bank default risks. Through the safety net channel, sovereign risk weakens the direct or indirect government guarantees securing the functioning of the financial system, thereby exposing banks to large deposit withdrawal risks.

The model features a rich set of real and financial frictions, including bankers' limited liability due to deposit insurance and macro-prudential regulation that pins down banks' portfolio decisions. Financial intermediaries face idiosyncratic shocks determining default risk depending on an individual bank's asset position and the financing thereof. The detailed description of the banking sector in this paper is motivated by the aim to understand and quantify the transmission channels of sovereign risk through the bank balance sheet. Interacting with the financial sector, the model features a government sector with long-term debt securities and can therefore connect to term premium information in the data, which is an important innovation compared to more standard models (see e.g. Rudebusch and Swanson (2012)). Finally, it is only due to the model's complexity regarding the bank sector that it allows us to realistically assess the transmission of unconventional monetary policy measures.

Regarding the transmission mechanism of sovereign risk, the paper finds and quantifies three main layers. The sovereign risk channel is particularly sensitive to *(a)* the credibility of government guarantees on bank deposits, *(b)* the loss absorption capacity of the banking system, and *(c)* its direct holdings of government securities. Moreover, it quantifies the degree of transmission of unconventional monetary policy, when shielding the effectiveness of fiscal stabilization. It shows that central bank asset purchase programs can limit the rise in sovereign spreads to start with and ease bank lending conditions through a portfolio re-balancing channel. Finally, non-standard measures that are targeted directly towards supporting bank funding, such as the TLTRO programs of the European Central Bank (ECB), prove effective in mitigating the pass-through of sovereign risk to the banking sector.

This paper relates to various strands of the literature, starting with the abundant research on the macroeconomic multipliers of discretionary fiscal interventions in crisis time. In the low-interest rate environment prevailing until the pandemic, the DSGE literature found fiscal spending effects to be surprisingly large (starting with Christiano et al. (2011) and Erceg and Lindé (2014)). The puzzling behavior of multipliers has been explained by too stark generalizations of the standard model (e.g. missing welfare considerations as in Bilbiie et al. (2019) and Michaillat and Saez (2021) or missing liquidity spreads as in Bayer et al. (2020) and Bredemeier et al. (2022)). Fiscal multipliers under constrained monetary policy also have been studied for combined tax and expenditure packages (Drautzburg and Uhlig (2015)) where the average multipliers arise as an aggregate across different shocks. Furthermore, fiscal policy can be thought of as being especially effective during a period of financial distress when more households face borrowing constraints (e.g. in Auerbach and Gale (2009)). Moreover, in an active fiscal - passive monetary policy regime, where fiscal instruments only respond weakly to debt stabilization and the monetary authority allows for more inflation, fiscal spending is found to exhibit multipliers above 1 in DSGE models (see Leeper et al. (2017)).

In this work, the sovereign default risk is assumed to be proportional to the public debt-to-GDP ratio and this model, therefore, creates a positive correlation between a fiscal expansion and the sovereign spread. The literature does not find a generalized relationship in this regard. Some empirical findings in the literature show that austerity measures in response to the debt crisis could be self-defeating by actually further increasing the risk premium (Born et al. (2020)). This argument can be related to the incentive effects of tax hikes in a vulnerable economy (Arellano and Bai (2017)) or to endogenous distortionary tax adjustments that counter-finance expenditure cuts (Corsetti et al. (2013)). On the other hand, empirical (Born et al. (2020)) and structural work (Gourinchas et al. (2017)) point to a positive co-movement of government spending increases and sovereign risk for distressed economies, i.e. for countries with high debt levels, a large share of external borrowing or persistent current account imbalances.

There is an active debate wether an increase in public debt matters. For the US economy, Blanchard, Olivier J. (2019) highlighted that in the long-term, nominal economic growth exceeds the rate of return on safe assets. Therefore, if the repayment of government bonds is credibly committed, public debt financing poses only limited economic costs. In a European context, however, the GFC showed that investors may doubt the ability of governments to fully service their debt in the future. This notion has been conceptualized by introducing stochastic fiscal limits in structural models by Bi and Leeper (2010), Huixin Bi (2012) and Corsetti et al. (2013). Bi and Traum (2012) also estimate an RBC model with sovereign default on euro area country data. These types of models expose the additional risk premium as a pricing factor on government debt as it approaches some abstract limit without the default actually occurring. Debt-dependence of fiscal policy measures also arises in the model of Bianchi et al. (2019) who study the trade-off from fiscal expansion under a rising risk premium from an optimal policy perspective. In their setting, a Keynesian stimulus can become contractionary since the level of debt enters the value function of the government when choosing whether to default or not.

Relative to the literature, this model has the explicit advantage to study the interaction with the banking sector. It can therefore explicitly spell out the sovereign-bank-nexus which enriches the literature that investigates increases in private sector borrowing costs in response to higher sovereign spreads on a very generalized level (Giavazzi and Pagano (1990)). Empirically, the literature on the nexus between sovereign risk and bank risk is well documented (see for example Schnabel and Schüwer (2017)). Finally, this paper closely relates to Bocola, Luigi (2016) and Ester Faia (2017) who present structural models with bank exposure to sovereign risk. The former analyses to which extent the sovereign default risk was passed through on the example of Italy. Their model includes a bank sector specification based on Gertler and Karadi (2011), but different to us they do not find a substantial role of unconventional monetary policy to shield the economy from sovereign risk transmissions. The work by Ester Faia (2017) is more theoretical but also builds on an explicit bank funding cost channel that depends on sovereign riskiness. In comparison to those authors, this work's value added is to provide quantifications of fiscal multipliers in an estimated model which also highlights the scope of policy interventions.

The rest of the paper is structured as follows. Section 2 presents the theoretical model, while Section 3 discusses the calibration strategy of sovereign risk and bank fragility; as well as the estimation. Section 4 shows simulations to explore the fiscal multipliers in a benchmark case, in an economy with sovereign risk and in an environment of strong bank fragility. Section 5 discussed the interaction of fiscal stabilization with monetary and macro-prudential policy. Finally, Section 6 concludes.

2 The model economy

The model economy is largely based on the specification of Darracq Pariès et al. (2019), to which we ad sovereign risk as well as a sovereign-banking nexus. The model consists of households, intermediate labor unions, and labor packers, intermediate and final goods-producing firms, capital producers, and non-financial firms (called entrepreneurs) investing in capital projects. Since households cannot provide their savings directly to the real sector, the model also consists of banks that intermediate these funds to the projects of non-financial firms. Both entrepreneurs and banks are exposed to endogenous borrowing constraints. Because the loan market operates under imperfect competition, financial frictions and market power in the loan market create inefficiencies in borrowing conditions. The real sector is rather standard and follows Smets and Wouters (2007). The model economy evolves along a balanced-growth path driven by a positive trend, γ, in the technological progress of the intermediate goods production and a positive steady state inflation rate, $\pi^{\star}$. In the description of the model, stock and flow variables are expressed in real and effective terms (except if mentioned otherwise): they are deflated by the price level and the technology-related balanced growth path trend.

2.1 Households

The economy is populated by a continuum of heterogeneous infinitely-lived households, where each household is characterized by the quality of its labor services, $h \in [0,1]$, and has access to financial markets.

In the beginning of period t, households hold three types of assets: short-term risk-free bonds $B^{rf}_{t-1}(h)$, with nominal gross return R_{t-1}, retail deposits $D_{t-1}(h)$, with nominal gross return $\tilde{R}_{D,t}$, and long-term government bonds $B_{H,t-1}(h)$, with nominal gross return $R_{G,t}$ and price $Q_{B,t-1}$. The risk-free bonds are assumed to be in zero net supply and are used by the monetary policy authority to implement standard monetary policy and their interest rate is predetermined in period t. Due to the deposit insurance scheme, deposits are considered risk-free by the households (see Section 2.2), paying a nominal gross interest of $R_{D,t}$. Nevertheless, as in Clerc et al. (2015), households face transactional costs in case of bank default, defined as follows

$$\widetilde{R}_{D,t+1} = \left(1 - \Lambda_{\Psi}\Gamma_b\left(\overline{\omega}_{b,t+1}\right)\right) R_{D,t} \tag{1}$$

where Λ_{Ψ} captures the semi-elasticity to bank default probability $\Gamma_b\left(\overline{\omega}_{b,t+1}\right)$. This cost should not be thought of as being related to any loss on deposits since the presence of the deposit insurance agency guarantees that its financing needs are fully recouped out of government spending. It should rather be thought of as a transaction cost associated with bank restructuring in the case of default. As in the end deposit rates are net of these transaction costs, they are not predetermined in period t.

During period t, households purchase $C_t(h)$ units of consumption goods, decide on the amount of risk-free bonds $B^{rf}_t(h)$, retail deposits $D_t(h)$ and government bonds $B_{H,t}(h)$, with the latter being subject to quadratic portfolio adjustment costs defined as follows

$$\frac{1}{2}\chi_H\left(B_{H,t}(h) - \overline{B}_H\right)^2 \tag{2}$$

where $\overline{B}_H$ is the steady state level of government bonds holdings while χ_H denotes the portfolio adjustment cost parameter.

Furthermore, during period t, households supply $N_t^S(h)$ units of labour at the nominal wage W_t^h (expressed in effective terms) net of the time-varying labour tax $\tau_{w,t}$.

At the end of period t, the household receives nominal transfers from the government $T_t(h)$ and real profits $\Pi_t(h)$ from the various productive and financial segments owned by them. The household then faces the following budget constraint

$$\begin{aligned} D_t(h) + B_t^{rf}(h) + Q_{B,t}\left[B_{H,t}(h) + \frac{1}{2}\chi_H\left(B_{H,t}(h) - \overline{B}_H\right)^2\right] + C_t(h) \\ = \frac{\left(1 - \Lambda_\Psi \Gamma_b\left(\overline{\omega}_{b,t}\right)\right) R_{D,t-1} D_{t-1}(h) + R_{t-1} B_{t-1}^{rf}(h) + R_{G,t} Q_{B,t-1} B_{H,t-1}(h)}{\gamma \pi_t} \\ + \frac{\left(1 - \tau_{w,t}\right) W_t^h N_t^S(h)}{P_t} + T_t(h) + \Pi_t(h) \end{aligned} \tag{3}$$

where P_t is an aggregate price index and $\pi_{t+1} = P_{t+1}/P_t$ is the one-period ahead inflation rate.

The generic household h at time t obtains utility from consumption of an aggregate index $C_t(h)$, relative to internal habits depending on its past consumption, while receiving disutility from the supply of its homogeneous labor $N_t^S(h)$. The instantaneous household utility $\mathcal{U}$ has the following functional form

$$\mathcal{U}_t(h) \equiv \frac{\left(C_{t+j}(h) - \frac{\eta C_{t+j-1}(h)}{\gamma}\right)^{1-\sigma_c}}{1-\sigma_c} \exp\left(\widetilde{L}\frac{(\sigma_c - 1)}{(1+\sigma_l)} N_{t+j}^S(h)^{1+\sigma_l}\right) \tag{4}$$

where $\widetilde{L}$ is a positive scale parameter, η is the habit's parameter, σ_c is the intertemporal elasticity of substitution and σ_l is the inverse of the elasticity of work effort with respect to the real wage (Frisch elasticity).

The household, therefore, chooses $C_t(h)$, $N_t^S(h)$, $D_t(h)$ and $B_{H,t}(h)$ to maximise its intertemporal utility function, $\mathcal{W}_t(h)$, defined as follows

$$\max_{\{C_t(h), N_t^S(h), B_t^{rf}(h), D_t(h), B_{H,t}(h)\}} \mathbb{E}_t \sum_{j=0}^{\infty} \left(\beta \gamma^{1-\sigma_c}\right)^j \varepsilon_{t+j}^b \mathcal{U}\left(C_{t+j}(h) - \frac{\eta C_{t+j-1}(h)}{\gamma}, N_{t+j}^S(h)\right) \tag{5}$$

where $\beta = \frac{1}{1+r_\beta/100}$ is the discount factor, r_β is the rate of time preference and ε_t^b is a consumption preference shock.

In equilibrium, households' choices in terms of consumption, working hours, risk-free bonds, deposits, and government bond holdings are identical and their first-order conditions, respectively, are as follows

$$\varepsilon_t^b \frac{\exp\left(\widetilde{L}\frac{(\sigma_c-1)}{(1+\sigma_l)}(N_t^S)^{1+\sigma_l}\right)}{1-\sigma_c} = \beta\eta\gamma^{-\sigma_c}\mathbb{E}_t\left[\varepsilon_{t+1}^b \frac{\exp\left(\widetilde{L}\frac{(\sigma_c-1)}{(1+\sigma_l)}(N_{t+1}^S)^{1+\sigma_l}\right)}{1-\sigma_c}\right] + \Lambda_t \tag{6}$$

$$\varepsilon_t^b \widetilde{L}(\sigma_c - 1)(N_t^S)^{\sigma_l}\mathcal{U}_t = \Lambda_t \frac{\left(1-\tau_{w,t}\right) W_t^h}{P_t} \tag{7}$$

$$\mathbb{E}_t\left[\Xi_{t,t+1}\frac{R_t}{\pi_{t+1}}\right]=1 \tag{8}$$

$$\mathbb{E}_t\left[\Xi_{t,t+1}\frac{\left(1-\Lambda_\Psi\Gamma_b\left(\overline{\omega}_{b,t+1}\right)\right)R_{D,t}}{\pi_{t+1}}\right]=1 \tag{9}$$

$$\mathbb{E}_t\left[\Xi_{t,t+1}\frac{R_{G,t+1}}{\pi_{t+1}}\right]=1+\chi_H\left(B_{H,t}-\overline{B}_H\right) \tag{10}$$

where Λ_t is the Lagrange multiplier associated with the budget constraint and $\Xi_{t,t+1}=\beta\gamma^{-\sigma_c}\frac{\Lambda_{t+1}}{\Lambda_t}$ is the period t stochastic discount factor of the households for nominal income streams at period $t+1$.

2.2 Banking sector

The banking sector is owned by households and is segmented into various parts. First, bankers collect household deposits and provide funds to the retail lending branches. In doing so, they face capital requirements that are sensitive to the riskiness of the loan contract, forcing them to hoard a sufficient level of equity and benefit from limited liability under a deposit insurance scheme. Bankers invest in government bonds and loans to the retail banking branches, subject to adjustment costs on banker's bonds holdings which introduces some portfolio rebalancing frictions. Bankers may default when their return on assets is not sufficient to cover their deposit repayments. Second, retail lending branches receive funding from bankers and allocate it to loan officers. In the retail segment, a second wedge results from banks operating under monopolistic competition and facing nominal rigidity in their interest rate setting. Last, loan officers extend loan contracts to entrepreneurs as explained previously, which implies a third financing cost wedge related to credit risk compensation.

Every period a fraction $(1-f)$ of household members are workers, a fraction fe are entrepreneurs while the remaining mass $f(1-e)$ are bankers. Bankers face a probability ζ_b of staying bankers over the next period and probability $(1-\zeta_b)$ of becoming a worker again. When a banker exits, accumulated earnings are transferred to the respective household while newly entering bankers receive initial funds from their household. Overall, households transfer a real amount $\Psi_{B,t}$ to new bankers for each period t. As shown later in this section, bankers' decisions are identical so the decision problem is exposed for a representative banker.

2.2.1 Bankers

Bankers operate in competitive markets providing loans to retail lending branches, $L_{BE,t}$. They can also purchase government securities, $B_{B,t}$, at price $Q_{B,t}$. To finance their lending activities, bankers receive deposits, D_t, from households, with a gross interest rate $R_{D,t}$ and accumulate net worth, $NW_{B,t}$. Their balance identity, in real terms, reads as follows

$$L_{BE,t}+Q_{B,t}B_{B,t}=D_t+NW_{B,t}. \tag{11}$$

Bankers' assets are subject to idiosyncratic shock, $\omega_{b,t}$, which is independent and identically distributed across time and across bankers. $\omega_{b,t}$ follows a lognormal cumulative distribution function (CDF) $F_b(\omega_{b,t})$, with mean 1 and variance σ_b.

As in households, purchasing and selling of government bonds poses quadratic costs to the banker, as a fraction of net worth, of the following magnitude

$$\varrho_t NW_{B,t} = \frac{1}{2}\chi_B \left(\frac{Q_{B,t}B_{B,t}}{NW_{B,t}} - \frac{\overline{Q}_B \overline{B}_H}{\overline{NW}_B} \right)^2 NW_{B,t} \tag{12}$$

where χ_B denotes the portfolio adjustment cost parameter, while $\overline{Q}_B$ and $\overline{NW}_B$ are the steady state price of government bonds and accumulated net worth, respectively.

The operating profit of the banker for the period $t+1$, OP^b_{t+1}, results from the gross interest received from the loans to the retail lending bank, the return on sovereign bond holding, the lump-sum share of profits (and losses) coming from retail lending branches and loan officers activity, $\Pi^R_{B,t}$, pro-rated according to each banker's net worth, minus the gross interest paid on deposits and is defined as follows

$$OP^b_{t+1}(\omega_{b,t+1}) \equiv \omega_{b,t+1} R_{BLE,t} L_{BE,t} + R_{G,t+1} Q_{B,t} B_{B,t} - \varrho_t NW_{B,t} - R_{D,t} D_{B,t} + \Pi^R_{B,t+1} \tag{13}$$

where $R_{BLE,t}$ is the banker's financing rate.

The first key friction in the decision problem of bankers relates to ***limited liability***, resulting in payoffs that are always positive, i.e. bankers default when their return on asset is not sufficient to cover the repayments due to deposits. Therefore, the corresponding constraint is as follows

$$OP^b_{t+1} \geq 0 \tag{14}$$

and is not holding for draws of $\omega_{b,t+1}$ that fall below the threshold $\overline{\omega}_{b,t+1}$ given by

$$\overline{\omega}_{b,t+1} \equiv \frac{R_{D,t} D_t - R_{G,t+1} Q_{B,t} B_{B,t} + \varrho_t NW_{B,t} - \Pi^R_{B,t+1}}{R_{BLE,t} L_{BE,t}}. \tag{15}$$

Denoting the leverage ratios for loans and government bonds as $\kappa^l_{B,t} = \frac{L_{BE,t}}{NW_{B,t}}$ and $\kappa^g_{B,t} = \frac{Q_{B,t}B_{B,t}}{NW_{B,t}}$, respectively, the default cutoff point can be expressed as follows

$$\overline{\omega}_{b,t+1} \equiv \frac{R_{D,t}\left(\kappa^l_{B,t} + \kappa^g_{B,t} - 1\right) - R_{G,t+1}\kappa^g_{B,t} - \frac{\Pi^R_{B,t+1}}{NW_{B,t}} + \varrho_t}{\kappa^l_{B,t} R_{BLE,t}}. \tag{16}$$

When bankers default, the deposit insurance agency serves the depositors and takes over the loan portfolio of the failed banker subject to resolution costs, μ_b, expressed as a fraction of the banker's assets. The overall cost of the deposit insurance, $\Omega_{b,t}$, is given by

$$\Omega_{b,t} \equiv \left[\overline{\omega}_{b,t} - \Gamma_b(\overline{\omega}_{b,t}) + \mu_b \int_0^{\overline{\omega}_{b,t}} \omega \mathrm{d}F_b(\omega) \right] R_{BLE,t} L_{BE,t} \tag{17}$$

where $\Gamma_b(\overline{\omega})$ is defined as follows

$$\Gamma_b(\overline{\omega}) \equiv (1 - F_b(\overline{\omega}))\overline{\omega} + \int_0^{\overline{\omega}} \omega \mathrm{d}F_b(\omega). \tag{18}$$

If bankers do not default, **the second key friction** in their decision problem relates to a **regulatory *penalty*** which is imposed if operating profit is less than a fraction of each risk-weighted asset class.

$$\chi_b \left(L_{BE,t} + Q_{B,t} B_{B,t} \right). \tag{19}$$

where χ_b is the regulatory penalty. Therefore, the corresponding non-binding constraint is as follows

$$OP^b_{t+1} > \nu_b \left(\omega_{b,t+1} R_{BLE,t} L_{BE,t} \right) + \nu_g \left(R_{G,t+1} Q_{B,t} B_{B,t} \right) \tag{20}$$

where ν_b denotes the bank capital requirement for loans and ν_g is the minimum fraction for government bonds.

In order to minimize the risk of violating bank capital requirements, bankers decide on holding excess capital, i.e. capital buffer. While both constraints are exogenously taken into the bankers' decision, the bank capital buffer and the bank balance sheet composition are endogenously determined by each bank.

Therefore, the penalty will be paid for realizations of $\omega_{b,t+1}$ which implies that bankers' operating profits fall below the certain fraction of risk-weighted assets specified above. In this respect, the second threshold $\overline{\omega}^{\nu}_{b,t+1} > \overline{\omega}_{b,t+1}$ is given by

$$\overline{\omega}^{\nu}_{b,t+1} \equiv \frac{R_{D,t}\left(\kappa^l_{B,t} + \kappa^g_{B,t} - 1\right) - \left(1-\nu_g\right) R_{G,t+1}\kappa^g_{B,t} - \frac{\Pi^R_{B,t+1}}{NW_{B,t}} + \frac{1}{2}\chi_B \left(\kappa^g_{B,t} - \overline{\kappa}^g_B\right)^2}{\left(1-\nu_b\right)\kappa^l_{B,t} R_{BLE,t}}. \tag{21}$$

Based on the above two key assumptions, the expected return on net worth from period t to $t+1$ can be expressed as follows

$$\mathbb{E}_t \left\{ \begin{array}{c} \widetilde{E}\left[OP^b_{t+1}\left(\omega_{b,t+1}\right) \mid \omega_{b,t+1} \geq \overline{\omega}_{b,t+1} \right] \\ -\widetilde{E}\left[\chi_b \left(L_{BE,t} + Q_{B,t} B_{B,t} \right) \mid \overline{\omega}_{b,t+1} \leq \omega_{b,t+1} \leq \overline{\omega}^{\nu}_{b,t+1} \right] \end{array} \right\} \tag{22}$$

where $\widetilde{E}$ is the conditional expectation operator for the cross-sectional distribution of idiosyncratic banker returns on private loans. After some modifications, the one-period return on the bank's net worth, $R^B_{N,t+1}$, can be formulated as follows

$$R^B_{N,t+1} \equiv R_{BLE,t}\kappa^l_{B,t}\left[1 - \Gamma_b\left(\overline{\omega}_{b,t+1}\right)\right] - \chi_b\left(\kappa^l_{B,t} + \kappa^g_{B,t}\right)\left(F\left(\overline{\omega}^{\nu}_{b,t+1}\right) - F\left(\overline{\omega}_{b,t+1}\right)\right). \tag{23}$$

Given bankers' myopic view, each banker maximises its expected next period return to net worth summarised by equation (23) for the exposures to private sector loans $\kappa^l_{b,t}$ and government securities $\kappa^g_{b,t}$.

The third key friction in Bankers decision problem is the ***sovereign-bank nexus*** distortion. When the government defaults on its outstanding bonds, we assume that bankers are subject to an idiosyncratic "*run-type*" liquidity risk with probability $p^{\xi_G}_B$ of materializing. If the liquidity shock occurs, we assume that the banker is forced into default.

Taking into account sovereign risk, the decision problem of the bankers becomes

$$\max_{\{\kappa^l_{B,t},\kappa^g_{B,t}\}} \left(1-p_t^{\xi_G}\right)\mathbb{E}_t\left[\Xi_{t,t+1}\frac{R^B_{N,t+1}NW_{B,t}}{\gamma\pi_{t+1}} \mid R_{G,t+1}=R^{rf}_{G,t+1}\right]$$
$$+p_t^{\xi_G}\left(1-p_B^{\xi_G}\right)\mathbb{E}_t\left[\Xi_{t,t+1}\frac{R^B_{N,t+1}NW_{B,t}}{\gamma\pi_{t+1}} \mid R_{G,t+1}=(1-\xi_G^{\max})R^{rf}_{G,t+1}\right] \tag{24}$$

The first-order conditions for this problem are then given by

$$\left(1-p_t^{\xi_G}\right)\mathbb{E}_t\left[\Xi_{t,t+1}\frac{\partial R^B_{N,t+1}}{\partial\kappa^l_{B,t}}\big/\pi_{t+1}\gamma \mid R_{G,t+1}=R^{rf}_{G,t+1}\right]$$
$$+p_t^{\xi_G}\left(1-p_B^{\xi_G}\right)\mathbb{E}_t\left[\Xi_{t,t+1}\frac{\partial R^B_{N,t+1}}{\partial\kappa^l_{B,t}}\big/\pi_{t+1}\gamma \mid R_{G,t+1}=(1-\xi_G^{\max})R^{rf}_{G,t+1}\right]=0 \tag{25}$$

and

$$\left(1-p_t^{\xi_G}\right)\mathbb{E}_t\left[\Xi_{t,t+1}\frac{\partial R^B_{N,t+1}}{\partial\kappa^g_{B,t}}\big/\pi_{t+1}\gamma \mid R_{G,t+1}=R^{rf}_{G,t+1}\right]$$
$$+p_t^{\xi_G}\left(1-p_B^{\xi_G}\right)\mathbb{E}_t\left[\Xi_{t,t+1}\frac{\partial R^B_{N,t+1}}{\partial\kappa^g_{B,t}}\big/\pi_{t+1}\gamma \mid R_{G,t+1}=(1-\xi_G^{\max})R^{rf}_{G,t+1}\right]=0 \tag{26}$$

Finally, aggregating across bankers, a fraction ζ_b continues operating into the next period while the rest exits from the industry. The new bankers are endowed with starting net worth, $\Psi_{B,t}$, proportional to the assets of the old bankers. Accordingly, the aggregate dynamics of bankers' net worth are given by

$$NW_{B,t}=\varepsilon_t^{\zeta_b}\zeta_b R^B_{N,t}\frac{NW_{B,t-1}}{\gamma\pi_t}+\Psi_{B,t}. \tag{27}$$

Where $\varepsilon_t^{\zeta_b}$ is a shock to the survival rate of bankers.

2.2.2 Retail lending branches and loan officers

A continuum of retail lending branches indexed by j provides differentiated loans to loan officers. The total financing needs of loan officers follow a CES aggregation of differentiated loans which are imperfect substitutes with elasticity of substitution $\frac{\mu_E^R}{\mu_E^R-1}>1$ and defined as follows

$$L_{E,t}=\left[\int_0^1 L_{E,t}(j)^{\frac{1}{\mu_E^R}}\,\mathrm{d}j\right]^{\mu_E^R} \tag{28}$$

while the corresponding average return on loans is defined as follows

$$R_{LE}=\left[\int_0^1 R_{LE}(j)^{\frac{1}{1-\mu_E^R}}\,\mathrm{d}j\right]^{1-\mu_E^R}. \tag{29}$$

Retail lending branches are monopolistic competitors which levy funds from the *bankers* and set gross nominal interest rates on a staggered basis *à la* Calvo (1983), facing each period a constant probability $1-\xi_E^R$ of being able to re-optimize. This staggered lending rate setting acts in the model as maturity transformation in banking activity and leads to imperfect pass-through of market interest rates on bank lending rates. If a retail lending branch cannot re-optimize its interest rate, then the interest rate is left at its previous period level

$$R_{LE,t}(j) = R_{LE,t-1}(j). \tag{30}$$

Therefore, the retail lending branch j chooses $\hat{R}_{LE,t}(j)$ to maximize its intertemporal profits

$$\max_{\{\hat{R}_{LE,t}(j)\}} \mathbb{E}_t \left[\sum_{k=0}^{\infty} \left(\beta\gamma^{-\sigma_c}\xi_E^R\right)^k \frac{\Lambda_{t+k}}{\Lambda_t} \left(\hat{R}_{LE,t}(j) L_{E,t+k}(j) - R_{BLE,t+k}(j) L_{E,t+k}(j) \right) \right] \tag{31}$$

where the demand from the loan officers is given by

$$L_{E,t+k}(j) = \left(\frac{\hat{R}_{LE,t}(j)}{R_{LE,t}} \right)^{-\frac{\mu_E^R}{\mu_E^R - 1}} \left(\frac{R_{LE,t}}{R_{LE,t+k}} \right)^{-\frac{\mu_E^R}{\mu_E^R - 1}} L_{LE,t+k}. \tag{32}$$

Finally, loan officers, that operate in perfect competition, receive one-period loans from the retail lending branches, which cost an aggregate gross nominal interest rate $R_{LE,t}$ that is set at the beginning of period t and extend loan contracts to entrepreneurs which pay a state-contingent return $\widetilde{R}_{LE,t+1}$. Loan officers have no other source of funds so the volume of the loans they provide to the entrepreneurs equals the volume of funding they receive. Therefore, they seek to maximize the discounted intertemporal flow of income so that the first-order condition of its decision problem gives

$$\mathbb{E}_t \left[\Xi_{t,t+1} \frac{\left(\widetilde{R}_{LE,t+1} - R_{LE,t} \right)}{\pi_{t+1}} \right] = 0. \tag{33}$$

In the end, profits and losses made by retail branches and loan officers are transferred back to the bankers.

2.3 Entrepreneurs

As explained before, every period a fraction fe of the representative households are entrepreneurs. Like bankers, each entrepreneur faces a probability ζ_e of staying an entrepreneur over the next period and a probability $(1 - \zeta_e)$ of becoming a worker again. To keep the share of entrepreneurs constant, it is assumed that a similar number of workers randomly become entrepreneurs. When an entrepreneur exits, their accumulated earnings are transferred to the respective household. At the same time, newly entering entrepreneurs receive initial funds from their households. Overall, households transfer a real amount $\Psi_{E,t}$ to the entrepreneurs for each period t. Finally, as it will become clear later, entrepreneurs' decisions for leverage and lending rate are independent of their net worth and therefore identical.[1]

At the end of period t, entrepreneurs buy the capital stock K_t from the capital producers at real price Q_t (expressed in terms of consumption goods). They transform the capital stock into an effective capital stock $u_{t+1}K_t$ by choosing the utilisation rate u_{t+1} subject to adjustment costs. This

[1] Accordingly, the decision problem is exposed for a representative entrepreneur.

adjustment cost on the capacity utilisation rate are defined per unit of capital stock $\Gamma_u(u_{t+1})$.[2]

The effective capital stock can then be rented out to intermediate goods producers at a nominal rental rate of $r_{K,t+1}$. Finally, by the end of period $t+1$, entrepreneurs sell back the depreciated capital stock $(1-\delta)K_t$ to capital producer at price Q_{t+1}.

The gross nominal rate of return on capital from period t to $t+1$ is therefore given by

$$R_{KK,t+1} \equiv \pi_{t+1} \frac{r_{K,t+1}u_{t+1} - \Gamma_u(u_{t+1}) + (1-\delta)Q_{t+1}}{Q_t}. \tag{34}$$

Each entrepreneur's return on capital is subject to a multiplicative idiosyncratic shock ω_e. These shocks are independent and identically distributed across time and across entrepreneurs. $\omega_{e,t}$ follows a lognormal CDF $F_e(\omega_e)$, with mean 1 and variance σ_e. For the estimation, we assume the variance σ_e is attached to a multiplicative shock $\varepsilon_t^{\sigma_e}$.

By the law of large numbers, the average across entrepreneurs (denoted with the operator $\widetilde{E}$) expected return on capital is given by

$$\widetilde{E}\left[\mathbb{E}_t\left(\omega_{e,t+1}R_{KK,t+1}\right)\right] = \mathbb{E}_t\left(\int_0^\infty \omega_{e,t+1}\mathrm{d}F_{e,t}(\omega)\, R_{KK,t+1}\right) = \mathbb{E}_t\left(R_{KK,t+1}\right). \tag{35}$$

Entrepreneur's choice over capacity utilization is independent from the idiosyncratic shock and implies that

$$r_{K,t} = \Gamma_u'(u_t). \tag{36}$$

Entrepreneurs finance their purchase of capital stock with their net worth $NW_{E,t}$ and a one-period loan $L_{E,t}$ (expressed in real terms) from the commercial lending branches. Therefore, their balance identity in real terms reads as follows

$$Q_tK_t = NW_{E,t} + L_{E,t}. \tag{37}$$

In the tradition of costly state verification frameworks, lenders cannot observe the realization of the idiosyncratic shock unless they pay monitoring cost μ_e per unit of assets that can be transferred to the bank in case of default. The set of lending contracts available to entrepreneurs is constrained since they can only use debt contracts in which the lending rate $R_{LLE,t}$ is predetermined at the previous time period.

Default occurs when the entrepreneurial income that can be seized by the lender falls short of the agreed repayment of the loan. At period $t+1$, once aggregate shocks are realized, default will happen for draws of the idiosyncratic shock below a certain threshold $\overline{\omega}_{e,t}$, given by

$$\overline{\omega}_{e,t+1}\chi_e R_{KK,t+1}\kappa_{e,t} = (R_{LLE,t}+1)(\kappa_{e,t}-1) \tag{38}$$

where $R_{LLE,t}$ is the nominal lending rate determined at period t, χ_e represents the share of the entrepreneur's assets (gross of capital return) that banks can recover in case of default and $\kappa_{e,t}$ is

[2]The cost (or benefit) Γ_u is an increasing function of capacity utilization and is zero at steady state, $\Gamma_u(u^\star) = 0$. The functional forms used for the adjustment costs on capacity utilization is given by

$$\Gamma_u(X) = \frac{\overline{\overline{r_K}}}{\varphi}\left(\exp\left[\varphi(X-1)\right]-1\right).$$

the corporate leverage defined as follows

$$\kappa_{e,t} = \frac{Q_t K_t}{NW_{E,t}}. \tag{39}$$

It is also assumed that when banks take over the entrepreneur's assets, they have to pay monitoring costs.

The *ex post* return to the lender on the loan contract, denoted $\widetilde{R}_{LE,t}$, can then be expressed as follows

$$\widetilde{R}_{LE,t} = G(\overline{\omega}_{e,t})\chi_e R_{KK,t}\frac{\kappa_{e,t-1}}{\kappa_{e,t-1}-1} \tag{40}$$

where $G_e(\overline{\omega})$ is defined as follows

$$G_e(\overline{\omega}) = (1 - F_e(\overline{\omega}))\overline{\omega} + (1-\mu_e)\int_0^{\overline{\omega}} \omega \mathrm{d}F_e(\omega). \tag{41}$$

Furthermore, it is assumed that entrepreneurs are myopic and the end of period t contracting problem for entrepreneurs consists in maximizing the next period return on net worth for the lending rate and leverage, defined as follows

$$\max_{\{R_{LLE,t},\kappa_{e,t}\}} \mathbb{E}_t\left[(1-\chi_e\Gamma_e(\overline{\omega}_{e,t+1}))\, R_{KK,t+1}\kappa_{e,t}\right] \tag{42}$$

subject to the participation constraint of the lender in equation (33) and the default threshold $\overline{\omega}_{e,t+1}$ in equation (38), where $\Gamma_e(\overline{\omega})$ is defined as follows

$$\Gamma_e(\overline{\omega}) = (1 - F_e(\overline{\omega}))\overline{\omega} + \int_0^{\overline{\omega}} \omega \mathrm{d}F_e(\omega). \tag{43}$$

Following some modifications, the first-order conditions for the lending rate and the leverage lead to the following

$$\mathbb{E}_t\left[(1-\chi_e\Gamma_e(\overline{\omega}_{e,t+1}))\, R_{KK,t+1}\kappa_{e,t}\right] = \frac{\mathbb{E}_t\left[\chi_e\Gamma'_e(\overline{\omega}_{e,t+1})\right]}{\mathbb{E}_t\left[\Xi_{t,t+1}G'_e(\overline{\omega}_{e,t+1})\right]}\mathbb{E}_t\left[\Xi_{t,t+1}\right] R_{LE,t} \tag{44}$$

where $\Gamma'_e(\overline{\omega})$ is defined as follows

$$\Gamma'_e(\overline{\omega}) = (1 - F_e(\overline{\omega})) \text{ and } G'_e(\overline{\omega}) = (1 - F_e(\overline{\omega})) - \mu_e\overline{\omega}\mathrm{d}F_e(\overline{\omega}). \tag{45}$$

As anticipated at the beginning of the section, the solution to the problem shows that all entrepreneurs choose the same leverage and lending rate. Moreover, the features of the contracting problem imply that the *ex post* return to the lender $\widetilde{R}_{LE,t}$ will differ from the *ex ante* return $R_{LE,t-1}$.[3]

Finally, aggregating across entrepreneurs, a fraction ζ_e continues operating into the next period while the rest exits from the industry. The new entrepreneurs are endowed with starting net worth, proportional to the assets of the old entrepreneurs. Accordingly, the aggregate dynamics of

[3] Log-linearising equation (44) and the participation constraint in equation (33), one can show that innovations in the *ex post* return are notably driven by innovations in $R_{KK,t}$.

entrepreneurs' net worth are given by

$$NW_{E,t} = \varepsilon_t^{\zeta_e} \left(1 - \chi_e \Gamma_e(\overline{\omega}_{e,t})\right) \frac{R_{KK,t}}{\pi_{t-1}} \kappa_{e,t-1} NW_{E,t-1} / \gamma + \Psi_{E,t}. \tag{46}$$

where $\varepsilon_t^{\zeta_e}$ is a shock on the survival rate of entrepreneurs.

2.4 Capital producers

Using investment goods, a segment of perfectly competitive firms, owned by households, produce a stock of fixed capital. At the beginning of period t, these firms buy back the depreciated capital stocks $(1-\delta)K_{t-1}$ at real prices (in terms of consumption goods) Q_t. Then they augment the various stocks using distributed goods and face adjustment costs. The augmented stocks are sold back to entrepreneurs at the end of the period for the same price. The decision problem of capital stock producers is given by

$$\max_{\{K_t, I_t\}} \mathbb{E}_t \sum_{k=0}^{\infty} \Xi_{t,t+k} \left\{ Q_{t+k}(K_{t+k} - (1-\delta)K_{t+k-1}/\gamma) - I_{t+k} \right\} \tag{47}$$

subject to the constraint

$$K_t = (1-\delta)K_{t-1}/\gamma + \left[1 - S\left(\gamma \frac{I_t \varepsilon_t^I}{I_{t-1}}\right)\right] I_t \tag{48}$$

where S is a non-negative adjustment cost function formulated in terms of the gross rate of change in investment denoted by I_t.[4] Furthermore, ε_t^I is an efficiency shock to the technology of fixed capital accumulation.

2.5 Goods-producing firms

There are two types of firms in the model, the intermediate and the final goods-producing firms, with the former being monopolistic competitors while the latter operating in a competitive environment.

2.5.1 Intermediate goods-producing firms

In the intermediate goods-producing sector, there exists a continuum of firms $z \in [0,1]$. The firms are monopolistic competitors and produce differentiated products by using a common Cobb-Douglas technology defined as follows

$$Y_t(z) = \varepsilon_t^a \left(u_t K_{t-1}(z)/\gamma\right)^\alpha \left[N^D(z)\right]^{1-\alpha} - \Omega_{a,t} \tag{49}$$

where ε_t^a is an exogenous productivity shock and $\Omega_{a,t} > 0$ is a fixed cost. A firm z utilises capital $\widetilde{K}_t(z)$ defined as follows

$$\widetilde{K}_t(z) = u_t K_{t-1}(z) \tag{50}$$

and labor $N_t^D(z)$ on a competitive market by minimizing its production cost. Due to our assumptions on the labor market and the rental rate of capital, the real marginal cost is identical across producers.

[4] The functional form adopted is $S(x) = \phi/2 \ (x-\gamma)^2$.

The model also introduces a time-varying tax on firms' revenues which is affected by an independent and identically distributed shock, ε_t^p, defined as follows

$$\varepsilon_t^p = \frac{1-\tau_{p,t}}{1-\overline{\tau}_p}. \tag{51}$$

where $\overline{\tau}_p$ is the steady state tax rate, which is set to zero in the steady state.

In each period, a firm z faces a constant (across time and firms) probability, $1-\alpha_p$, of being able to re-optimize its nominal price, say $P_t^*(z)$. If a firm cannot re-optimize its price, the nominal price evolves according to the following rule

$$P_t(z) = \pi_{t-1}^{\xi_p}\,[\overline{\pi}]^{(1-\xi_p)}\,P_{t-1}(z) \tag{52}$$

with ξ_p representing the price indexation, *i.e.* the nominal price is indexed on past inflation and steady-state inflation. In the model, all firms that can re-optimize their price at time t choose the same level, denoted p_t^* in real terms.

2.5.2 Final goods-producing firms

Final producers operating in a competitive environment produce an aggregate final good Y_t (expressed in effective terms), that may be used for consumption and investment. This product is obtained using a continuum of differentiated intermediate goods $Y_t(z)$ (expressed in effective terms), where each firm z produces based on the Kimball (1995) technology. The Kimball aggregator is defined as follows

$$\int_0^1 G\left(\frac{Y_t(z)}{Y_t};\theta_p,\psi\right)\mathrm{d}z = 1 \tag{53}$$

with its functional form being as follows

$$\begin{aligned} G\left(\frac{Y_t(z)}{Y_t}\right) \quad &= \quad \frac{\theta_p}{(\theta_p(1+\psi)-1)}\left[(1+\psi)\,\frac{Y_t(z)}{Y_t}-\psi\right]^{\frac{\theta_p(1+\psi)-1}{\theta_p(1+\psi)}} \\ &\quad - \left[\frac{\theta_p}{(\theta_p(1+\psi)-1)}-1\right] \end{aligned} \tag{54}$$

where θ_p and ψ represent the elasticity of substitution between goods and the curvature of the Kimball aggregator in the goods market, respectively.

The representative final good-producing firms maximise profits defined as follows

$$P_tY_t - \int_0^1 P_t(z)Y_t(z)\mathrm{d}z \tag{55}$$

subject to the production function, taking as given the final good price P_t and the prices of all intermediate goods. The price mark-up $\mu_p = \frac{\theta_p}{\theta_p-1}$ is determined based on the Lagrange multiplier on the constraint.

2.6 Intermediate labor unions and labor packers

The differentiated labor services are produced by a continuum of unions that transform the homogeneous household labor supply, set wages subject to a Calvo scheme and offer those labor services to intermediate labor packers.

Intermediate goods-producing firms make use of a labor input N_t^D produced by a segment of labor packers. Those labor packers operate in a competitive environment and aggregate a continuum of differentiated labor services $N_t(i)$, $i \in [0,1]$ using a Kimball (1995) technology where the Kimball aggregator is defined as follows

$$\int_0^1 H\left(\frac{N_t(i)}{N_t^D};\theta_w,\psi_w\right)\mathrm{d}i = 1 \tag{56}$$

and its functional form is as follows

$$\begin{aligned} H\left(\frac{N_t(i)}{N_t^D}\right) &= \frac{\theta_w}{(\theta_w(1+\psi_w)-1)}\left[(1+\psi_w)\frac{N_t(i)}{N_t^D}-\psi_w\right]^{\frac{\theta_w(1+\psi_w)-1}{\theta_w(1+\psi_w)}} \\ &\quad -\left[\frac{\theta_w}{(\theta_w(1+\psi_w)-1)}-1\right] \end{aligned} \tag{57}$$

where the parameter θ_w and ψ_w determine the elasticity of substitution between labor inputs and the curvature of the demand curve in the wage market, respectively. The wage markup $\mu_w = \frac{\theta_w}{\theta_w - 1}$ is determined based on the Lagrange multiplier on the constraint.[5]

Each labor union is a monopoly supplier of differentiated labor service and sets its wage on a staggered basis, paying households the nominal wage rate W_t^h. Every period all unions face a constant probability $1-\alpha_w$ of optimally adjusting its nominal wage, say $W_t^*(i)$, which will be the same for all suppliers of differentiated labor services.

The aggregate real wage (expressed in effective terms) that intermediate producers pay for the labor input provided by the labor packers, thereafter is denoted by W_t, while W_t^* denotes the effective real wage claimed by re-optimizing unions. Taking into account that unions might not be able to choose their nominal wage optimally in a near future, $W_t^*(i)$ is chosen to maximize their intertemporal profit under the labor demand from labor packers. In the case that unions cannot re-optimize, wages are indexed on past inflation and steady state inflation according to the following indexation rule

$$W_t(i) = \gamma\left[\pi_{t-1}\right]^{\xi_w}\left[\overline{\pi}\right]^{1-\xi_w} W_{t-1}(i) \tag{58}$$

with ξ_w being the degree of wage indexation. Furthermore, unions are subject to a time-varying tax rate $\tau_{w,t}$ which follows a fiscal rule described in the next section.

2.7 Government sector

Public expenditures $G^\star$ (expressed in effective terms) are subject to random shocks ε_t^g that follow an AR(1) process and are assumed to be correlated with technology shocks, for the purpose of estimation. The government covers the financing costs for the deposit insurance agency $\Omega_{b,t}$ as defined in equation (17) and finances its public spending with labor tax, product tax, and lump-sum transfers so that the *ex-post* government debt $Q_{B,t}B_G$ (expressed in real effective terms) accumulates

[5] This function has the advantage that under the restriction $\psi_w = 0$ it reduces to the standard expression of the Dixit Stiglitz world.

accordingly as below

$$Q_{B,t}B_{G,t} = \frac{R_{G,t}}{\pi_t}Q_{B,t-1}B_{G,t-1}/\gamma + G^{\star}\varepsilon_t^g - \tau_{w,t}w_tL_t - T_t + \Omega_{b,t}. \tag{59}$$

The fiscal authority uses lump-sum transfers\taxes to stabilize deviations of the public debt path from its steady state. The lump-sum fiscal rule is therefore

$$T_t - \overline{T} = \rho_T(T_{t-1} - \overline{T}) + (1-\rho_T)\phi_T(\frac{B_{G,t}}{\overline{Y}} - \frac{\overline{B}_G}{\overline{Y}}) \tag{60}$$

where $\overline{T}$, $\overline{B}_G$, and $\overline{Y}$ are the steady state values of lump-sum transfers, government debt, and output respectively.

Similarly, the labor income tax follows the following rule:

$$\tau_{w,t} - \overline{\tau_w} = \rho_{\tau_w}(\tau_{w,t-1} - \overline{\tau_w}) + (1-\rho_{\tau_w})\phi_{\tau_w}(\frac{B_{G,t}}{\overline{Y}} - \frac{\overline{B}_G}{\overline{Y}})\frac{\overline{Y}}{\overline{w}\overline{L}} \tag{61}$$

where $\overline{w}\overline{L}$ refers to labor income in the steady state.

Following Corsetti et al. (2013) we allow for sovereign default as a consequence of the government's inability to raise the funds necessary to honor its *ex-ante* debt obligations. It is assumed that the probability of default is closely and nonlinearly linked to the level of *ex-ante* public debt. Subsequently, sovereign risk premia respond to changes in the *ex-ante* fiscal outlook of the country, opening up a sovereign risk channel that raises the cost of financial intermediation, as described in Section 2.2.

More explicitly, sovereign default is operationalized with the notion of a fiscal limit in a manner similar to Corsetti et al. (2013). Whenever the debt level rises above the fiscal limit, defined as $B_Y^{\max}$, default occurs. The fiscal limit is determined stochastically capturing the uncertainty that surrounds the political process in the context of sovereign default. It is assumed that for each period the limit will be drawn from a logistic distribution, defined as follows

$$p_t^{\xi_G} \equiv \frac{exp\left(-\eta_1 + \eta_2\frac{B_{G,t}}{4Y_t}\right)}{1 + exp\left(-\eta_1 + \eta_2\frac{B_{G,t}}{4Y_t}\right)} \tag{62}$$

where $p_t^{\xi_G}$ is the *ex ante* probability of a default and η_1 and η_2 are parameters of the logistic distribution setting its location and scale. The two parameters, together with the fiscal limit, are determined based on the steady-state sovereign risk premium, the sensitivity of the sovereign government bond spread to a 1% increase in the debt-to-GDP ratio, and the haircut in case of default.

By assuming that the size of the haircut in case of a default is constant, the actual haircut in the economy is defined as follows

$$\xi_{G,t} = \begin{cases} \xi_G^{\max}, & \text{with probability } p_t^{\xi_G} \\ 0, & \text{with probability } 1 - p_t^{\xi_G} \end{cases} \tag{63}$$

Long-term sovereign debt is introduced by assuming that government securities are perpetuities, which pay geometrically-decaying coupons where c_g is the coupon rate and τ_g is the decaying factor.[6] Therefore the sovereign risk-free nominal return on sovereign bond holding from period t to period $t+1$ is as follows

$$R^{rf}_{G,t+1} = \varepsilon^{R_G}_{t+1} \frac{c_g + (1-\tau_g) Q_{G,t+1}}{Q_{G,t}} \tag{64}$$

where $\varepsilon^{R_G}_t$ is an *ad hoc* government bond valuation shock introduced for the purpose of the empirical analysis. This reduced-form shock is meant to capture time-variation in the excess bond return not captured by our bank-centric formulation of the term premium.

Although *ex-ante* there is a non-negligible probability of government default, *ex-post* debt stock is neutral in the sense that it will not be affected by sovereign risk. As argued in Corsetti et al. (2013) sovereign default causes redistribution among households leading to asymptotic risk sharing which allows households to insure themselves against that. Nevertheless, despite debt stock neutrality, it is expected that sovereign risk *ex-post* impacts sovereign risk. Furthermore, van der Kwaak and van Wijnbergen (2014) supports such an assumption since as argued government maximally defaults over less than 1.5% of the outstanding debt stock, hence sovereign default risk operates mostly through an *ex-ante* anticipation effect. Therefore, regardless of the neutral *ex-post* debt stock neutrality to sovereign risk, it is expected that the *ex-ante* probability of default is crucial for the pricing of government debt $R_{G,t}$, specified as follows

$$R_{G,t+1} \;=\; \begin{cases} (1-\xi^{\max}_G) R^{rf}_{G,t+1}, & \text{with probability } p^{\xi_G}_t \\ R^{rf}_{G,t+1}, & \text{with probability } 1 - p^{\xi_G}_t \end{cases} \tag{65}$$

and for real activity via sovereign-bank feedback loops.

2.8 Monetary policy

To conduct standard monetary policy, the central bank aims at steering the risk-free rate R_t. Similar to Smets and Wouters (2007), the central bank policy follows an interest rate rule given by

$$\hat{R}_t \;=\; \rho \hat{R}_{t-1} + (1-\rho)\, r_\pi \hat{\pi}_t + r_{\Delta y} \Delta y_t + r_{\Delta \pi} \Delta \pi_t + \ln(\varepsilon^r_t) \tag{66}$$

where interest rate deviation from the steady state value, $\hat{R}_t$, is specified in terms of inflation deviations from its steady state value, $\hat{\pi}$, output growth, Δy_t, and inflation changes, $\Delta\pi$. ρ stands for the interest rate inertia (smoothing), while r_π, $r_{\Delta y}$ and $r_{\Delta\pi}$ capture the interest rate sensitivities to inflation, output growth, and inflation changes, respectively.[7] ε^r_t captures the non-systemic component, namely monetary policy shock.

2.9 Market clearing condition

In what follows, we provide details of the market clearing conditions that comprise the goods, the labor, and the financial markets.

[6] In other words, in the first period the bond pays c_g, in the second period $(1-\tau_g)c_g$, in the third period $(1-\tau_g)^2 c_g$, etc..

[7] $\hat{x_t} = ln(x_t/\overline{x})$ denotes the log-deviation of a generic variable x from its deterministic steady-state level $\overline{x}$.

2.9.1 Goods market

The market clearing condition on the goods market is as follows

$$Y_t = C_t + I_t + G^{\star}\varepsilon_t^g + \Psi\left(u_t\right) K_{t-1}/\gamma + \mu_e \int_0^{\overline{\omega}} \omega \mathrm{d}F_e\left(\omega\right) K_{t-1}/\gamma. \tag{67}$$

2.9.2 Labor market

Equilibrium in the labor market implies that

$$\Delta_{wk,t} N_t^D = N_t^S \tag{68}$$

and

$$\Delta_{pk,t} Y_t = \varepsilon_t^a \left(u_t K_{t-1}/\gamma\right)^{\alpha} \left(N_t^D\right)^{1-\alpha} - \Omega \tag{69}$$

where $N_t^D = \int_0^1 N_t^D(z)dz$ and $N_t^S = \int_0^1 N_t^S(h)dh$. $\Delta_{wk,t}$ and $\Delta_{pk,t}$ are the wage and price dispersion indices, respectively.

2.9.3 Debt market

On the private credit market, the following conditions hold

$$L_{BE,t} = \Delta_{E,t}^R L_{E,t} \tag{70}$$

where $\Delta_{E,t}^R = \int_0^1 \left(\frac{R_{E,t}(j)}{R_{E,t}}\right)^{-\frac{\mu_E^R}{\mu_E^R - 1}} \mathrm{d}j$ is the dispersion index among retail bank interest rates due to nominal rigidity in the setting of interest rate by retail banking branches.

Moreover, in equilibrium, the lump-sum transfer to bankers per unit of net worth from retail lending and loan officer profits and losses is given by

$$\frac{\Pi_{B,t+1}^R}{NW_{b,t}} = \left(\widetilde{R}_{LE,t+1} - R_{BLE,t}\right) \kappa_{B,t}^l. \tag{71}$$

Finally, on the government bond market, the fixed supply is distributed across holdings by households, bankers, and the central bank, as follows

$$B_{H,t} + B_{B,t} + B_{CB,t} = B_{G,t} \tag{72}$$

where $B_{CB,t}$ account for any central bank government bond purchases, which are zero inthe steady state.

3 Parametrization strategy

The model is estimated using quarterly euro area data from 1995Q1 to 2019Q4 applying standard Bayesian techniques, however, certain parameters are treated as fixed. The purpose of this empirical validation is to obtain a satisfactory level of data consistency with the model propagation mechanism, without exhaustively reviewing the structural determinants of euro area business cycle properties.

The estimation strategy thus closely follows the standard literature, e.g. as in Smets and Wouters (2007).

3.1 Calibration of benchmark and scenario sovereign risk

We start with the strategy for calibrating sovereign risk in the model. We create two versions: first, a benchmark calibration on which the model is estimated, and a scenario calibration. In the benchmark case, sovereign riskiness is fixed to a euro area average. The sovereign spread level is treated as constant and it is assumed that there is no sensitivity in the spread to public debt variation. In a second calibration used in the scenario exercises in the remainder of the paper, a "high sovereign risk" specification is adopted, which features a higher debt and risk spread level, as well as significant spread sensitivity to public debt.

The key parameters determining sovereign default probability are the location, η_1, and scale, η_2, parameters of the logistic function as stated in equation (62). These two parameters can be determined by solving a two-equation system, in which the first equation links sovereign risk spread to a given public debt level and expected haircut as follows

$$\frac{R_G}{R_G^{rf}} \equiv 1 + \xi_G^{\max} \frac{exp\left(-\eta_1 + \eta_2 \overline{\frac{B_G}{4Y}}\right)}{1 + exp\left(-\eta_1 + \eta_2 \overline{\frac{B_G}{4Y}}\right)} \tag{73}$$

while the second equation emerges by setting a spread sensitivity, $\Delta_{\frac{R_G}{R_G^{rf}}}$, with respect to a given increase in the public debt-to-GDP ratio as follows

$$\frac{R_G}{R_G^{rf}} + \Delta_{\frac{R_G}{R_G^{rf}}} \equiv 1 + \xi_G^{\max} \frac{exp\left(-\eta_1 + \eta_2 (\overline{\frac{B_G}{4Y}} + \Delta_{\frac{B_G}{4Y}}\right)}{1 + exp\left(-\eta_1 + \eta_2 (\overline{\frac{B_G}{4Y}} + \Delta_{\frac{B_G}{4Y}})\right)} \tag{74}$$

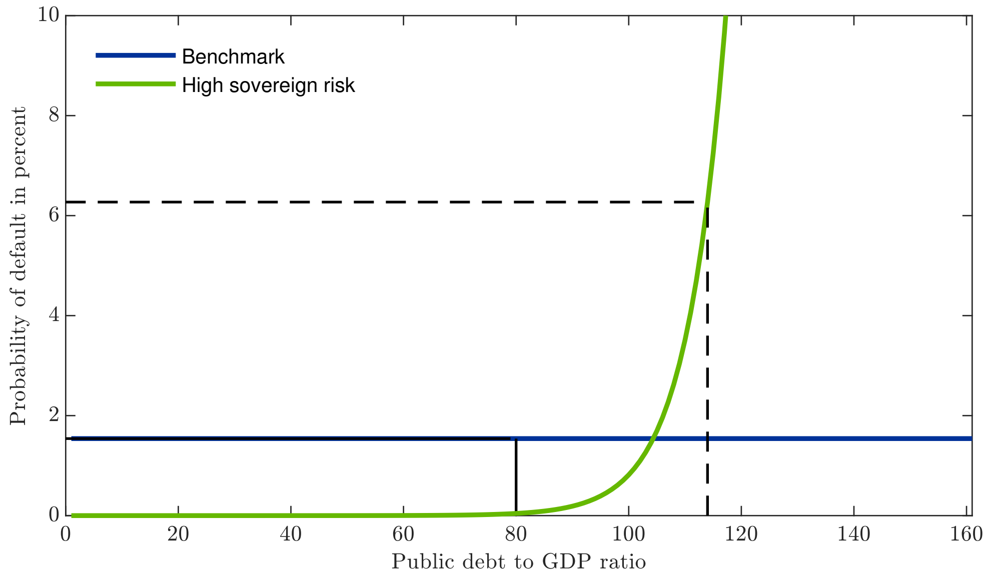
where $\xi_G^{\max} p_t^{\xi_G}$ captures any per period sovereign spread compensation due to possible expected losses in case of default. The level of the haircut on the bond value, $\xi_G^{\max}$, is calibrated to 0.37, which according to Cruces and Trebesch (2013) corresponds to the median haircut calculated from a sample of sovereign debt restructuring between 1970 and 2010.

Starting with the benchmark calibration and as seen in Table 3, the steady-state public debt ratio $\overline{\frac{B_G}{4Y}}$ as well as the (annual) sovereign risk spread $\frac{R_G}{R_G^{rf}}$ are set to the euro area average. Since we assume no time variation, it is imposed that $\eta_2 = 0$. This allows to back out $\eta_1 = 5.6$ from equation (73) as our benchmark calibration.

In calibrating the case of "high sovereign risk", we rely on a study by Beirne and Fratzscher (2013). Following their classification, we define an aggregate across Greece, Italy, Portugal, Spain, and Ireland (called periphery in the following) as a group representing a vulnerable fiscal position. Beirne and Fratzscher (2013) estimate a spread sensitivity for the periphery countries during the GFC and sovereign debt crisis. We therefore set the debt ratio $\overline{\frac{B_G}{4Y}}$ and the spread level $\frac{R_G}{R_G^{rf}}$ to the GDP-weighted average across this group in the post-crisis part of our sample (2009-19). Since the estimated spread sensitivity focuses on a relatively limited time window and is found to be relatively low (e.g. compared to Borgy et al. (2011)), we construct a more severe case by doubling the sensitivity $\Delta_{\frac{R_G}{R_G^{rf}}}$ to 36 bps per 1 p.p. increase in the debt ratio. This allows the illustration of a high-risk case.

Figure 3 gives a visual representation of the calibration of the sovereign default probabilities arising from the two calibrations. In the benchmark, this is a 1.5% annualized probability of default, which leads to an annualized sovereign risk spread level of 0.578%. The "high sovereign risk" calibration yields an annualized probability of sovereign default of 6.3% and therefore a risk spread level of 2.361% (see Table 3 for a full overview).

Figure 3: Logistic function for sovereign's probability of default



Notes: The default probability is annualized. Public debt-to-GDP as a ratio to annual GDP.

3.2 Calibration of benchmark and scenario bank fragility

Regarding bank fragility, we again first create a benchmark calibration that is used for estimation, as well as three scenario calibrations. The first scenario connects the "high sovereign risk" calibration from above with bank riskiness. Starting from this connection, we then present two alternative specifications that illustrate higher bank fragility in the sense that banks are weakly capitalized or banks are stronger exposed to the sovereign bond market risk. Table 4 gives an overview.

Starting with the benchmark calibration, the ratio of banks' holdings of government bonds to their loan book, $\alpha_B = \frac{\kappa_B^g}{\kappa_B^l}$, is set at 14%, which is the average 1999-2019 euro area value from the ECB's aggregate BSI statistics. Similarly to Clerc et al. (2015), the bank resolution costs, μ_b, is set at 0.3, implying losses of 30% of asset value for creditors repossessing assets from defaulting borrowers. The minimum capital requirements, ν_b, is set to 9% and covers the Pillar 1 and 2 requirements, the capital conservation buffer, and the systemic risk buffer (see EU (2013a) and EU (2013b)). Equivalently, the minimum requirement for government bonds, ν_g, is set to 5%, therefore lower than requirements on loans.

The parameters governing the adjustment cost frictions of sovereign securities for both households, χ_H, and bankers, χ_B, are set to target a transmission pattern of central bank asset purchases as described in the literature (Darracq Pariès et al. (2019)). We aim at the lowest degree of adjustment costs which generates a compression of sovereign yields of around 50 basis points and a pass-through to lending rate spreads close to 1 after two years. For the household first-order condition on sovereign bond holdings to be consistent with the steady-state sovereign spread and the share of bank holding of sovereign bonds, we let $\overline{B}_H$ clear the steady-state relationship associated with this equation.

The rest of the parameters in the banker's problem, i.e. the standard deviation of the idiosyncratic shock, σ_b, the regulatory penalty, χ_b, the continuation probability of bankers, ζ_b and the transfers to new bankers, Ψ_B are set in order to target other endogenous variables in the steady state, such as the capital ratio, probabilities of default and overall lending rate spread. In this respect, σ_b is set at 0.0351, χ_b at 0.4 and ζ_b at 0.93, in order to create a very small annualized steady-state probability of bank default. This level of bank riskiness is well below the probability of bank default as measured by financial market indicators and also well below estimated bank run risk in the literature (Dermine (2015)). This benchmark calibration also leads to an endogenous capital buffer above minimum requirements of around 3%, which is consistent with historical SREP outcomes (see EBA (2014) and ESRB (2014)). Lastly, it leads to an overall commercial lending rate spread of around 3.3% which is close to a historical euro area average as shown in Darracq Pariès and Papadopoulou (2020). Finally, Ψ_B clears the net worth accumulation equation for given spreads and the capital ratio.

In a second scenario calibration, we now blend bank riskiness with sovereign riskiness to create the first version of higher bank fragility (see the second column in Table 4). Bank default risk can be viewed as conditional on the commitment of the sovereign to guarantee the bank deposits of households. If the government itself would default, it cannot credibly commit anymore to bail out depositors, nationalize banks or guarantee deposit insurance. This notion is encapsulated in the parameter $p_B^{\xi_G}$ which creates a mechanical association of bank default risk with sovereign default risk. We, therefore, label this scenario as a "safety-net channel". We set $p_B^{\xi_G}$ equal to 0.5, which is motivated by the covariance of bank and sovereign default probabilities observed in periphery countries during the sovereign debt crisis. It is also close to the covariance of bank and sovereign default probabilities that endogenously arise in the model in response to a shock on the bankers' survival rate (under high sovereign risk).

We now create additional bank fragility scenarios. We first vary the degree of bank capitalization (see the third column in Table 4). Contrary to the benchmark calibration with very safe banks, in this counterfactual scenario, we target a bank default probability of 3.5% annualized (net of sovereign risk). We derived this setting from estimates by Dermine (2015) who evaluates the probability of bank runs in a very adverse scenario where bank assets are little diversified and the probability of defaults across the loan book is the highest. In our model, this calibration is implemented by setting the regulatory bank capital requirement parameter ν_b to 0.0425. This scenario is labeled "weak bank capitalization" hereafter.

Lastly, a second bank fragility is created (see fourth column in Table 4). Here, fragility is increased in the sense that banks are more exposed to sovereign riskiness in their steady-state portfolio allocation. For this illustration, we increase banks' sovereign bond holdings relative to other assets $\frac{\kappa_B^g}{\kappa_B^l}$ to 0.3, which resembles the maximum value observed in the median periphery country data[8] according to the ECB's BSI statistics on bank balance sheets. This scenario is labeled

[8] The periphery data shows a strong dispersion. Greece is a special case with very strong bond holdings at the

"high sovereign bond exposure" hereafter.

3.3 Calibration of other parameters

Table 5 gives an overview of the other parameter calibrations. These are benchmark calibrations and are not varied during the scenario exercises.

Starting with households, Λ_Ψ, governs the transaction costs faced by households upon bank restructuring related to a bank and government joint default probability event, $\Gamma_b(\overline{\omega}_{b,t+1})$. It is calibrated to 0.15 representing any transactional costs that they face in case of bank default not associated with any loss on deposits as those are guaranteed by the deposit insurance. This value is close to the one in Clerc et al. (2015). Households' steady-state sovereign bond holdings $B_H/(4Y)$ are set according to the euro sample average found in securities data from the ECB. The adjustment cost parameter on household's holding of sovereign securities χ_H are set to match transmission patterns of ECB bond purchase shocks (see Darracq Pariès et al. (2019)).

Regarding entrepreneurs, we target default frequencies for firms of 2.6% (close to the expected default probabilities calculculated by Moody's) and a credit risk compensation on corporate loans of 50 bps (in annual terms) which broadly corresponds to one-third of the sample mean. The external finance premium $100\left(\frac{R_{KK}}{R_{LE}}-1\right)$ is set at 200 bps (in annual terms), which is very close to the estimated historical average value by Gelain (2010) for the euro area. We also aim at matching a credit-to-GDP ratio consistent with the loan data under consideration (around 50%, which is close to the sample mean). Four parameters are assigned to those targets: the monitoring costs μ_e, the standard deviation of the idiosyncratic shock σ_e, the limited seizability parameter χ_e and entrepreneurs' survival probability ζ_e. We assume that the additional transfers to new entrepreneurs, Ψ_E, are zero.

Concerning other calibrated parameters, the depreciation rate of the capital stock δ is set at 0.025. The steady-state labor market markup is fixed at 1.5 and the curvature parameter of the Kimball aggregators is set at 10.

Turning to the government sector, the share of government spending in output is set to 20%, which is the euro area mean value in our estimation sample. The sovereign debt-to-GDP ratio as well as the steady-state labor income tax rate (this includes social security contributions paid on labor income by the employee) is also calibrated to equal the euro area data mean. We set the geometric decay of the perpetual coupons on sovereign bond τ_g so that the duration of the securities is 10 years. The initial coupon level c_g is adjusted to ensure that the steady state sovereign bond price Q_B equals 1.

The fiscal authority uses lump-sum transfers/taxes to stabilize public debt in the long run. The parameters of the fiscal rule are set to $\rho_T = 0$ and $\phi_T = 0.1$ such that the transfers react slowly to the debt build-up and have no persistence. The debt stabilization coefficient is relatively low compared to the reference literature. For example, Leeper et al. (2010) estimates a value of 0.5 for the United States. We therefore conduct a sensitivity exercise (see Appendix Figure A1). The benchmark fiscal rule calibration is compared against lump-sum transfers reacting faster to public debt $\phi_T = 0.5$ and to fiscal rules where labor income tax adjustments are used to stabilize public debt. The benchmark

beginning of the sample that reduced to extremely low levels during the period of (partial) default and the dis-functioning of the sovereign bond market. We, therefore, pick a value of the median country in the periphery group, rather than the mean of the aggregate.

fiscal rule is chosen because it allows studying the implications of largely debt-financing the increase in government expenditure. By using lump-sum transfers instead of labor income taxation, we can focus in isolating the spending impulse without distortions to labor markets when counter-financing the expansion.

3.4 Data and estimation results

We consider 10 key macroeconomic quarterly time series: output, private consumption, fixed investment, hours worked, real wages, the GDP deflator inflation rate, the three-month short-term interest rate, bank lending spreads (based on lending to non-financial corporations), credit volume to non-financial corporations, and the (weighted) 10-year euro area sovereign spread. The data are *not* filtered prior to the estimation.[9]

The number of exogenous shocks plus measurement errors is larget than the number of observable variables:[10] shocks on technology ϵ_t^a, investment ϵ_t^I, public expenditures ϵ_t^g and consumption preferences ϵ_t^b, price markups ϵ_t^p, wage markups ϵ_t^w, entrepreneurs idiosyncratic risk $\epsilon_t^{\sigma_e}$, the valuation of sovereign bonds $\epsilon_t^{R_G}$, the bankers' survival rate $\epsilon_t^{\zeta_b}$, the entrepreuners' survival rate $\epsilon_t^{\zeta_e}$ and on the monetary policy rule ϵ_t^r.

For the estimation, the quarterly growth rate of GDP, private consumption, investment, and loans, are all expressed in real terms and divided by the working-age population. The employment variable is also divided by the working-age population. Real wages are measured with respect to the consumption deflator. Interest rates and spreads are measured quarterly. With the exception of loan growth and the employment rate for which specific trend developments are not pinned down by the model, transformed data are not demeaned as the model features non-zero steady-state values for such variables. A set of parameters are therefore estimated to ensure enough degrees of freedom to account for the mean values of the observed variables. Trend productivity growth γ captures the common mean of GDP, private and public consumption, investment, and real wage growth; $\overline{L}$ is a level shift that we allow between the observed detrended employment rate and the model-consistent one; $\overline{\pi}$ is the steady state inflation rate which controls for the CPI inflation rate mean; and we also estimate the preference rate $r_\beta = 100(1/\beta - 1)$ which, combined with $\overline{\pi}$ and γ, pins down the mean of the nominal interest rate.

The prior distributions are chosen to be in line with Smets and Wouters (2005) and previous literature, in particular, similar to Darracq Pariès et al. (2019). The main differences relate to the choice of uniform priors for the standard deviations of the exogenous shocks.

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[9]Data for GDP, private consumption, government consumption, investment, employment, wages and consumption-deflator are based on Fagan et al. (2001) and Eurostat. Employment numbers replace hours. Consequently, as in Smets and Wouters (2005), hours are linked to the number of people employed e_t^* with the following dynamics

$$e_t^* = \beta \mathbb{E}_t e_{t+1}^* + \frac{(1-\beta\lambda_e)(1-\lambda_e)}{\lambda_e}(l_t^* - e_t^*)$$

The three-month money market rate is the three-month Euribor taken from the ECB website and we use backdated series for the period prior to 1999 based on national data sources. Data on retail bank lending rates and volumes to non-financial corporations are based on official ECB statistics from January 2003 onwards and on ECB internal estimates based on national sources in the period before. The lending rates refer to new business rates. For the period prior to January 2003 the area area aggregate series have been weighted using corresponding loan volumes (outstanding amounts) by country.

[10]All the AR(1) processes are written as: $\log(\varepsilon_t^x) = \rho_x \log(\varepsilon_{t-1}^x) + \epsilon_t^x$ where $\epsilon_t^x \sim \mathcal{N}(0, \sigma_{\varepsilon^x})$. ARMA(1,1) are of the form $\log(\varepsilon_t^x) = \rho_x \log(\varepsilon_{t-1}^x) - \eta_x \epsilon_{t-1}^x + \epsilon_t^x$. The government spending shock is correlated with the technology shock: $\log(\varepsilon_t^g) = \rho_g \log(\varepsilon_{t-1}^g) + \epsilon_t^g + \rho_{g,a}\epsilon_t^a$. All shock processes ε_t^x are equal to 1 in the steady state.

Tables 6 shows an overview of these priors set and the posterior results. Core structural parameter estimates of the model are well inside the common range found in the literature. With a value below one, the mode of the Frisch elasticity σ_l is reasonable. The inverse of the intertemporal elasticity of substitution σ_c is also well identified by the model. With respect to household preferences, the estimation shows a considerable level of habit formation η with a mode at 0.825. The estimated time preference rate r_β translates into a discount factor of β equal to 0.999.

For the Calvo lottery parameter related to retail lending rate setting, ξ_E^R, we choose a relatively uninformative prior. The posterior mode is estimated to be around 0.5 indicating that the data is not very informative for our model specification.

The value for capital utilization adjustment cost φ implies a standard degree of rigidity in capital adjustment. The investment adjustment costs ϕ are rather low compared to the range reported in the literature. Moreover, the data indicate a modest trend of growth productivity, while the estimated capital share α is relatively low compared to standard figures in the literature. As known for the euro area, price stickiness exceeds wage stickiness, $\alpha_p > \alpha_w$, while the mean of the price markup, μ_p is around the same as the calibrated value for wages. These estimates indicate a moderate degree of price and wage indexation, ξ_p and ξ_w, respectively.

The steady-state inflation rate π is around 2% which is consistent with the ECB target and the average inflation for the period. The posterior means of the parameters governing the monetary policy rule are in line with Smets and Wouters (2007). The monetary policy response to inflation deviations from the steady state is broadly standard, while the reaction to deviations from inflation is almost insignificant. Furthermore, the reaction to output deviations is rather low. Last, the interest rate smoothing parameter ρ points to high inertia in the monetary policy conduct.

The estimation sample covers the period of very low inflation and nominal interest rates. We do not explicitly account for the ELB as a special period of different economic features. In principle, our model features unconventional monetary policy channels which also drive the monetary stance beyond the standard conduct using interest rate setting. Therefore, shadow rate concepts cannot be easily applied. Instead, we run a second alternative estimation on a restricted sample (1995-2014) to cross-check our main estimation results. The results can be found in Appendix Table A1. The parameter estimation can be judged to be stable since the alternative estimation does not create material differences in the posterior mode or means.

We are not investigating the full cyclical properties of our estimation but instead focus on the determinants of the government spending shock transmission, which is the source of variation of interest in the remainder of the paper. Figure 4 shows the impulse responses of the model economy to this shock and the parameter uncertainty. The bands cover a quantile range of up to 80% around the posterior mean draw, calculated by randomly selecting model simulations based on draws after the burn-in sample of the estimation's Markov chains. The illustration points to moderate parameter uncertainty. The inflation response is not very pronounced, because the government spending shock is correlated with the technology shock, for the purpose of estimation. Furthermore, we do not allow government debt to vary over the cycle in the benchmark calibration. Finally, investigating the impulse responses based on the mean across parameter draws from the alternative estimation described above, the economy does not react differently to the spending impulse. We conclude, that our estimation over the period that covers exceptionally low interest rates does not derail the main messages of the analysis that follows.

4 Fiscal multipliers with risky sovereigns and risky banks

This section discusses the main experiments of debt-financed fiscal expansion across different scenario calibrations. We conduct the exercise starting with the benchmark calibration, before adding sovereign risk and a varying degree of bank fragility.

All exercises are conducted by running stochastic simulations of a government spending shock in the linerized model, where the steady state calibrations differ. Departing from the estimation setup, in the simulation settings, we allow for the government spending shock not to correlate with the technology shock ($\rho_{g,a} = 0$), and for sovereign debt variation to be active as described in equation (59).

4.1 Benchmark case and introduction of sovereign risk

The blue line in Figure 5 refers to the benchmark calibration of the model with debt responding but without sovereign default riskiness. The behavior of this model economy is well nested in the standard class of New Keynesian models. Households increase savings and reduce consumption in anticipation of future tax increases necessary to stabilize public debt. On impact, the additional spending also feeds directly into total demand for production creating upward pressure on prices. The central bank raises interest rates to stabilize output and inflation and the banking system passes higher refinancing costs through to higher lending rates resulting in a decrease in investment. Financial frictions in the banking system lead to an imperfect pass-through of monetary policy. Higher rates lead to a decrease in loan volumes as demand for funds drop. A higher policy rate also induces higher yields on long-term debt as investors demand compensation in the maturity transformation process. Eventually, banks shift their assets from loans towards buying sovereign bonds as those become relatively more attractive. The government bond issuance is therefore largely soaked up by banks. Note that this starting calibration already includes a mildly risky banking sector, however, banks are financed through enough equity for the default probability virtually not to react.

We now activate sovereign default risk and investigate its transmission through the economy. The dotted green lines in Figure 5 show the impulse response functions to a government spending shock in a vulnerable, high debt, and high spread sensitivity environment. Since the expansion is debt-financed, the sovereign default probability increases (see equation (62)). Sovereign bond yields rise because bondholders demand a higher risk compensation. The repricing of bonds held by banks on the balance sheet impairs their asset position on the impact of the shock, leading to a decline in bank net worth. While sovereigns are considered risky, banks are only mildly affected. Lower banks' net worth then creates incentives to increase profits by charging higher rates on new loans. Due to limited liability, banks have a risk-taking motive and therefore keep credit origination relatively stable while still increasing their holdings of sovereign bonds. Overall, sovereign riskiness that does not affect the banking sector riskiness, does not have detrimental effects on credit, investment, or output relative to the benchmark reaction.

The solid green line in Figure 5 evaluates the effects of a fiscal expansion in an economy where bank risk correlates with sovereign risk. The mechanism has been dubbed the safety net channel in the literature (see Dell'Ariccia et al. (2018)). This channel refers to the notion that banks depend on direct or indirect government guarantees to ensure the functioning of the financial system and especially secure a backstop for household deposits. The deposit insurance scheme in our model prevents actual default on deposits. Any loss of credibility in the deposit insurance creates a co-movement of bank and sovereign default probabilities.

In response to the increase in bank risk, households demand a higher risk premium on their deposits. This increase in bank funding costs triggers banks to increase lending rates on loans in order to stabilize their profit margins. The additional premium leads to a stronger decline in loan financing to firms and therefore to a sharp decrease in investment. The bank funding cost channel is the main transmission mechanism of creating adverse feedback of sovereign risk to the macroeconomy in our model.

4.2 The role of bank system fragility

As a next step, we turn to scenarios of stronger bank fragility. Red lines in Figure 6 refer to economies where the banking system is weakly capitalized. Comparing the two dotted lines, i.e. without the safety net channel yet, increased bank fragility creates more adverse macroeconomic feedback. With a weaker capital buffer, steady-state bank risk is higher and pure exposure to sovereign risk invokes a stronger marginal increase in bank risk. As the default risk increases, the bank funding cost channel leads banks to tighten credit supply and investment is adversely affected.

If the safety net channel is active (comparing the two solid lines in Figure 6), a weaker bank capitalization does not lead to a more adverse reaction. This is even though bank funding costs are very sensitive now and react in line with a harsher increase in banks' default probability. However, the key friction here is the limited liability of banks. Under this condition, financial intermediaries have a risk-shifting motive and reallocate their asset portfolio towards higher-yielding investments. Credit supply is therefore driven by a combination of both factors: tighter bank funding conditions tend to decrease loan operations, while risk-shifting tends to increase them. On balance, the loan response and therefore the investment response is not too different from the economy where banks are well capitalized but are exposed to sovereign risk through the "bank-run"-type correlation.

Weaker capitalized banks already highlight the role of sovereign bond exposure. We now turn to investigate the role of bank transmission by varying the sovereign bond share in total assets, while keeping steady-state capitalization constant. This allows us to investigate the sovereign-bank-nexus (see Dell'Ariccia et al. (2018)). Banks hold a considerable amount of sovereign bonds on their balance sheet for various purposes ranging from liquidity management to balancing portfolio risk. In addition, banks over-proportionally hold sovereign debt securities of their home country as opposed to geographically diversifying their portfolio (e.g. documented in Horvath et al. (2015)). If banks hold sovereign debt securities, sovereign default risk is endogenously transmitted to banks as asset valuations deteriorate.

In Figure 7, red lines represent the calibrations under "high sovereign bond exposure". The dotted red line adds the high exposure on the economy with sovereign default but without the safety net channel. The solid line adds high exposure to the economy with a safety net channel of the sovereign-bank-nexus. The strength of sovereign risk transmission increases with the steady-state bond holdings by banks. This is relevant even if there is no safety net channel. Then, pure exposure already allows the transmission of sovereign risk. If, however, we consider the presence of the safety net mechanism, then stronger exposure does not add more to the vulnerability that is already inherent in the economy.

Table 1 collects the output multipliers of fiscal spending for all the aforementioned exercises. Sovereign default risk that triggers the safety net channel considerably depresses the multiplier, especially when bank holdings of sovereign bonds are high. In the following section, we, therefore, take this very adverse result as a starting point calibration to investigate what policy responses can do to mitigate the setback.

Table 1: Output multipliers of government spending

PV(dY/dG)	over 20 qtrs	over $\lim_{t\to\infty}$
Benchmark	0.77	0.79
High sov. risk	0.76	0.84
High sov. risk + safety net channel	0.55	0.57
High sov. risk, weak bank capitalisation	0.69	0.76
High sov. risk + safety net channel, weak bank capitalisation	0.58	0.65
High sov. risk, high sov. bond exposure	0.68	0.74
High sov. risk + safety net channel, high sov. bond exposure	0.52	0.55

Notes: The present value fiscal multiplier at horizon k is defined as cumulated changes of output over cumulated changes of government spending, discounted by interest rate payoffs.

5 Interaction with monetary and macro-prudential policies

In this section, we investigate the of role monetary and macro-prudential policy in supporting the functioning of fiscal stabilization. We consider three types of conventional and unconventional monetary policy reactions: *First*, the provision of TLTRO-like favorable bank funding, *second*, a sovereign bond purchase program, and *third* a more restrained nominal interest rate setting behavior. *Lastly*, we consider a counter-cyclical capital requirement rule that smoothes credit creation.

5.1 Monetary policy responses

We start by creating an exercise that illustrates central bank intervention to ensure ample bank liquidity. This scenario is inspired by the conduct of targeted longer-term refinancing operations (TLTROs) implemented by the ECB which aimed at providing banks with funding under very favorable conditions. Starting in 2014, multiple TLTROs were communicated with the explicit aim of further easing the monetary policy stance and stimulating bank lending. Mapped into our model, this measure implies a shutdown of the adverse bank funding cost response to sovereign risk. We set the model parameter governing transaction costs of households in case of bank default Λ_Ψ to zero.

The solid green line in Figure 8 shows the economy response under very vulnerable high exposure conditions, but with an implemented TLTRO measure. The exercise brings the reactions of the economy closely back to the benchmark case. Effectively, this confirms that in our model, the bank funding cost channel is the main source of adversity from the sovereign risk pass-through.

Next, we turn to an exercise where the central bank purchases government bonds. This policy, labeled "CB bond purchases", is operationalized in the model by introducing a rule for the amount of central bank holdings of government bonds $B_{CB,t}$ as follows.

$$B_{CB,t} = \rho_{_{CB}} B_{CB,t-1} + (1-\rho_{_{CB}})\phi_{cb}\left[\frac{R_{G,t}}{R^{rf}_{G,t}} - \frac{\overline{R}_G}{\overline{R}^{rf}_G}\right]. \tag{75}$$

With the announcement of bond purchases in the context of the Pandemic Emergency Purchase Programme (PEPP), the ECB ensured a functioning monetary policy transmission mechanism. In this spirit, we calibrate the parameter ϕ_{cb} such that the sovereign yields react to a government spending impulse as in the benchmark case. Holdings of government bonds follow an AR(1) process where $\rho_{_{CB}}$ is calibrated to match the redemption schedule of 10-year bonds (see Darracq Pariès and Papadopoulou (2020) and Darracq Pariès et al. (2019)).

Figure 8 shows the simulation results of a government spending shock, where central bank asset purchases support the valuation of sovereign bonds. Due to the market intervention, bank balance sheets are impaired considerably less than before. The bank funding costs increase nonetheless, but to a lower extent than under the high exposure scenario. Bond purchasing creates credit pricing and firms' investment response similar to the TLTRO-type measure. The central bank purchase soaks up the bond supply, leading banks to shed bonds and reallocate their portfolio toward loans. This is the portfolio-rebalancing channel of central bank asset purchases. In our model, also households decrease their bond holding, albeit to a much lesser extent, and instead do not decrease consumption as much as before.

The next monetary policy setting we consider is a modified interest rate rule. The literature centered around Cúrdia and Woodford (2010) studied alternative specifications of the Taylor rule, where the credit spread is explicitly taken into account such that the monetary policy stance is not distorted by credit market frictions. In this tradition, we change the model's rule for the nominal short-term interest rate to:

$$\hat{R}_t = \rho\hat{R}_{t-1} + (1-\rho)\left(r_\pi\hat{\pi}_t + r_L\left[\frac{R_{LLE,t}}{R_t} - \frac{\bar{R}_{LLE}}{\bar{R}}\right]\right) + r_{\Delta y}\Delta y_t + r_{\Delta\pi}\Delta\pi_t + \ln\left(\varepsilon^r_t\right) \tag{76}$$

where r_L is calibrated to 0.5 which is the welfare optimal value found in Cúrdia and Woodford (2010).

Figure 8 also displays a simulation with the modified interest rate rule. The central bank increases the policy rate less aggressively in reaction to the fiscal stimulus because it observes the increase in the lending rate spread. This policy creates a similar loan volume response as the central bank bond purchases. Since the rate on the risk-free rate increases less, household consumption is more stable than in the adverse scenario. At the same fiscal stimulus, less aggressive monetary policy tightening leads to a higher inflation response.

As a final note on monetary policy, we present a side exercise in the Appendix that considers the interest rate is constrained at the ELB. This is useful because our estimation sample covers the period of exceptionally low-interest rates at and below zero. The constrained interest rate case can be thought of as an extreme corner case of very accommodative monetary policy support to the fiscal expansion. To implement an ELB scenario, the policy rate $\hat{R}_t$ is now being set as follows

$$\hat{R}_t = max\left(\underline{\hat{R}}, \hat{R}^*_t\right) \tag{77}$$

where $\hat{R}^*_t$ now refers to the model's standard Taylor rule as described in equation (66). $\hat{R}$ is the practical lower bound value for nominal interest rates. For the shock experiment, monetary policy is assumed to be constrained at the ELB for four consecutive quarters only, but without fiscal expansion pushing the economy out of the constraint.

Appendix Figure A2 shows response functions of the public spending shock with and without constrained interest rates. We consider the very adverse high sovereign risk and bank fragility calibration against what we already judged the other policy interventions. Fixing the nominal interest rate leads to a decrease in the real rate of return on risk-free bonds, incentivizing contemporaneous consumption. Capital investment becomes more attractive as its real return increases. Aggregate production then is stimulated considerably more than in the benchmark case. Buoyant tax growth in the ELB scenario avoids a strong public debt accumulation over the medium term. As a result, there is little sovereign risk that can be passed through to the fragile banking system. Nonetheless, there is still an adverse bond valuation effect on bank balance sheets which leads to some increase in bank funding costs and an increase in the lending rate spread.

5.2 Macro-prudential policy responses

Regulatory and macroprudential policies aim to ensure the resilience of individual banks through bank capital provision. In this regard, the main instrument is the setting of the capital requirement ratio.[11] In this respect, it is assumed that total capital requirements result from the summation of two components, specified as follows

$$\nu_b = \nu_{b,r} + \nu_{b,m,t} \tag{78}$$

where

1. $\nu_{b,r}$ denotes the regulatory requirement which aims to mitigate extreme risk exposure of the bank by equipping it with sufficient loss-absorbing capacity, and

2. $\nu_{b,m,t}$ denotes the macroprudential capital ratio that stands for the countercyclical bank capital buffer implemented to safeguard the soundness of the whole financial system.

In relation to the reform packages, CRR and CRD IV, the prudential capital demand comprises a minimum level of requirements, supplemented by various macroprudential buffers. The latter is expected to be time-varying through the financial cycle. Capital-based macroprudential policies operate through a countercyclical rule on the prudential capital demand ν_b. The countercyclical capital buffer (CCyB) is part of a set of macroprudential instruments that the European Systemic Risk Board (ESRB) may apply to systemically important financial institutions (see EBA (2014) and ESRB (2014)). Therefore, the countercyclical capital buffer is a source of variation for the bank capital requirement, largely at the discretion of national competent authorities.

In the model, the mechanism behind these policies is based on the requirement that bank equity must cover a fraction of ν_b of loan holdings and a fraction ν_g of government bond holdings. Due to its safe asset characteristics, the bond capital requirement ν_g serves as a proxy for other types of liquidity constraints that are beyond the scope of this study.

[11] Although, prudential policies are categorized into three broad areas, namely capital-based, asset-based and liquidity-based, and can be operationalized either or both as a micro- and macroprudential tool, this paper focuses only on capital-based micro- and macroprudential policies.

In line with the ESRB proposed rule, the capital requirement is set to endogenously react to the annualized credit-to-GDP ratio as follows

$$\nu_{b,m,t} = \nu_{b,m} + \phi_{\nu_b} \left[\frac{L_{BE,t}}{\sum_{j=0}^{3} Y_{t-j}} - \frac{\bar{L}_{BE}}{4\bar{Y}} \right] \tag{79}$$

where ϕ_{ν_b} determines its cyclical adjustment and is calibrated to 0.3125 as specified by ESRB (2014).

Figure 8 shows a simulation of the fiscal expansion exercise with sovereign risk, high bank exposure, and an active capital requirement rule. The credit-to-GDP ratio drops because credit origination decreases, in line with the tighter lending rate pricing, while GDP increases. Following the macro-prudential rule, the oversight authority would loosen capital requirements. This increases banks' available capital buffer above the default cut-off. The more accommodative capital requirements lead to lower capital charges on banks' risk pricing. Therefore, while bank funding costs increase to a similar extent as in the high sovereign bond exposure reference scenario, banks do not have to increase lending rates as much in order to defend their margin and build up additional net worth. Consequentially, loan operations are not curtailed as much, investment is cushioned and output is supported.

Table 2 collects the fiscal multipliers across the policy intervention scenarios we considered. All policies are effective in preventing the depression of the fiscal multiplier to various degrees. Given our calibration, sovereign yield control through bond purchases and the macro-prudential rule does not fully bring back the multiplier to the benchmark case. Bank funding cost interventions and lending spread responsiveness of interest rate setting fully restore the effectiveness of fiscal expansions.

Table 2: Output multipliers of government spending

PV(dY/dG)	over 20 qtrs	over $\lim_{t\to\infty}$
High sov. bond exposure	0.52	0.55
High sov. bond exposure, with TLTRO	0.77	0.81
High sov. bond exposure, with QE	0.70	0.72
High sov. bond exposure, with modified Taylor rule	0.79	0.82
High sov. bond exposure, with Macro-prudential rule	0.66	0.68

Notes: The present value fiscal multiplier at horizon k is defined as cumulated changes of output over cumulated changes of government spending, discounted by interest rate payoffs.

6 Conclusion

This paper quantified the size of fiscal multipliers of government spending in an economy with sovereign risk. We have formulated a DSGE model that can describe the sovereign-bank nexus and its various layers. The model features financial frictions that are paramount in understanding the sovereign-financial feedback mechanisms. We added a role for government debt through the specification of the sovereign risk premium. The explicit formulation of banks' balance sheet constraints and adjustment frictions also allows for studying the interplay with conventional and unconventional monetary policy interventions.

It finds that the output multiplier of fiscal expansions can be significantly dampened by sovereign risk feedback loops through the financial sector. A key channel of the sovereign-bank-nexus relates to the sensitivity of bank funding cost on sovereign risk. This arises in the model as bank depositors claim a risk compensation for the imperfect credibility of government deposit insurance. We have quantified the compression of the fiscal multiplier in very adverse conditions of high debt levels, strong risk sensitivity of government bonds, weak bank capitalization, and high direct exposure of the banking system to the domestic sovereign bond market. Finally, we have evaluated to which extent monetary and macro-prudential policy interventions can help mitigate the financial setbacks to fiscal policy expansion.

In conclusion, this work points to the first-order importance of maintaining sufficient fiscal capacity in good times in order to avoid entering a downturn or crisis in a vulnerable fiscal starting position. Beyond that, a stable and well-capitalized banking system is a pre-condition to prevent sovereign risk tensions from derailing the effects of fiscal interventions. The banking and capital market union are important steps to foster the integration of the banking system in Europe and therefore encourage more cross-country holding of sovereign debt. Establishing the Single Resolution Board and the Single Resolution Fund are milestones in finding common approaches to dealing with bank fragility in the union. Finally, macro-prudential policies can contribute to limiting the fallout from sovereign tensions being passed to the real economy. We have shown that bank capital-based macroprudential requirement rules as suggested by the ESRB are conducive to this end.

It has been shown that central bank interventions aiming at ensuring an adequate functioning of the sovereign bond market can contain the side effects of fiscal expansion at times of excessive sovereign risk sensitivity. Some remarks on this conclusion are in order. The primary objective of monetary policy is to deliver price stability and requires an effective monetary policy transmission mechanism through the banking system. During the Great Financial Crisis and the sovereign debt crisis, the central bank intervened to preserve the singleness of monetary policy in the euro area and ensure its proper transmission to the real economy. Since then, the union refined its tools to create an effective backstop, including the formation of the European Stability Mechanism (ESM). Loans under the ESM are subject to strong conditionality and as such might not entirely eliminate sovereign risk pricing. Finally, central bank interventions must be seen in the context of exceptional circumstances such as the economic fallout during the COVID pandemic. However, recurrent or continuous prevention of sovereign risk pricing creates moral hazard problems inside the union and interferes with the signaling function of financial markets.

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Appendices

A Model parameterization

Table 3: Calibration of sovereign risk

		Benchmark	HSR
Parameter			
$\frac{G^{\star}}{4Y}$	Sovereign debt-to-GDP ratio	0.79	1.13
η_1	Location logistic parameter	5.556	20.720
η_2	Scale logistic parameter	0	14.672
ξ_G^{max}	Expected bond haircut	0.37	0.37
Variable			
$R_G - R_G^{rf}$	Sovereign risk bond spread[a]	0.578	2.361
$R_G^{rf} - R$	Sovereign risk free bond spread[b]	1.171	1.036
$R_G - R$	Termspread$^{c \approx a+b}$	1.749	3.397
$\Delta_{\frac{R_G}{R_G^{rf}}}$	Sovereign risk bond sensitivity wrt. sov. debt	0	0.36
$p_t^{\xi_G}$	Probability of sovereign default	1.5	6.3

Notes: All rates and probabilities in annualized percentage points. Public debt-to-GDP as p.p. ratio to annual GDP. HSR = High sovereign risk.

Table 4: Calibration of bank fragility

		Benchmark	HSR SN	HSR SN+WB	HSR SN+HBE
Parameter					
σ_b	St.dev. of idiosyncratic shock	0.035	0.035	0.035	0.035
$\chi_B/100$	Portfolio adj. cost for bankers	0.5	0.5	0.5	0.5
μ_b	Bank resolution cost	0.3	0.3	0.3	0.3
ν_g	Reg. req. on gov. bonds	0.05	0.05	0.05	0.05
χ_b	Regulatory penalty	0.4	0.4	0.4	0.4
ζ_b	Survival prob. of bankers	0.93	0.93	0.93	0.93
Ψ_B/L_E	Transfers to new bankers	0.002	0.002	0.002	0.002
$p_B^{\xi_G}$	Safety net channel	0	0.5	0.5	0.5
ν_b	Reg. req. on loans	0.09	0.09	0.0425	0.09
κ_B^g/κ_B^l	Gov. bond to loan ratio	0.14	0.14	0.14	0.30
Variable					
$1-(1-F(\overline{\omega}_b))^4$	Prob. of default	0.046	0.034	3.645	0.007
$1-(1-\Gamma_b(\overline{\omega}))^4$	Bank-sov. joint default prob.	0.077	3.184	7.240	3.850
$1-\overline{\omega}_b$	Capital ratio	0.122	0.124	0.080	0.136
$R_{LL}-R$	Commercial lending rate spread	3.347	3.725	3.079	3.869

All rates and probabilities in annualized percentage points. Capital ratio in percent of assets and (quarterly) return on equity in percent. HSR = High sovereign risk. SN = Safety net channel. WB = Weak bank capital. HBE = High bond exposure.

Table 5: Calibrated parameters

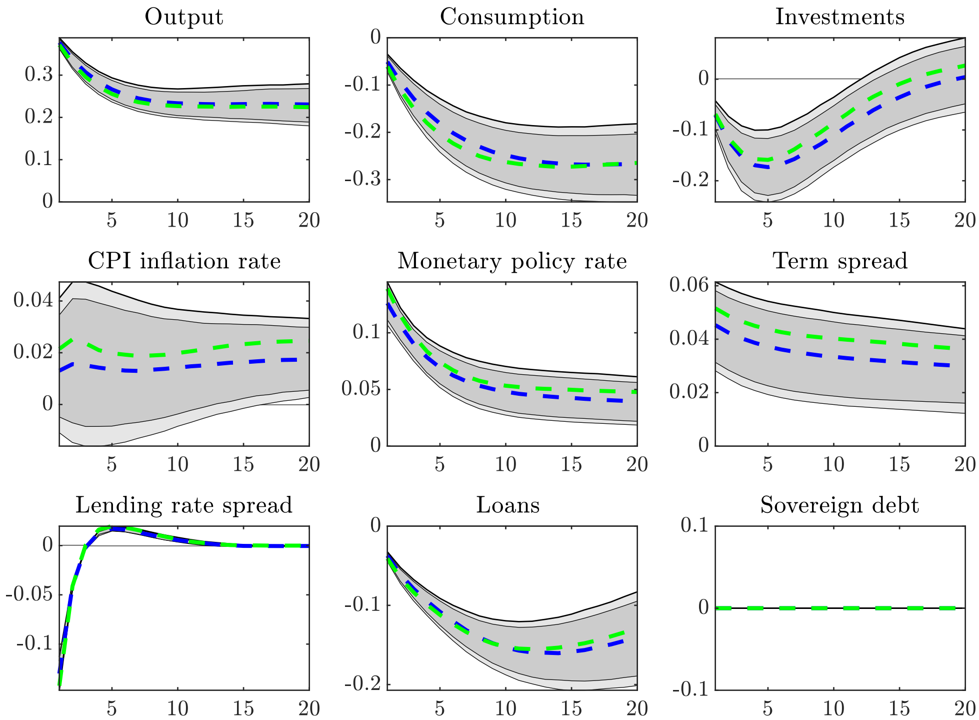
Parameters		Benchmark
Households		
Λ_Ψ	Transaction cost of bank default	0.15
$\chi_H/100$	Portfolio adj. cost for households	5.5
$\overline{B_H}/(4Y)$	Households target gov. bond holdings	0.27
Entrepreneurs		
σ_e	Std idiosyncratic entrepreneur risk	0.3
χ_e	Seizability rate	0.5
μ_e	Monitoring costs	0.1
$R_{KK} - R_L$	External financing premium	2.00
ζ_e	Survival probability for entrepreneurs	0.97
Ψ_E	Transfers to new entrepreneurs	0
Capital producers		
δ	Fixed capital stock depreciation rate	0.025
Firms		
ψ	Kimball goods aggregator parameter	10
Labour union and labour packers		
μ_w	Wage markup	1.5
ψ_w	Kimball labour aggregator parameter	10
Government sector		
$G^\star/Y$	Share of gov. expenditures to output	0.2
$\overline{\tau_w}$	SS labour income tax	0.42
ϕ_T	Lump-sum tax sensitivity to debt-to-GDP ratio	0.1
ρ_T	AR(1) lump-sum tax	0
ϕ_{τ_w}	Labour income tax sensitivity to debt-to-GDP ratio	0
ρ_{τ_w}	AR(1) labour income tax	0.9
c_g	Coupon rate	0.04
τ_g	Geometric decay factor for coupons	0.02

Notes: In annualised terms.

Table 6: Parameter estimates

Parameters			Prior			Posterior		
		Dist.	Mean	Std.	Mode	Mean	-45%	+45%
η	Habit formation	normal	0.7	0.1	0.825	0.834	0.772	0.899
σ_c	Intertemp. elasticity of subst.	gamma	1.5	0.2	1.844	1.792	1.456	2.128
σ_l	Labor disutility	gamma	2	0.75	1.003	1.360	0.496	2.203
r_β	Rate of time preference	gamma	0.25	0.1	0.079	0.095	0.036	0.150
φ	Cap. utilization adj. cost	beta	0.5	0.15	0.148	0.189	0.057	0.320
ϕ	Investment adj. cost	normal	4	1.5	4.133	4.304	2.717	5.865
γ	Trend productivity	gamma	0.3	0.1	0.143	0.143	0.104	0.182
α	Capital share	normal	0.3	0.05	0.406	0.395	0.346	0.444
λ_e	Employment adj. cost	beta	0.5	0.28	0.874	0.859	0.815	0.905
$\overline{L}$	Employment shift	normal	0	5	0.131	0.214	-2.671	3.089
ξ_p	Calvo lottery, price setting	beta	0.5	0.1	0.799	0.777	0.690	0.867
α_p	Indexation, price setting	beta	0.5	0.15	0.235	0.258	0.106	0.409
μ_p	Price markup	normal	1.25	0.12	1.517	1.555	1.388	1.728
ξ_w	Calvo lottery, wage setting	beta	0.5	0.1	0.663	0.681	0.575	0.788
α_w	Indexation, wage setting	beta	0.5	0.15	0.184	0.201	0.086	0.313
$\overline{\pi}$	SS inflation rate	gamma	0.5	0.05	0.573	0.573	0.490	0.655
ξ_E^R	Calvo lottery, lending rate	beta	0.5	0.25	0.501	0.494	0.442	0.546
ρ	Interest rate smoothing	beta	0.75	0.1	0.933	0.933	0.918	0.947
r_π	Taylor rule coef. on inflation	normal	1.5	0.25	1.864	1.915	1.608	2.223
$r_{\Delta Y}$	Taylor rule coef. on Δ(output)	normal	0.12	0.05	0.084	0.083	0.064	0.101
$r_{\Delta\pi}$	Taylor rule coef. on Δ(inflation)	gamma	0.3	0.1	0.041	0.044	0.023	0.065
AR or ARMA coefficients of exogenous shock processes								
ρ_a	AR(1) Technology	beta	0.5	0.25	0.919	0.921	0.883	0.957
ρ_I	AR(1) Inv. Technology	beta	0.5	0.2	0.756	0.671	0.417	0.886
ρ_g	AR(1) Gov. spending	beta	0.5	0.25	0.996	0.994	0.987	1.000
ρ_b	AR(1) Preference	beta	0.5	0.25	0.249	0.305	0.097	0.501
ρ_p	AR(1) Price markup	beta	0.5	0.2	0.745	0.707	0.503	0.986
η_p	MA(1) Price markup	beta	0.5	0.2	0.597	0.537	0.239	0.898
ρ_w	AR(1) Wage markup	beta	0.5	0.2	0.946	0.935	0.900	0.970
ρ_{σ_e}	AR(1) entrepr. risk	beta	0.9	0.05	0.960	0.953	0.926	0.981
ρ_{R_G}	AR(1) Gov. bond valuation	beta	0.5	0.2	0.992	0.986	0.975	0.999
ρ_{ζ_b}	AR(1) Bankers survival	beta	0.5	0.2	0.500	0.418	0.117	0.711
ρ_{ζ_e}	AR(1) Entrepreneurs survival	beta	0.5	0.2	0.543	0.542	0.359	0.728
$\rho_{g,a}$	Corr(Technology, Gov. spending)	uniform	4.5	3.1754	0.236	0.388	-0.168	0.964
Standard deviations of exogenous shock processes								
$\sigma_{\epsilon_t^a}$	Technology	uniform	5	2.9	0.8648	0.8149	0.4498	1.1828
$\sigma_{\epsilon_t^I}$	Inv. Technology	uniform	10	5.8	2.5533	2.5044	1.158	3.8883
$\sigma_{\epsilon_t^g}$	Gov. spending	uniform	5	2.9	1.6329	1.6654	1.4608	1.8681
$\sigma_{\epsilon_t^b}$	Preference	uniform	5	2.9	2.994	3.3352	2.1329	4.4723
$\sigma_{\epsilon_t^p}$	Price markup	uniform	0.25	0.1	0.1554	0.1588	0.1251	0.1937
$\sigma_{\epsilon_t^w}$	Wage markup	uniform	0.25	0.1	0.046	0.0485	0.0338	0.0626
$\sigma_{\epsilon_t^{\sigma_e}}$	Entrepreneurs risk	uniform	10	5.8	0.0587	0.0714	0.0403	0.101
$\sigma_{\epsilon_t^{R_G}}$	Gov. bond valuation	uniform	0.5	0.3	0.008	0.0091	0.0066	0.0116
$\sigma_{\epsilon_t^r}$	Policy rate	uniform	0.25	0.1	0.0776	0.0799	0.068	0.0917
$\sigma_{\epsilon_t^{\zeta_e}}$	Entrepreneurs survival	uniform	0.5	0.3	0.1722	0.1788	0.1559	0.201
$\sigma_{\epsilon_t^{\zeta_b}}$	Bankers survival	uniform	5	2.9	0.2015	0.2371	0.1076	0.3609

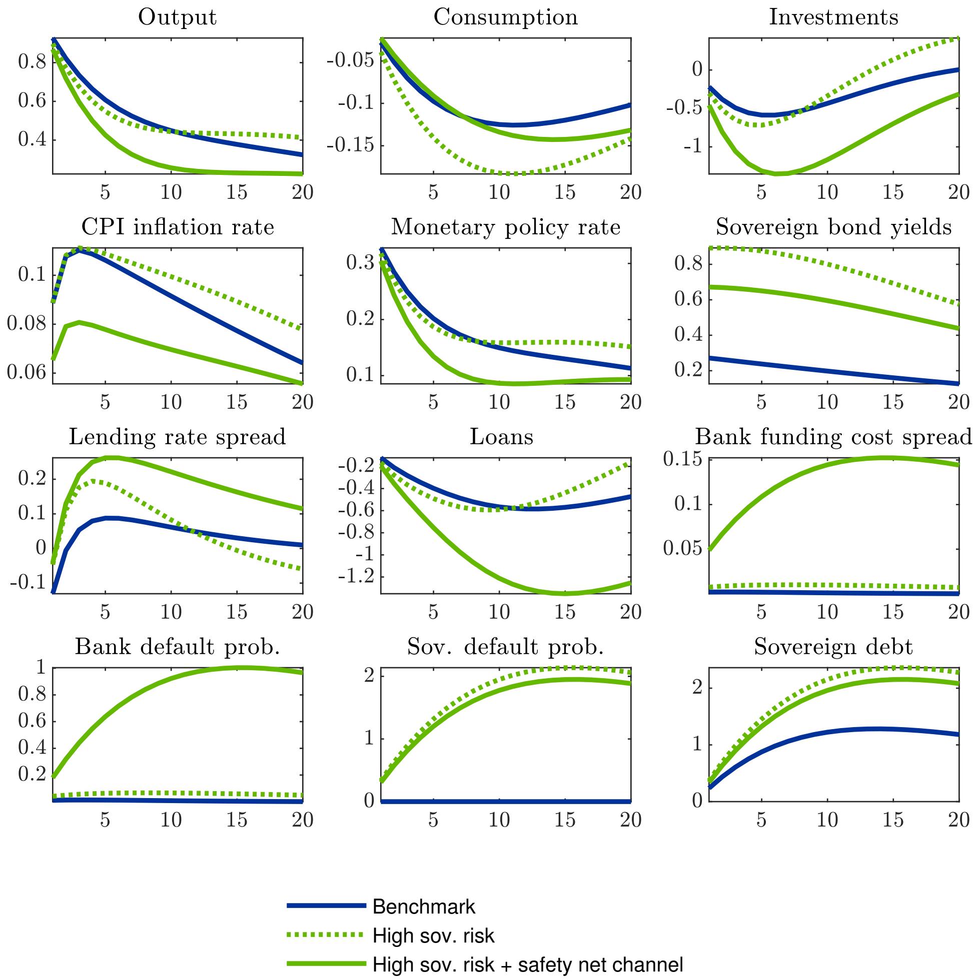
Figure 4: Public spending shock: parameter uncertainty



Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. The blue line refers to the mean 1995-2019 random parameter draw from the MCMC (after burn-in). The uncertainty bands around this mean cover 68% (dark grey) and 80% (light grey). The green line refers to the shorter sample mean 1995-2014, where parameters are randomly draw from the MCMC (after burn-in). Horizontal axis: in quarters. Vertical axis: Output, consumption, and investments are expressed in percentage deviations from the steady-state baseline. Sovereign debt is kept constant for the estimation. All other variables are presented in annual percentage point deviations. The lending rate is shown as spread w.r.t the policy rate.

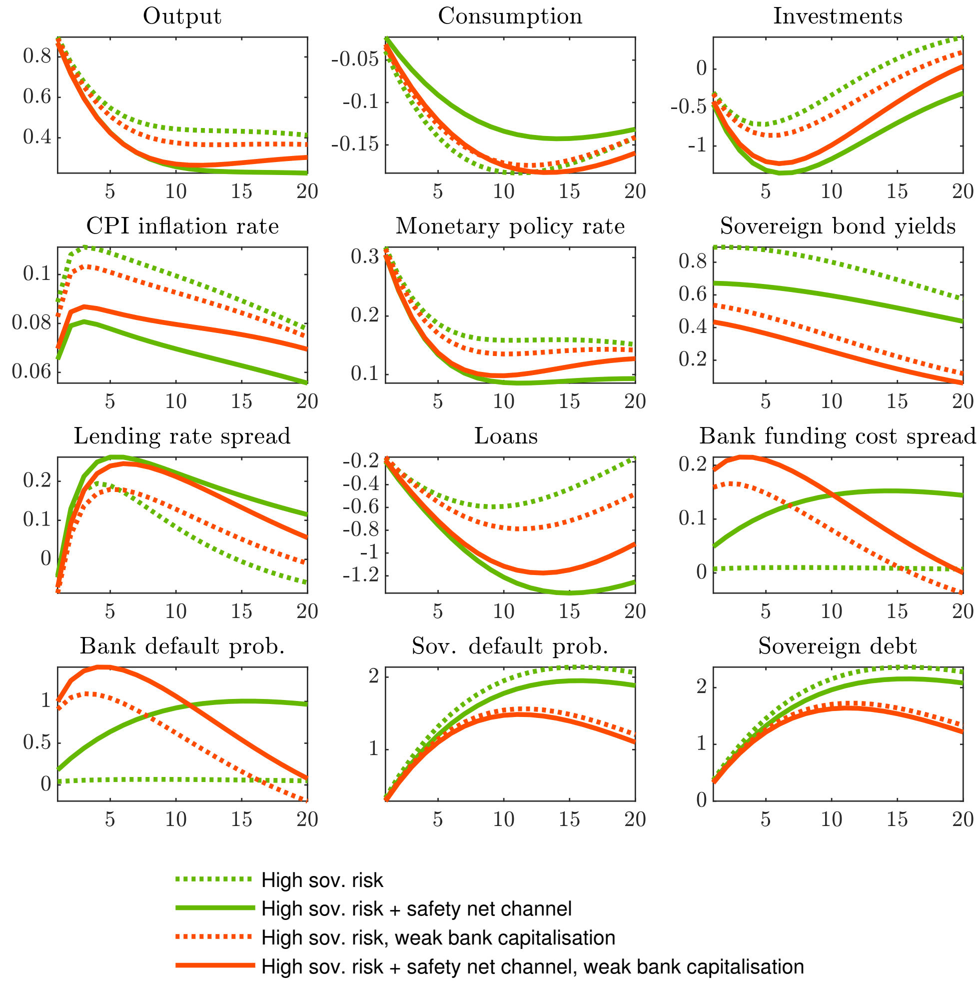
B Simulation results

Figure 5: Public spending shock: the sovereign-bank-nexus with safe banks



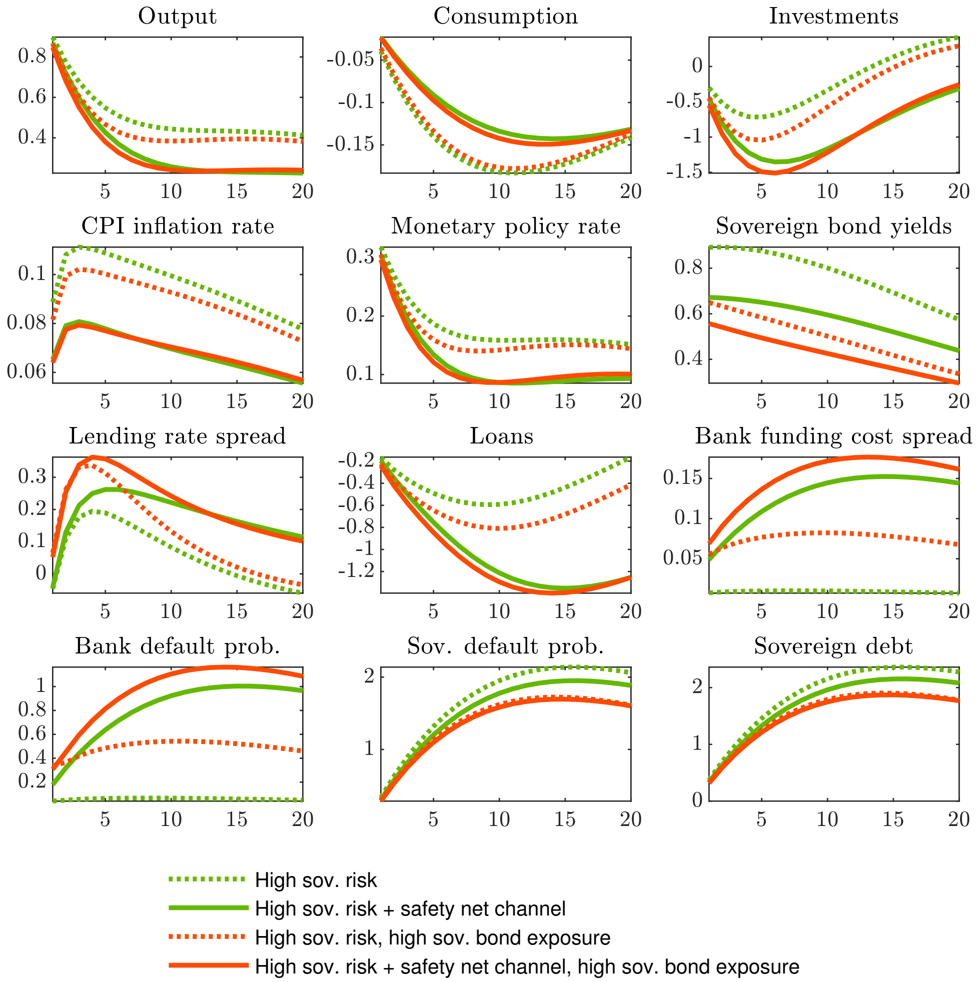
Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. The bank and the sovereign default probabilities are denoted in annualized percentage point deviations. Sovereign debt is shown as deviations of the annulized debt-to-GDP ratio to its steady state. All other variables are presented in annualized percentage point deviations. The lending rate and the bank's funding cost rate is shown as spread against the monetary policy rate.

Figure 6: Public spending shock: fragile banks with low capital requirements



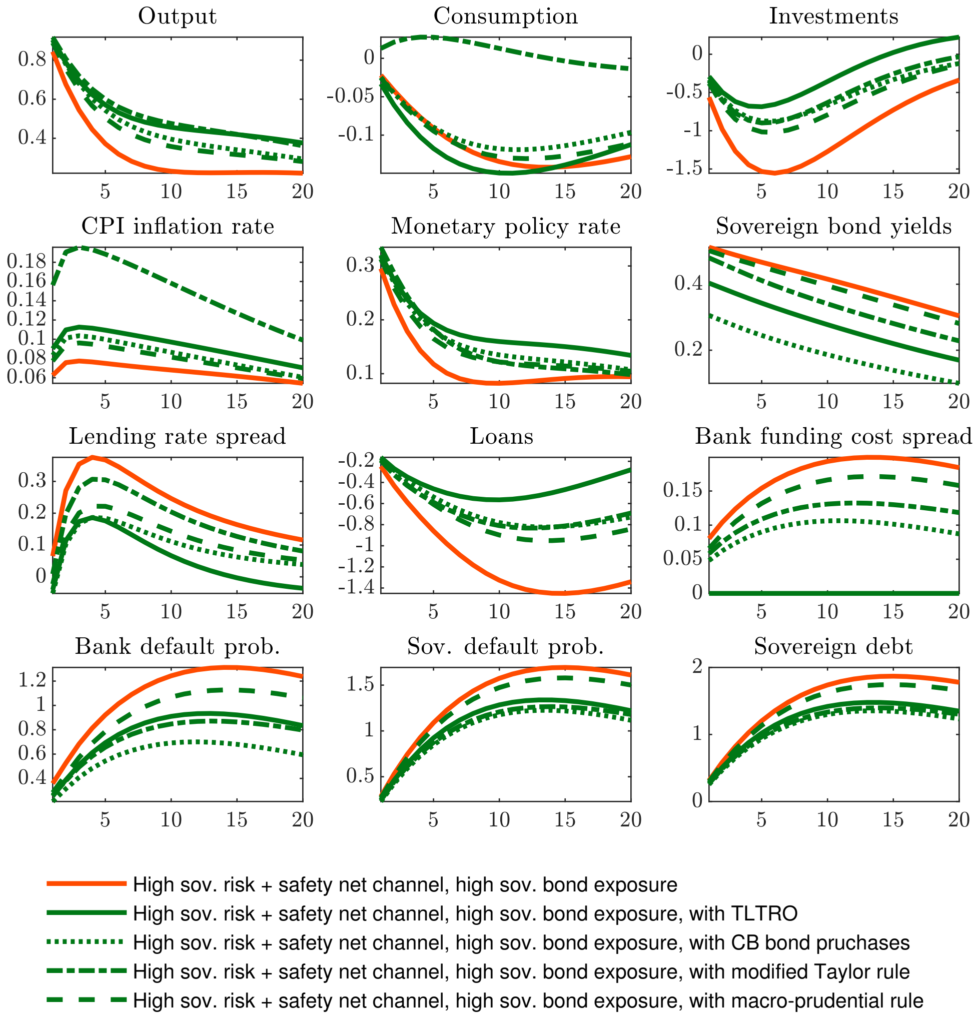
Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. The bank and the sovereign default probabilities are denoted in annualized percentage point deviations. Sovereign debt is shown as deviations of the annulized debt-to-GDP ratio to its steady state. All other variables are presented in annualized percentage point deviations. The lending rate and the bank's funding cost rate is shown as spread against the monetary policy rate.

Figure 7: Public spending shock: fragile banks with high sovereign bond exposure



Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. The bank and the sovereign default probabilities are denoted in annualized percentage point deviations. Sovereign debt is shown as deviations of the annulized debt-to-GDP ratio to its steady state. All other variables are presented in annualized percentage point deviations. The lending rate and the bank's funding cost rate is shown as spread against the monetary policy rate.

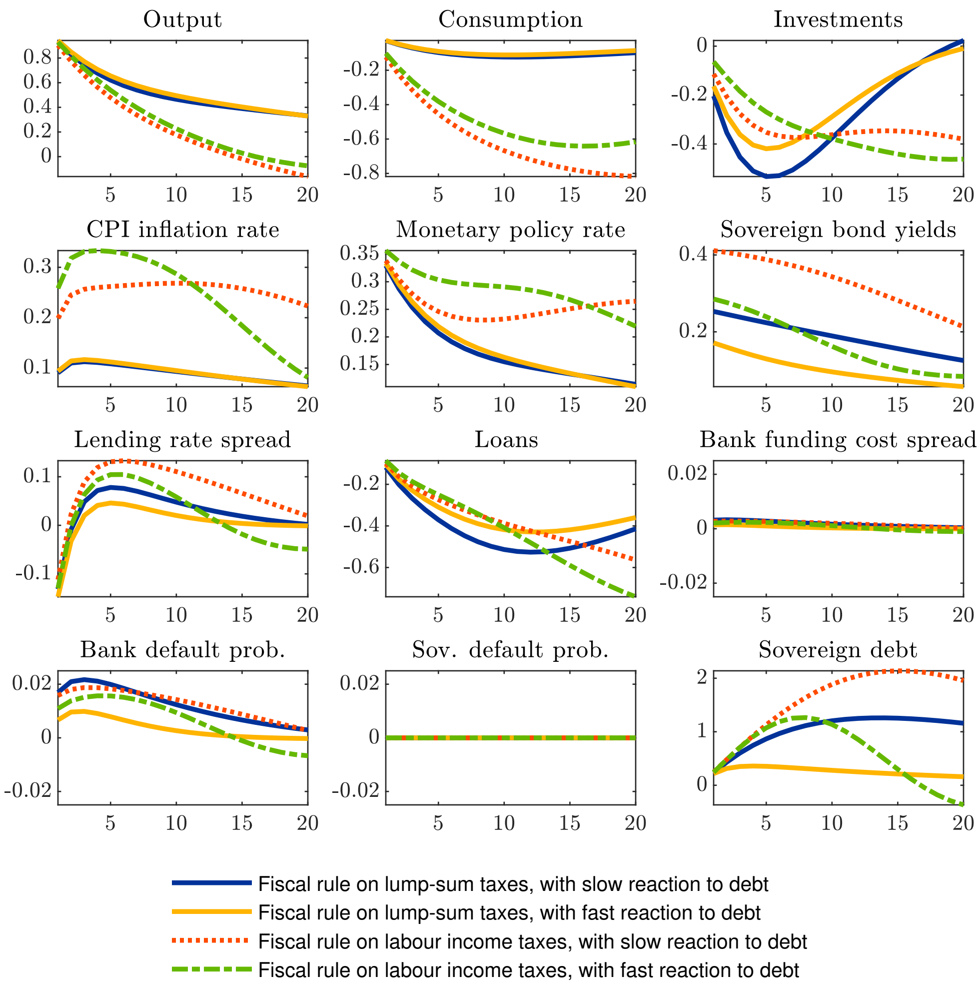
Figure 8: Public spending shock: policy responses to sovereign-bank feedbacks



Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. The bank and the sovereign default probabilities are denoted in annualized percentage point deviations. Sovereign debt is shown as deviations of the annulized debt-to-GDP ratio to its steady state. All other variables are presented in annualized percentage point deviations. The lending rate and the bank's funding cost rate is shown as spread against the monetary policy rate.

C Background simulations

Figure A1: Design of the fiscal expansion experiment: different debt stabilization rules

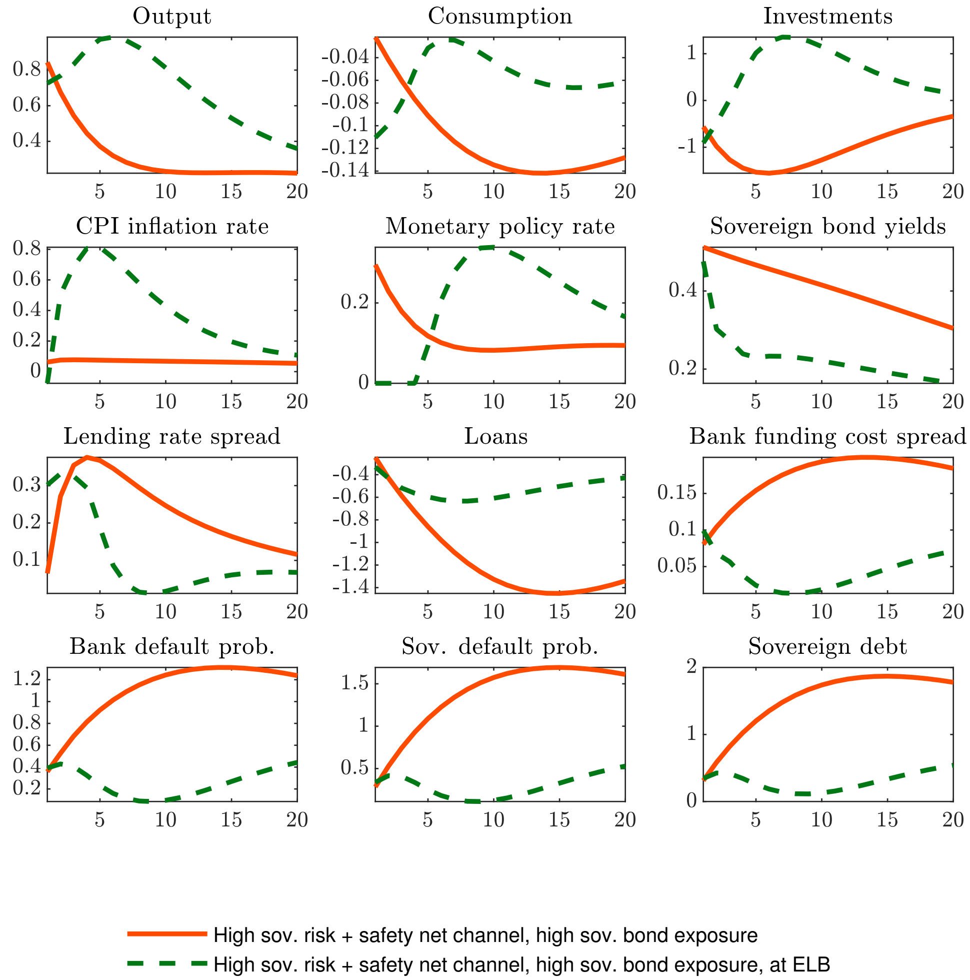


Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. The bank and the sovereign default probabilities are denoted in annualized percentage point deviations. Sovereign debt is shown as deviations of the annulized debt-to-GDP ratio to its steady state. All other variables are presented in annualized percentage point deviations. The lending rate and the bank's funding cost rate is shown as spread against the monetary policy rate.

Table A1: Parameter estimates - restricted sample: 1995Q1 to 2014Q4

Parameters			Prior		Posterior			
		Dist.	Mean	Std.	Mode	Mean	-45%	+45%
η	Habit formation	normal	0.7	0.1	0.795	0.802	0.734	0.873
σ_c	Intertemp. elasticity of subst.	gamma	1.5	0.2	1.815	1.755	1.423	2.090
σ_l	Labor disutility	gamma	2	0.75	1.047	1.323	0.483	2.136
r_β	Rate of time preference	gamma	0.25	0.1	0.098	0.117	0.046	0.186
φ	Cap. utilization adj. cost	beta	0.5	0.15	0.175	0.243	0.061	0.422
ϕ	Investment adj. cost	normal	4	1.5	3.617	3.833	2.370	5.298
γ	Trend productivity	gamma	0.3	0.1	0.144	0.151	0.097	0.200
α	Capital share	normal	0.3	0.05	0.403	0.386	0.332	0.439
λ_e	Employment adj. cost	beta	0.5	0.28	0.864	0.856	0.816	0.896
$\overline{L}$	Employment shift	normal	0	5	0.099	0.035	-2.718	2.836
ξ_p	Calvo lottery, price setting	beta	0.5	0.1	0.779	0.743	0.628	0.857
α_p	Indexation, price setting	beta	0.5	0.15	0.257	0.277	0.111	0.436
μ_p	Price markup	normal	1.25	0.12	1.491	1.509	1.344	1.675
ξ_w	Calvo lottery, wage setting	beta	0.5	0.1	0.623	0.646	0.528	0.763
α_w	Indexation, wage setting	beta	0.5	0.15	0.217	0.246	0.103	0.384
$\overline{\pi}$	SS inflation rate	gamma	0.5	0.05	0.557	0.555	0.474	0.638
ξ_E^R	Calvo lottery, lending rate	beta	0.5	0.25	0.487	0.482	0.425	0.540
ρ	Interest rate smoothing	beta	0.75	0.1	0.921	0.921	0.903	0.939
r_π	Taylor rule coef. on inflation	normal	1.5	0.25	1.693	1.759	1.449	2.067
$r_{\Delta Y}$	Taylor rule coef. on Δ(output)	normal	0.12	0.05	0.095	0.092	0.070	0.114
$r_{\Delta\pi}$	Taylor rule coef. on Δ(inflation)	gamma	0.3	0.1	0.049	0.054	0.028	0.078
AR or ARMA coefficients of exogenous shock processes								
ρ_a	AR(1) Technology	beta	0.5	0.25	0.915	0.908	0.861	0.956
ρ_I	AR(1) Inv. Technology	beta	0.5	0.2	0.722	0.594	0.265	0.870
ρ_g	AR(1) Gov. spending	beta	0.5	0.25	0.995	0.992	0.984	1.000
ρ_b	AR(1) Preference	beta	0.5	0.25	0.200	0.284	0.050	0.496
ρ_p	AR(1) Price markup	beta	0.5	0.2	0.746	0.750	0.559	1.000
η_p	MA(1) Price markup	beta	0.5	0.2	0.570	0.552	0.249	0.890
ρ_w	AR(1) Wage markup	beta	0.5	0.2	0.944	0.927	0.885	0.969
ρ_{σ_e}	AR(1) entrepr. risk	beta	0.9	0.05	0.938	0.931	0.893	0.973
ρ_{R_G}	AR(1) Gov. bond valuation	beta	0.5	0.2	0.990	0.981	0.963	0.999
ρ_{ζ_b}	AR(1) Bankers survival	beta	0.5	0.2	0.502	0.429	0.132	0.731
ρ_{ζ_e}	AR(1) Entrepreneurs survival	beta	0.5	0.2	0.617	0.608	0.431	0.786
$\rho_{g,a}$	Corr(Technology, Gov. spending)	uniform	4.5	3.1754	0.488	0.593	-0.109	1.305
Standard deviations of exogenous shock processes								
$\sigma_{\epsilon_t^a}$	Technology	uniform	5	2.9	0.770	0.775	0.455	1.090
$\sigma_{\epsilon_t^I}$	Inv. Technology	uniform	10	5.8	2.266	2.239	0.634	3.913
$\sigma_{\epsilon_t^g}$	Gov. spending	uniform	5	2.9	1.748	1.803	1.560	2.045
$\sigma_{\epsilon_t^b}$	Preference	uniform	5	2.9	2.601	2.876	1.888	3.875
$\sigma_{\epsilon_t^p}$	Price markup	uniform	0.25	0.1	0.157	0.162	0.121	0.203
$\sigma_{\epsilon_t^w}$	Wage markup	uniform	0.25	0.1	0.055	0.060	0.041	0.079
$\sigma_{\epsilon_t^{\sigma_e}}$	Entrepreneurs risk	uniform	10	5.8	0.078	0.092	0.052	0.131
$\sigma_{\epsilon_t^{R_G}}$	Gov. bond valuation	uniform	0.5	0.3	0.009	0.010	0.007	0.014
$\sigma_{\epsilon_t^r}$	Policy rate	uniform	0.25	0.1	0.086	0.089	0.075	0.103
$\sigma_{\epsilon_t^{\zeta_e}}$	Entrepreneurs survival	uniform	0.5	0.3	0.174	0.183	0.156	0.210
$\sigma_{\epsilon_t^{\zeta_b}}$	Bankers survival	uniform	5	2.9	0.211	0.246	0.110	0.378

Figure A2: Public spending shock: monetary policy rate at the Effective Lower Bound



Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. The bank and the sovereign default probabilities are denoted in annualized percentage point deviations. Sovereign debt is shown as deviations of the annulized debt-to-GDP ratio to its steady state. All other variables are presented in annualized percentage point deviations. The lending rate and the bank's funding cost rate is shown as spread against the monetary policy rate.