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Fiscal multipliers with financial fragmentation risk and interactions with monetary policy

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Abstract

We quantify the size of fiscal multipliers under financial fragmentation risk and demonstrate how non-standard monetary policy can support the macroeconomic transmission of fiscal interventions. We employ a DSGE model with financial frictions whereby the interplay of corporate, banks and sovereign solvency risk affect the transmission of fiscal policy. The output multiplier of fiscal expansion is found to be significantly dampened by tighter financial conditions in case households are less certain about implicit and explicit state-guarantees for the banking system, or banks are weakly capitalized and highly exposed to the government sector. In this context, we show that central bank asset purchases or liquidity operations designed to ensure favourable bank funding conditions can restore fiscal multipliers.

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

JEL classification: E44, E52, E62.

Non-technical summary

Understanding the effectiveness of fiscal policy intervention is crucial in the current environment. With Europe facing a major downturn triggered by the outbreak of the Coronavirus and the implementation of measures to contain its spread, active fiscal stabilization is called for. While it is widely accepted that fiscal automatic stabilizers need to play in order to cushion economic shocks and mitigate the effect of cyclical movements on output and employment, it is the experience since the previous crisis in Europe that active fiscal intervention to support the economy is necessary to cushion unusually large shocks. On the one hand, discretionary fiscal action can be considered as especially effective in the current environment of low interest rates but on the other hand fiscal spending creates additional sovereign debt with the risk of financial fragmentation given heterogeneous debt levels across member states. At the same time, since the outbreak of the sovereign debt crisis, the European Central Bank established various tools to prevent financial fragmentation.

We develop a dynamic stochastic general equilibrium (DSGE) model to investigate these fiscal-financial interactions and show that monetary policy measures can mitigate impediments for fiscal policy to fulfil its stabilization function. In the model, an endogenous sovereign-bank-nexus arises via two channels. 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. Altogether, our specification of the sovereign-bank nexus opens up for a transmission mechanism between sovereign risk, bank risk and bank lending conditions to the real economy.

We then proceed by investigating how fiscal stabilization under the sovereign-bank nexus interacts with monetary policy. First, we evaluate a fiscal stimulus in an economy sensitive to sovereign debt levels and with a fragile banking sector in a situation where the policy rate is constrained at the Effective Lower Bound. Typically, standard New Keynesian quantification features very high fiscal multipliers when the nominal policy rate is fixed. We show that a strong sovereign-bank-nexus has the potential to depress the multiplier considerably. Thereafter, we highlight the scope for non-standard monetary policy interventions to contain the sovereign-bank nexus distortions and help restore fiscal multipliers: central bank asset purchase programmes limit the rise in sovereign spreads to start with and exert easing pressures on bank lending conditions through a portfolio rebalancing channel. Besides, non-standard measures that are targeted directly at supporting bank funding such as the TLTRO programmes of the European Central Bank, prove effective in mitigating the pass-through of sovereign risk to the banking sector. Depending on the calibration, these policies can partially or fully restore fiscal multipliers to a baseline size without sovereign-bank-nexus.

1 Introduction

The interaction of fiscal and monetary policy within the euro area is the subject of an active research and policy debate, notably as Europe faces the Covid-19 crisis and fiscal stabilization is called on the front line. Although it is commonly accepted that automatic fiscal stabilizers are superior to discretionary action, as the latter has an implementation lag and therefore might fail acting as counter-cyclical cushioning (Taylor (2000)), discretionary fiscal policy actions become of the essence in crisis time.

Due to the institutional design of the euro area, understanding the mechanics of fiscal stabilization under various layers of financial and sovereign risk is warranted. The euro area might indeed be prone to financial fragmentation risk whereby sovereign default risk and bank default risk becomes excessively intertwined. In this case, fiscal expansions can trigger a tightening of financial conditions which hampers its transmission to the economy. The sovereign debt crisis has shown that public sector solvency concerns have particularly adverse effects on the economy if tensions meet a fragile financial sector. Figure 2 shows that sovereign and bank sector risk is correlated to some extend (as measured by CDS pricing). Indeed this relationship has been especially strong during the sovereign debt crisis years of 2011 and 2012 (see Figure 3) and particularly so for some euro area member states. More recently, following the March 2018 elections in Italy, the announcement of a fiscal package was accompanied by a marked increase in yields on Italian sovereign bonds in Autumn 2018 (see Figure 1).

Against this background, this paper focuses on two aspects: a) the presence of financial fragmentation risks in the euro area which may hamper the effectiveness of fiscal interventions and b) the scope for non-standard monetary policy measures to mitigate such risks and support the fiscal stabilization objective.

We propose a dynamic stochastic general equilibrium (DSGE) model which can account for feedback loop 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)). We highlight another source of multiplier variation that is due to the sovereign-bank-nexus. We build on the model of Darracq Pariès et al. (2016) and Darracq Pariès et al. (2019), which qualifies for analysing the transmission mechanisms of fiscal shocks through the financial sector because it incorporates a risky banking sector with the presence of an endogenous stochastic public debt limit. In our model, an endogenous sovereign-bank-nexus arises through two channels (see also Dell'Ariccia et al. (2018) for a deeper discussion). 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. Altogether, our specification of the sovereign-bank nexus opens up for a transmission mechanism between sovereign risk, bank risk and bank lending conditions to the real economy.

More specifically, the model describes the euro area as a closed economy, featuring a rich set of real and financial frictions, including banker's limited liability due to deposit insurance and macro-prudential regulation that pins down bank's portfolio decisions. Financial intermediaries face idiosyncratic shocks determining default risk depending on individual bank's asset position and the financing thereof. Interacting with the financial sector, the model features a government sector with long-term debt securities and distortionary tax instruments. The government exhibits default risk proportional to its sovereign debt-to-GDP level, for which investors demand compensation. Finally, monetary policy follows a standard Taylor-type rule if unconstrained but can also intervene via asset purchases.

The main contribution of the paper is to evaluate the effectiveness of fiscal stimulus in the presence of financial fragmentation risk and assess the interactions with monetary policy. First, we show that the sovereign-bank-nexus has the potential to considerably depress fiscal multipliers, also when the monetary policy rate is constrained at the ELB. The sovereign risk channel of fiscal interventions 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. In this context, we show that non-standard monetary policy interventions can contain the sovereign-bank nexus distortions and help restore fiscal multipliers: central bank asset purchase programmes limit the rise in sovereign spreads to start with and exert easing pressures on bank lending conditions through a portfolio rebalancing channel. Besides, non-standard measures that are targeted directly at supporting bank funding such as the TLTRO programmes of the European Central Bank, prove effective in mitigating the pass-through of sovereign risk to the banking sector. Depending on the calibration, these policies can partially or fully restore fiscal multipliers to a baseline size without sovereign-bank-nexus.

Our 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 particular, as monetary policy rate cuts brought nominal interest rates to the ELB, DSGE models find fiscal multipliers for small spending increases to exceed 1 (e.g. Christiano et al. (2011), Erceg and Lindé (2014)). The ELB actually prevents standard crowding out of consumption and investment. Furthermore, fiscal policy can be thought of being especially effective during a period of financial distress when more households face borrowing constraints (e.g. in Auerbach and Gale (2009)). Besides, 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)).

The discussion on the possibility of high multipliers of fiscal spending is largely driven by the US experience in the literature. For example, Blanchard, Olivier J. (2019) recently highlighted again that in the long-term nominal economic growth exceeds the rate of return on safe assets. Therefore, if repayment of government bonds is credibly committed, public debt financing poses only little economic cost. In a European context, the global financial crisis showed that investors may fundamentally revalue their perception of sovereign risk. Following these experiences, the presence of stochastic fiscal limits in structural models has been introduced 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 asked by investors as government debt approaches some abstract limit without the default to actually occur.

The literature on the nexus between the sovereign risk and bank risk is well documented empirically (e.g. Schnabel and Schüwer (2017)). On the theoretical side, the literature distinguishes two channels of sovereign risk translating into tension for the banking sector. First, financial intermediaries are themselves bond investors and funding costs increase when government bond yields increase. Second, lenders revalue the risk of default of their counter-parties in the economy as higher government default increases systemic country risk. Both channels lead banks to increase their lending rates, which adversely affects the real economy as households and firms face higher borrowing costs. Recent exposition of such models can be found for example in Bocola, Luigi (2016) and Ester Faia (2017). Note that the pressure on activity due to tighter borrowing conditions in turn leads to repricing of sovereign risk in models with endogenous fiscal limits, thereby completing the feedback loop.

The rest of the paper is structured as follows. Section 2 presents the theoretical model, while Section 3 discusses the benchmark calibration and the calibration of sovereign risk, bank fragility and the sovereign-bank nexus. Section 4 discusses the model results and mechanics of a fiscal expansion shock under a sovereign-bank-nexus with Subsection 4.1 clarifying the experiment set-up, Subsection 4.2 introducing concepts of sovereign risk and the safety net channel, Subsection 4.3 focuses on the endogenous sovereign-bank-nexus mechanics due to sovereign bond exposure and Subsection 4.4 discussing the role of bank fragility. Section 5 discussed the interaction of fiscal stabilization with monetary policy and 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 had sovereign risk as well as a sovereign-banking nexus. The model consists of households, intermediate labour unions and labour packers, intermediate and final goods-producing firms, capital producers and non-financial firms (called entrepreneurs) investing into capital projects. Since households cannot provide their savings directly to the real sector, the model also consists of banks who intermediate these funds to the projects of non-financial firms. Both entrepreneurs and banks are exposed to endogenous borrowing constraints. Due to the fact that 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 labour 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 as 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 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 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 $B_t^{rf}(h)$, 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 labour $N_t^S(h)$. 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, the risk-free bond, deposit and government bond holdings are identical and its first order conditions, respectively, are as follows

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

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

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

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

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

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 the households and is segmented in various parts. First, bankers collect household deposits and provide funds to the retail lending branches. In doing so, they face capital requirements which are sensitive to the riskiness of the loan contract, forcing them to hoard a sufficient level of equity and benefiting 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 the bankers and allocate it to the 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 extent 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's 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 banker over 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 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

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

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

$$\overline{\omega}_{b,t+1} \equiv \frac{R_{D,t}\left(\kappa_{B,t}^{l}+\kappa_{B,t}^{g}-1\right)-R_{G,t+1}\kappa_{B,t}^{g}-\frac{\Pi_{B,t+1}^{R}}{NW_{B,t}}+\varrho_{t}}{\kappa_{B,t}^{l}R_{BLE,t}}. \tag{16}$$

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

$$\Omega_{b,t} \equiv \left[\overline{\omega}_{b,t}-\Gamma_{b}\left(\overline{\omega}_{b,t}\right)+\mu_{b}\int_{0}^{\overline{\omega}_{b,t}}\omega \mathrm{d}F_{b}\left(\omega\right)\right]R_{BLE,t}L_{BE,t} \tag{17}$$

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

$$\Gamma_{b}(\overline{\omega}) \equiv (1-F_{b}\left(\overline{\omega}\right))\overline{\omega}+\int_{0}^{\overline{\omega}}\omega \mathrm{d}F_{b}\left(\omega\right). \tag{18}$$

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

$$OP_{t+1}^{b} > \nu_{b}\left(\omega_{b,t+1}R_{BLE,t}L_{BE,t}\right)+\nu_{g}\left(R_{G,t+1}Q_{B,t}B_{B,t}\right) \tag{20}$$

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

In order to minimise 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 is endogenously determined by each bank.

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

$$\overline{\omega}_{b,t+1}^{\nu} \equiv \frac{R_{D,t}\left(\kappa_{B,t}^{l}+\kappa_{B,t}^{g}-1\right)-\left(1-\nu_{g}\right)R_{G,t+1}\kappa_{B,t}^{g}-\frac{\Pi_{B,t+1}^{R}}{NW_{B,t}}+\frac{1}{2}\chi_{B}\left(\kappa_{B,t}^{g}-\overline{\kappa}_{B}^{g}\right)^{2}}{\left(1-\nu_{b}\right)\kappa_{B,t}^{l}R_{BLE,t}}. \tag{21}$$

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

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

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 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 a idiosyncratic "*run-type*" liquidity risk with probability $p^{\xi_G}_B$ of materialising. 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

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

The first order conditions for this problem are then given by

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

and

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

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 is given by

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

2.2.2 Retail lending branches and loan officers

A continuum of retail lending branches indexed by j provide 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 that the volume of the loans they provide to the entrepreneurs equals the volume of funding they receive. Therefore, they seek to maximise its 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 entrepreneurs over 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 becomes 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 household. 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 from 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 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 entrepreneurs' 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 realisation of the idiosyncratic shock unless they pay a monitoring cost μ_e per unit of assets that can be transferred

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

[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

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

to the bank in case of default. The set of lending contracts available to entrepreneurs is constraint, 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 realised, default will happen for draws of the idiosyncratic shock below a certain threshold $\overline{\omega}_{e,t}$, given by

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

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 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

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

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

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

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

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

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

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

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

$$\Gamma_e'(\overline{\omega}) = (1-F_e\left(\overline{\omega}\right)) \text{ and } G_e'(\overline{\omega}) = (1-F_e\left(\overline{\omega}\right)) - \mu_e\overline{\omega}\mathrm{d}F_e\left(\overline{\omega}\right). \tag{45}$$

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 entrepreneurs' net worth is given by

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

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

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

subject to the constraint

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

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

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

[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 $R_{KK,t}$.

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

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 labour $N_t^D(z)$ on a competitive market by minimising its production cost. Due to our assumptions on the labour market and the rental rate of capital, the real marginal cost is identical across producers. The model also introduces a time varying tax on firm's 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-optimise its price, the nominal price evolves according to the following rule

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

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-optimise 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 production 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

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

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

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

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 μ_p is determined based on the Lagrange multiplier on the constraint.

2.6 Intermediate labour unions and labour packers

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

Intermediate goods-producing firms make use of a labour input N_t^D produced by a segment of labour packers. Those labour packers operate in a competitive environment and aggregate a continuum of differentiated labour 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 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 labour inputs and the curvature of the demand curve in the wage market, respectively. The wage mark-up μ_w is determined based on the Lagrange multiplier on the constraint.[5]

Each labour union is a monopoly supplier of a differentiated labour 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 labour services.

The aggregate real wage (expressed in effective terms) that intermediate producers pay for the labour input provided by the labour 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 maximise their intertemporal profit under the labour demand from labour packers. In the case that unions cannot re-optimise, 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 is affected by an independent and identically distributed shock, ε_t^w defined as follows

$$\varepsilon_t^w = \frac{1-\tau_{w,t}}{1-\overline{\tau}_w}. \tag{59}$$

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

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

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. 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 labour 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 accordingly as below

$$Q_{B,t}B_{G,t} = \frac{R_{G,t}}{\pi_t} Q_{B,t-1}B_{G,t-1}/\gamma + G^\star \varepsilon_t^g - \tau_{w,t}w_t L_t - \tau_{p,t}Y_t - T_t + \Omega_{b,t}. \tag{60}$$

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

$$T_t - \overline{T} = \rho_T(T_{t-1} - \overline{T}) + (1-\rho_T)\phi_T(\frac{B_{G,t}}{\overline{Y}} - \frac{\overline{B}}{\overline{Y}}) \tag{61}$$

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

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, openning up a sovereign risk channel which raises the cost of financial intermediation, as described in Section 2.2.

More explicitly, sovereign default is operationalised 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 each period the limit will be drawn from a logistic distribution, defined as follows

$$p_t^{\xi_G} \equiv \frac{exp\,(-\eta_1 + \eta_2 B_{Y,t})}{1 + exp\,(-\eta_1 + \eta_2 B_{Y,t})} \tag{62}$$

where $p_t^{\xi_G}$ is the *ex ante* probability of a default, $B_{Y,t} = \frac{B_t}{4Y_t}$ is the annual debt-to-GDP 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

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

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

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

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 riskfree rate R_t. Similar to Smets and Wouters (2007), the central bank policy follows an interest rate rule given by

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

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 labour and 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 Labour market

Equilibrium in the labour 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 holds

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

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 and bankers.

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

3 Calibration

The calibration of the model is largely based on Darracq Pariès et al. (2019) where the authors estimate on euro area data a medium-scale DSGE which correspond to the model of this paper in the absence of sovereign risk and with constant stock of public debt. Further empirical validation of the model with its new features is beyond the scope of the paper. The benchmark calibration from Darracq Pariès et al. (2019) brings realistic enough propagation mechanism for the euro area and we explore the implications of alternative calibration for sovereign risk, bank fragility and sovereign-bank nexus. The parameters of the calibration consistent with Darracq Pariès et al. (2019) are reported in Tables 1 and 2.

3.1 Benchmark calibration

Like in Smets and Wouters (2007), some parameters are treated as fixed in the estimation. The depreciation rate of the capital stock δ is set at 0.025 and the share of government spending in output at 18%. The steady state labour market markup is fixed at 1.5 and the curvature parameter of the Kimball aggregators is set at 10.

The ratio of banks' holdings of government bonds to their loan book, $\alpha_B = \frac{\kappa_B^g}{\kappa_B^l}$, is set at 12%, in line with aggregate BSI statistics from the ECB.

Starting with the entrepreneurs, we target default frequencies for firms of 0.7% and a credit risk compensation on corporate loans of 50 bps (in annual terms) which broadly corresponds to one third of the sample mean of the lending spreads. The external finance premium $100\left(\frac{R_{KK}}{R_{LE}} - 1\right)$ is set at 200 bps (in annual terms). We also aim at a matching a credit to GDP ratio consistent with the loan data under consideration. 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 the entrepreneurs survival probability ζ_e. We assume that the additional transfers to new entrepreneurs, Ψ_E, are null.

Turning to the bankers, we calibrate the standard deviation of the idiosyncratic shock σ_b so that the annual percentage of banks violating the minimum capital adequacy ratio is approximately equal to 15%, corresponding to a 4% per quarter as in Benes and Kumhof (2015). The bank resolution cost, μ_b, is calibrated to 0.3. The minimum capital requirements, ν_b, is set to 8% while the steady-state capital ratio of bankers is set approximately to 13%. A symmetric capital buffer of around 4-4.5% is consistent with available empirical evidence over the post-crisis period. Furthermore, we calibrate regulatory penalty, χ_b, such that in the steady state, the bank capital wedge which is the spread over and above the funding cost is equal to 150 basis points (in annual terms). The continuation probability of bankers, ζ_b, ensures that in the steady state, the return on equity is 20% (gross of operating costs and other costs which are not accounted for in our model but represent at least half of the net operating income in the euro area). The transfers to new bankers, Ψ_B, clear the net worth accumulation equation for given spreads and capital ratio. This calibration leads to a negligible steady-state probability of bankers defaulting. In this context, the limited liability distortions become almost irrelevant.

Darracq Pariès et al. (2019) consider 9 key macroeconomic quarterly time series from 1995q1 to 2014q2: output, consumption, fixed investment, hours worked, real wages, the GDP deflator inflation rate, the three-month short-term interest rate, bank lending spreads and the (weighted) 10-year euro area sovereign spread. The data are *not* filtered prior to the estimation.[8]

The number of shocks is equal to the number of observed variables[9]: shocks on technology

[8] Data for GDP, 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 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 Euro area aggregate series have been weighted using corresponding loan volumes (outstanding amounts) by country.

[9] 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

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 $\epsilon_t^{R_G}$ and on the monetary policy rule ϵ_t^r.

For the estimation, the quarterly growth rate of GDP, consumption, investment and loans, are all expressed in real terms and divided by working age population. The employment variable is also divided by 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 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, 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.

While the competitive margin in the retail banking segment is set 60 bps (in annual terms), the Calvo lottery parameter related to retail lending rate setting, ξ_E^R, is estimated at around 0.5.

Given the capital structure of the banking system, the steady state level of sovereign spread, $(R_G - R_D)$, is jointly determined with r_B through the bankers first order conditions for bond holdings and loan origination. In the baseline calibration, the sovereign spread is at 120 basis points (in annual terms). 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 is adjusted to ensure that the steady state sovereign bond price Q_B equals 1. 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.

Regarding adjustment cost parameters on the holding of sovereign securities for both households, χ_H, and bankers, χ_B, Darracq Pariès et al. (2019) set them so that the transmission of a central bank asset purchase programme like the ECB's January 2015 announcement displays the relevant stylised features found in the literature. In particular, 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.

Regarding the other structural parameters, most of the estimates match with values in the literature and are commented in greater details in Darracq Pariès et al. (2019).

3.2 Calibration of sovereign risk, bank fragility and sovereign-bank nexus

The fiscal authority uses lump-sum taxes to stabilize public debt in the long-run. The parametrisation is set to $\rho_T = 0$ and $\phi_T = 0.1$ such that the fiscal rule reacts slowly to debt build-up and has no persistence. Figure 12 investigates different fiscal rules as alternative sensitivity. By choosing a relatively passive fiscal rule we allow for some build-up in public debt after a fiscal expansion. By choosing the lump-sum tax instrument any tax increases necessary to bring back public debt to its steady state in the future will not be distortive.

form $\log(\varepsilon_t^x) = \rho_x \log(\varepsilon_{t-1}^x) - \eta_x \epsilon_{t-1}^x + \epsilon_t^x$. All shock processes ε_t^x are equal to one in the steady state.

We label the benchmark calibration outline until now as 'No sov. default'. Next, we open structural channels one by one by changing key parameters related to sovereign and bank riskiness. An overview is shown in Table 3. Turning first to sovereign default risk, we calibrate the parameters of the logistic distribution which links the probability of default of the government to the public debt-to-GDP level with location parameter η_1 and scale parameter η_2. We calibrate both parameters by mapping them with two endogenous variables of the model. The first being the average level of sovereign risk premium as observed from the ten-year credit default swaps. The second is the sensitivity of the sovereign government bond spread to a 1% increase in the debt-to-GDP ratio. These elasticities are based on euro area country results from Borgy et al. (2011). The level of haircut, $\xi_G^{\max}$, in case of sovereign default, is calibrated symmetrically across countries to 0.37, which according to Cruces and Trebesch (2013) corresponds to the median haircut calculated from a sample of sovereign debt re-structuring between 1970 and 2010. Following this calibration strategy, we present three cases to illustrate the importance of the debt-to-GDP level and the spread sensitivity. Figure 4 demonstrates how the different configurations determine the probability of default and the curvature of the logistic function at the steady state. The first case labelled EA calibration represents a low debt, low sovereign spread, low spread sensitivity scenario. It considers a debt-to-GDP ratio of 77.81% and an annualised sovereign bond spread of 80bps, both averages of observable values across time and countries. The sovereign bond spread sensitivity is set to 12bps per 1pp increase in debt-to-GDP, a cross-country average following the study above. As second case, we choose a calibration resembling Italy in normal times, with a debt-to-GDP ratio of 115.02% and an annualised sovereign bond spread of 205bps. The sovereign bond spread sensitivity, according to the study above, is set to 23bps per 1pp increase in debt-to-GDP. Finally, we illustrate a vulnerable country scenario with debt levels and sovereign spreads as before, but setting the spread sensitivity to 40bps per 1pp increase in debt-to-GDP. This reflects a market condition, where financial investors strongly react to an increase in perceived risk of no repayment in the face of macroeconomic or political tensions. The resulting values for the logistic distribution are $\eta_1 = 16$ and $\eta_2 = 14$ for case 1, $\eta_1 = 16.6$ and $\eta_2 = 10.7$ for case 2 and $\eta_1 = 25$ and $\eta_2 = 18$ for case 3. We choose the later case as calibration for what is labelled 'Sov. default' in the following analysis.

There are two key parameters in calibrating the pass-through of sovereign default risk to the macro-economy, i.e. the core of the sovereign-bank-nexus. First, bank default risk can be associated with a perception of the sovereign not being able fulfil its deposit guarantee schemes. If the government itself would default, it cannot credibly commit anymore to bail-out depositors, nationalise banks or guarantee deposit insurances. $p_B^{\xi_G}$ creates a mechanical association of bank default risk with sovereign default risk. We therefore label this structural wedge as 'safety-net channel'. To demonstrate the effect of these run-type fears we set $p_B^{\xi_G}$ equal to 0.5, which illustrates the covariance of bank and sovereign default probabilities similar to the ones observed in Italy during the sovereign debt crisis. Second, bank default risk must be perceived by households as costly. The parameter Λ_Ψ governs the transaction costs faced by households upon bank restructuring following their default. We choose to set $\Lambda_\Psi = 0.15$ representing a vulnerable household position that demands a considerable compensation even for a low possibility of loosing part of its bank deposits.

The second layer of connecting bank and sovereign risk is the exposure of bank portfolios to sovereign debt. $\frac{\kappa_B^g}{\kappa_B^l}$ governs the asset portfolio in steady-state. It is set to 0.12 in the benchmark case. To illustrate the effects of elevated endogenous exposure of the banking system to the value of sovereign debt, we create a calibration with $\frac{\kappa_B^g}{\kappa_B^l} = 0.3$ and label this scenario as 'high sovereign bond exposure'.

Regarding general financial sector risk, the benchmark calibration represents a fairly safe banking system in the sense that it is well capitalised, does not take on excessive leverage and has a balanced investment portfolio such that the steady state bank probability of default is close to (but not exactly) zero. To illustrate the role of bank fragility, we first create an under-capitalised banking system by reducing the regulatory bank capital requirement ν_b to 0.0425 which targets a steady state bank default probability of 9% annualised. This scenario is labelled 'weak bank capitalisation' hereafter.

4 Debt-financed fiscal stabilization and the sovereign-bank-nexus

This section discussed the main experiments around a debt-financed fiscal expansion. First, we highlight why we investigate the effects of a public spending increase as opposed to other forms of government intervention like tax cuts. It sets the fiscal rule of debt-stabilization inherent to the following exercises. The following section introduces sovereign risk and the safety net channel of the sovereign-bank-nexus. Next we discuss the sovereign exposure channel of the sovereign-bank-nexus and contrast the mechanics with the previous layer of risk spillovers. The last subsection investigates the sovereign-bank-nexus channels under a more fragile bank system.

4.1 Design of the fiscal policy intervention experiment

Fiscal intervention in the economy can take a variety of forms. In the discussion at hand we will focus primarily on a fiscal expansion through an increase in government spending because this type of shock has a direct positive demand effect. We also assume that this expansion is ex-ante leading to a worsening in the fiscal balance and is therefore financed by issuing additional sovereign bonds. In what follows, we can then illustrate the emerging trade-off between an outright positive demand stimulus and the adverse consequences of higher sovereign debt through the financial market risk pricing. The multiplier of a public spending shock depends on the exact setting and simulation modality. As a benchmark, we choose an unanticipated increase in spending under active monetary policy reaction.

Figure 11 displays the two main public deficit expansions on either the expenditure side or the revenue side of the budget. This illustration considers an expansion of similar ex-ante magnitude (in terms of steady-state GDP) and the economy is not unsettled by any sovereign default risk. The behaviour of the model economy is well nested in the standard class of New Keynesian models. Additional spending (blue line) is initially financed via creating more sovereign debt. Households increase saving and reduce consumption in anticipation of future tax increases necessary to stabilize debt. On impact, the additional spending also feeds directly into total demand for production creating upward pressure on prices. The monetary authority raises interest rates to stabilize output and inflation and the banking system passes higher refinancing costs through to higher lending rates resulting in a crowding-out of consumption and investment. Yet, financial frictions in the banking system lead to an imperfect pass-through of monetary policy. These 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 therefore shift their assets from loans towards buying sovereign bonds as those become relatively more attractive. The initial debt built-up is therefore largely financed by banks. Note that this starting calibration already includes a somewhat risky bank sector, however banks hold enough equity to shun fundamental fears regarding their liquidity.

A similar impulse via tax reduction on labour income, i.e. the yellow line in Figure 11, produces a considerably weaker ex-post stimulus on production. The tax relieve has a positive impact on household disposable income that leads to higher consumption. Households increase their labour supply as the marginal gain of working more is now higher. This leads to lower aggregate wages and informatively to lower prices as firm costs fall. As a response, the monetary authority lowers rates to stabilize deflationary pressures. This stimulus is imperfectly passed through the financial system and credit conditions are easing somewhat. Favourable lending rates lead to a spur in investment further improving output. Contrary to the spending-based stimulus, bond yields do not increase because the policy rate does not. Yet, ricardian households increase their saving in anticipation of the need to stabilize the public debt path. These funds are channelled as deposits through the banking system and intermediaries cannot only further expand the loan book but also buy sovereign bonds.

A fiscal expansion creates already in the benchmark model an increase in government debt and we know that different fiscal interventions can yield very different output multipliers. The investigation displayed in Figure 12 strengthens this point. Any increase in debt cannot be permanent in our setting and will be stabilized, thus expansion is refinanced at some point in the future. Typically, it is assumed that lump-sum taxes will do this job because they are non distortionary and therefore allow to focus on understanding the channels at work for the shock the researcher is directly interested in. Our benchmark calibration features a fiscal rule on lump-sum taxes that only slowly reacts to debt (blue line). Therefore, we allow the fiscal authority to initially create debt that finances the fiscal expansion. The sensitivity simulation results in Figure 12 show that a debt-rule that is more aggressively reacting to government debt can also strongly prevent bond issuance. Indeed in the extreme example, lump-sum taxes are increased so much that the fiscal expansion is completely counter-financed (yellow line). As a result, banks would shift less assets into the bond market and instead not reduce so much credit volumes. To achieve this, loans are put on the market with a slightly lower premium compared to the benchmark case and thus investment is less affected. On total output, the fiscal multiplier however is quite similar. The sensitivity further shows that if it is assumed that the rebalancing of debt happens via labour income tax instruments, very different output multipliers can even be the result as they are very distortionary on the labour market outcome. Households would considerably decrease their consumption as they anticipate a tax increase that includes all the detrimental impact on the economy. We want to study the channels of the sovereign bank nexus and therefore need the fiscal authority to create debt, at the same time we focus on a debt rule that is not distortive in order to focus on the transmission mechanism of the questions at hand. A lump-sum tax fiscal rule with moderate speed of debt stabilization is therefore our choice of benchmark.

4.2 Sovereign risk and the safety net channel

We now introduce sovereign default risk in the economy by considering a calibration that resembles current features of the Italian state of the macroeconomy and financial markets with a high sensitivity of sovereign yields to public debt. The dotted green line in Figure 5 shows the impulse response functions with respect to the same public spending shock as before. The increase in the debt-to-GDP ratio after the fiscal expansion triggers now an increase in the sovereign default probability. As a result, holders of public debt demand higher risk compensation such that sovereign bond yields increase. The repricing of riskier bonds held on the balance sheet impairs the bank's asset position immediately and leads to lower bank profits over time. Lower bank net worth in turn creates pressure to cut funds for lending operations. Note however that the bank funding cost spread over the risk free rate does virtually not increase more than in the benchmark case because bank's default risk only marginally increases due to the asset revaluation. Instead, banker's passing through the increase in the risk-free rate to the lending branches still dominates the transmission mechanism at this stage. Credit volumes behave similar as before and consequently do not derail macroeconomic activity more consequentially than in the benchmark case. It is also worth noting that banks' limited liability due to the deposit insurance creates a risk shifting motive where bank portfolios change composition towards assets with higher return without internalising the full marginal risk increase. The additional demand from the holders of sovereign bonds contributes to a more intense snowballing of sovereign debt compared to the benchmark case without sovereign default. Note that this intermediate step does not yet create a full sovereign-ban-nexus because the bank system risk is unaffected; instead banks' net worth is actually positively affected in the medium-term because higher yields of the still relatively safe government sector bonds improve earning expectations. Therefore, the banking system has also more funds available for firm financing compared to the benchmark case and investment suffers only initially somewhat.

The solid green line in Figure 5 adds what has been dubbed in the literature as safety net channel (see Dell'Ariccia et al. (2018)). This channel depicts the fact that banks depend directly or indirectly on government guarantees securing the functioning of the financial system and especially secures a backstop for household deposits. The deposits insurance scheme in our model prevents actual default on deposits. By activating $p_B^{\xi_G}$ however, we open a the channel that can be interpreted as loss of credibility in the deposit insurance. Once the direct and indirect backstops provided by the state become less credible as the government's riskiness itself rises, bank riskiness is directly affected. Note that the risk spillover is mutual. Bank risk increases because it becomes less likely that the sovereign can bailout banks, but also sovereign riskiness increases as it becomes more likely that the government needs to intervene in the financial system. The parameter $p_B^{\xi_G}$ creates a correlation of bank and sovereign default probabilities depicting the mechanics of bank-run fears by depositors as sovereign riskiness rises. Indeed the mutual spill-overs between bank and sovereign risk is at the core of the sovereign-bank nexus.

The main transmission mechanics in our model works through the bank funding costs, where deposit risk premiums increase in line with the rise of banker's default probability. Banks pass on higher financing costs to the lending branches and they increase lending rates in order to stabilize the profit margin. In the end, the stronger hike in lending spreads leads to a larger decline in investment and eventually a lower output multiplier of the fiscal impulse. Note that at the same time the public debt path increases somewhat less than in the calibration that activated sovereign default only. This is because agents internalise the additional risk associated with the safety net channel spillovers. As a result, sovereign yields increase by less than the pure sovereign default case, but still stronger than in the case without absolutely no sovereign risk. Note that due to banker's limited liability, portfolio investments flow into sovereign bonds despite the risk increase to an extent that they actually crowd out household holdings.

As an intermediate conclusion, we notice adverse effects of sovereign risk are transmitted to the economy via financial system riskiness. Higher sovereign yields reflecting elevated government default probability have double sided consequences. On the one hand, they reflect a decrease in the portfolio value of bank holdings, but on the other hand it becomes more attractive to invest further into the bond market as lower prices promise higher returns for the future. This is possible due to limited liability of banks. The resulting effect is ex-ante not clear. To create a full sovereign-bank nexus in the model it is necessary that banker's risk of default also increases in line with sovereign risk. At the same time, households need to price in the additional risk for their deposit return. This opens a bank funding cost channel that is the main transmission mechanism of sovereign risk to the macro-economy.

4.3 Mechanics of the endogeneous sovereign-bank-nexus

We have seen that model features a sovereign-bank-nexus channel that stands for perceived obstructions of the sovereign's safety net provided to the financial system. Another layer of the sovereign-bank-nexus is what has been described as the sovereign exposure channel (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. Furthermore, banks over-proportionally hold debt securities of the domestic sovereign as opposed to geographically diversify their portfolios. The existance of home-bias of sovereign bond holding, e.g. documented in Horvath et al. (2015), rationalises the fully domestic and strong sovereign bond exposure of the next exercise.

If banks invested a considerable share of their portfolio in sovereign debt securities, sovereign default risk is endogenously transmitted to banks as asset valuations deteriorate. In the exercise conducted previously, this exposure did not create a strong sovereign-bank nexus because banks had a strong capital buffer in steady-state and the sovereign bond exposure was sufficiently low not to derail bank default probability. For now, we maintain the assumption of well capitalized banks, but a higher sovereign debt exposure anyway creates a notable pass-through of sovereign risk to bank system risk.

In the following experiment, we increase the steady-state exposure of banks to sovereign debt to create a marked sovereign exposure channel. In Figure 6 red lines now represent response functions with a banking system that is more exposed to sovereign bonds then before, i.e. sovereign bonds represent a larger share in banks asset portfolio at the steady state. The dotted red line adds the high exposure on the economy with sovereign default but without the safety net channel. Again sovereign risk increases as the government accumulates debt. Bank default probability now builds up fast as government debt securities on their balance sheet loose value. This endogenous exposure is perceived by depositors who demand a higher spread and thus activate the bank funding cost channel. The effect is considerably higher in this calibration and therefore lending rates increase more, investment is effected more and the fiscal multiplier on output is less.

The solid red line in Figure 6 represents an economy that also includes the safety net channel on top of the strong sovereign exposure channel. Note that higher bond exposure of banks already created an endogenous correlation between sovereign default and bank default risk, which dominates the correlation introduced by the safety net channel and thus both simulations (dotted and solid red lines) are similar. In other words, the additional effect due to lower credibility of the deposit insurance becomes less relevant as the endogenous exposure to sovereign risk becomes more prominent.

4.4 The role of bank system fragility

So far, the banking sector in our model was still relatively safe with a steady state probability of default of virtually zero. We have shown above that it is possible to create a sovereign-bank nexus by connecting the banking sector with sovereign default. As a next step, we assume fundamental bank fragility in a sense that the economy's banks are weakly capitalized in steady-state and therefore have lower reserves to absorb losses. Technically, this can be achieved by reducing the capital requirement parameter ν_b that pins down bank's net worth. It implies that in steady-state bank equity is lower, bank net worth is lower and leverage ratios are higher. Ultimately, weaker bank capitalization creates a higher bank default probability in steady state and intermediaries are therefore more sensitive to marginal movements along the cumulative distribution function.

Figure 7 shows the response functions of the economy after a fiscal spending impulse now with the presence of a weaker capitalized banking system for the calibrations with sovereign default and with the sovereign-bank-nexus activated via the shifter $p_B^{\xi_G}$. Upon a debt-financed fiscal expansion, the riskier bank positions now create an endogenous increase of the bank's default probability again already in the sovereign default only case (dotted red line). This is because the sovereign risk repricing in the bond market adversely affects the asset positions of banks and lowers banks' net worth on impact. Bank's probability of default reacts much more sensitive such that the sovereign exposure channel that has been muted before now becomes active. Households include a heftier risk premium in the deposit return and the bank funding cost channel is therefore active. Under the calibration illustrated here, this transmission channel as well as the result of a reduction in lending activities and adverse investment developments is similar to the safety-net channel calibration with strong capitalised banks (solid green).

Indeed the presence of a riskier bank sector compounds the transmission of sovereign risk considerably. Increases in bank default fears are more easily triggered. This is illustrated by the solid red line in Figure 7, which on top of a weakly capitalized banking sector activates the safety net channel via $p_B^{\xi_G}$. The bank funding cost channel is stronger, investment is more negatively affected, the output multiplier of fiscal spending is markedly lower. Note that this calibration leads to a less favourable debt-to-GDP path, which compounds on the sovereign default probability. Two factors are the drivers behind this. First, the output multiplier is substantially lower such that the denominator supports less. Additionally, debt increases substantially above the previous cases. The underlying reason is that the loss of the sovereign's credibility to fulfil its backstop guarantees is much more sever the more fragile is the banking system in the first place. Note also that sovereign bond holding remains attractive from the demand side due to limited liability of banks, which induces a risk-shifting motive towards higher return assets. Being under-capitalized, they seek to recoup earning also by financing higher yield sovereign debt securities.

Overall, a risky bank system compounds the effect of both layers of the sovereign-bank nexus. The safety net channel is more sever as weakly capitalized banks are in a worse position to face weak state guarantees. Mutual spill-overs are stronger. On top of that, weaker capitalized banks already activate a strong sovereign bond exposure channel effect even for a steady-state calibration of a relatively low sovereign bond leverage ratio. Looking at it the other way around, a safer bank system helps mitigate the pass-through of sovereign risk to the macro-economy.

A first policy take-away is therefore that regulatory and macro-prudential policies have the means to shield the economy from sovereign risk by setting appropriate capital requirements thus creating buffers in the banking system to eliminate concerns regarding bank liquidity. We also note that a risky bank system is a key factor in explaining the severity of the sovereign debt crisis in Europe. This crisis was driven by concerns regarding both parameters: sovereign debt sustainability as well as bank system liquidity. A major lesson is therefore to implement policy rules and a banking framework that ensures resilience of the financial intermediaries to withstand also strong adverse shocks.

We have shown that sovereign default risk gets compounded through the banking system and thereby greatly reduce the effectiveness of a fiscal stimulus. The model is able to produce this financial market backlash because banks can get squeezed by adverse asset revaluations and because financing costs include a risk premium that depends on bank's probability of default. We show that adding further vulnerability to the banking sector therefore amplifies the transmission of sovereign risk to the macro-economy. Indeed this financial market backlash might depress the fiscal multiplier on output considerably.

5 Interaction of fiscal stabilization with monetary policy

In what follows, we investigate the role monetary policy in supporting the functioning of fiscal stabilization. We consider three accommodative monetary policy regimes: *First*, the nominal policy rate being constrained at the Effective Lower Bound (ELB). *Second*, a sovereign bond purchase programme that targets capping sovereign bond yields and *third*, a TLTRO-style intervention that shields bank's funding costs from sovereign risk exposure.

First, we conduct an exercise with monetary policy being constrained by the Effective Lower Bound. The risk free interest rate $\hat{R}_t^*$ thus follows equation (73), i.e. it follows the Taylor rule if it leaves the lower bound constraint.

$$\hat{R}_t = max\left(\underline{\hat{R}}, \hat{R}_t^*\right) \tag{73}$$

$$\hat{R}_t^* = \rho \hat{R}_{t-1}^* + (1-\rho)\left[r_\pi \hat{\pi}_t + r_{\Delta y}\Delta y_t\right] + r_{\Delta\pi}\Delta\pi_t + \ln\left(\varepsilon_t^r\right) \tag{74}$$

Figure 8 shows response functions of the standard public spending shock and Table 5 summarizes the respective fiscal multipliers. Monetary policy is constrained at the Effective Lower Bound for four consecutive quarters. Turning first to the 'no sovereign default' benchmark specification, it can be seen that constraining the main policy rate at zero leads to considerably higher fiscal multipliers, which highlights that our model and ELB implementation is well nested in its class of models. Fixing the nominal interest rate leads to a market increase in the real rate of return on risk-free bonds given upward price pressures from the demand shock. This leads to higher borrowing incentives to boost household consumption and capital investments. The strong output expansion leads to buoyant growth in government receipts and therefore avoids sovereign debt creation. Indeed long-term bond yields jump less on impact. As sovereign bonds do not yield attractive returns, banks have an incentive to not reduce portfolio exposure to loans too much. Note that the domestic boom is not financed through bank lending here. Instead, households increase consumption through dissaving from short-term assets and the increase in investment is driven by the pricing effect of capital goods, which requires more investment in the capital stock in order to keep up with the demand pressure on production.

Figure 8 further shows the response for a specification where banks hold a relatively high share of sovereign bonds in their portfolio, again with and without monetary policy being constrained at the ELB. With banks exhibiting a strong endogenous sovereign-bank-nexus, the fiscal multiplier is not as large anymore as in the benchmark case. The below-one fiscal multiplier upon impact is enough to create additional sovereign debt, leading to an increase in sovereign debt probability of default and thus a hike on yields. As before, this opens a strong funding cost channel with repercussions on bank lending activities and eventually on real demand components. Compared to a scenario of high sovereign exposure but unconstrained monetary policy, however, the bank funding cost increase is not as pronounced because banks are able to mitigate the adverse balance sheet effects through keeping lending operations more robust. The effect of the real interest rate on risk free bonds still pushes demand and production up in the medium term, which tames to some extent the sovereign debt increase and eventually the whole adverse effect of the sovereign-bank-nexus.

Next, we turn to an exercise where the central bank intervenes via an asset purchase programme. This non-standard, Quantitative Easing(QE)-type of monetary policy can be operationalized via direct purchases of government bonds of the amount $B_{CB,t}$ by the monetary authority. We introduce a rule of central bank sovereign bond purchases that react to impairments of transmission of other monetary policy measures as proxied be an additional risk premium embedded in sovereign spreads. The programme thus caps the long-term sovereign bond yield increase roughly to the benchmark simulation increase observed for the 'no sovereign default' case:

$$B_{CB,t} = \rho_B B_{CB,t-1} + 0.4(R_{G,t} - \overline{R}_G) + \varepsilon_{CB,t} \tag{75}$$

where $\varepsilon_{CB,t}$ are additional stochastic disturbances on the central bank's bond purchases. After $B_{CB,t}$ has smoothed out sovereign yield deviations from its steady-state denoted by $R_{G,t} - \overline{R}_G$, an AR(1) process with ρ_B unwinds the bond buying programme.

The government bond market clearing condition now becomes

$$B_{H,t} + B_{B,t} + B_{CB,t} = B_{G,t}. \tag{76}$$

Figure 9 shows the simulation results of a government spending shock under a sovereign-bank-nexus calibration with high sovereign bond exposure by banks while activating the rule above. We choose this calibration in order to start from the worst fiscal multiplier in our analysis. The non-standard monetary policy intervention crowds out other government bond holding sectors by definition. Because this calibration entails banks with a high steady state sovereign bond exposure, they have a high incentive to shed government bonds as their balance sheets are strongly sensitive to sovereign risk increases. As a result, banker's default probability stays low and consequently avoids risk pricing hikes by depositors. In fact, the central bank intervention is so strong that this illustration leads to declining banker's probability of default in the longer term and therefore to a positive effect via bank funding cost on bank lending operation. This effects investment positively and not only restores the fiscal multiplier but even improves it in future periods. Note also that the peak sovereign debt increase is not as pronounced as without the bond purchase intervention because the capped sovereign bond yield increase leads to a milder interest snow-balling of debt.

The final exercise investigates the importance of central bank interventions designed to avoid bottlenecks on bank liquidity. This setting is engineered to follow the logic of targeted longer-term refinancing operations (TLTROs), that the European Central Bank decided to implement at the height of the sovereign debt crisis in order to provide banks with additional funding under favourable conditions. The measure implies an easing of the bank funding cost channel on the economy. In the following, we create an experiment that resembles this policy intervention. We reduce the parameter governing transaction costs of households in case of bank default Λ_{Ψ} to zero. This completely closes bank funding costs spreads above the policy rate. Figure 10 shows a simulation of our standard public spending expansion in a setting with the sovereign-bank nexus active and again with banks having a high sovereign bond exposure but additionally with the implemented parameter changed. The exercise brings the reactions of the economy closely back to the 'no sovereign default' benchmark case. Effectively, with this parameter change households do not demand higher risk compensation after the increase in bank asset's riskiness. This is despite that banker's default probability increases visibly, but the central bank commitment to provide adequate liquidity fully avoids private sector concerns towards bank-run fears. Eventually, this largely tames the bank lending impact on the real economy. While the bank funding cost channel is completely shut down, bank assets still drop in valuation with somewhat adverse consequences on bank lending activity. But the later effect is quantified to be much milder.

6 Conclusion

This paper reviews the size of fiscal multipliers of government spending in economies facing financial fragmentation risk. During and following the Great Financial Crisis, the role and scope of fiscal stabilisation was of central importance to the debate especially in Europe with its heterogeneous economies and separated sovereign bond markets. At the same time, monetary policy developed an array of novel tools and approaches to limit the consequences of financial fragmentation risk. The current health crisis surrounding the Covid-19 outbreak and the measures undertaken to contain the spread of the virus now again calls for fiscal intervention to cushion the economic downturn. In this context, the effectiveness of fiscal stabilisation is vital. In this paper, we formulate a DSGE model that can describe the sovereign-bank-nexus dimension limiting fiscal stabilisation efforts in an environment of risky banks and risky sovereigns. There are two main findings of this paper. First, we find that the output multiplier of fiscal expansion can be significantly dampened by financial fragmentation risk. Second, we show that non-standard monetary policy action can largely contain the sovereign-bank-nexus mechanism and therefore helps to restore fiscal multipliers.

We develop a DSGE model which can account for feedback loop between risky banks and risky sovereign debt in order to highlight one source of fiscal multiplier variation. We show that an endogenous sovereign-bank-nexus arises through two channels. First, 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. Second, 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. Our calibration of the sovereign-bank-nexus describes sovereign risk being passed-on to the real economy through tighter bank lending conditions. This lending rate sensitivity is found to be stronger when the loss absorption capacity of the banking system is limited.

We have further investigated the interaction of the sovereign-bank-nexus with monetary policy. In a low interest rate environment, fiscal stimuli tend to be more effective, but as we have shown, the safety net channel still has the potential to considerably depress the fiscal multiplier and even more so in an economy where the banking system is weakly capitalized. On the other hand, non-standard monetary policy measures such as central bank asset purchases can mitigate the adverse effects from the sovereign-bank-nexus by containing the rise in sovereign spreads. This prevents adverse valuation effects on bank assets and also induces banks to shift their portfolio into higher yielding lending operations to the private sector. Finally, because the bank funding cost channel is the main transmission mechanism of sovereign risk to the banking sector, policy measures to directly address the bank funding conditions such as the TLTRO programmes of the European Central Bank are a powerful tool in containing the sovereign-bank-nexus.

As policy conclusion, this work points to the first order importance of maintaining sufficient fiscal capacity in good times in order to avoid financial fragmentation risk to arise in bad times. Second, macro-prudential regulation is central to ensure a resilient banking system with sufficient loss absorption capacity that ultimately limits the pass-through of sovereign risk to the real economy. Improving the banking and capital market union should increase the integration of the banking system in Europe and therefore encourage more cross-country holding of sovereign debt. This mitigates the well documented home bias of bank's sovereign debt holding (e.g. Horvath et al. (2015)) and leads to more diversification of bank portfolios. Finally, even in the presence of financial fragmentation risk, non-standard monetary policy measures are effective in addressing adverse sovereign-bank-nexus effects.

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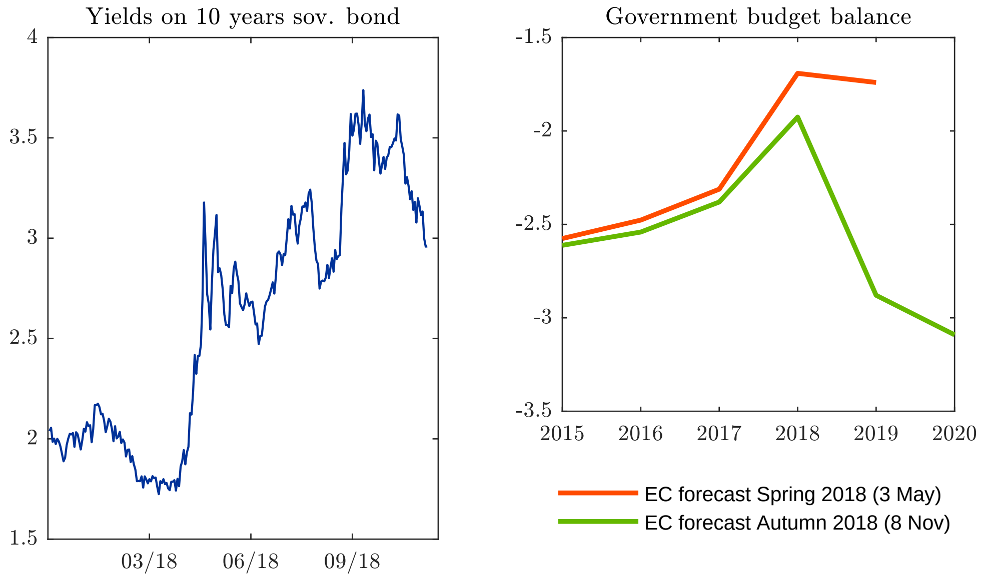
Appendices

A Stylized facts

Figure 1: Sovereign bond market response to fiscal stimulus announcement in Italy



Notes: The yields are shown in percent and observations are business daily through 2018. The budget balance forecast is shown according to the European Commissions forecasts and are in percent of GDP.

Figure 2: Business daily observations of sovereign and bank CDS, 2008-2018, in bps

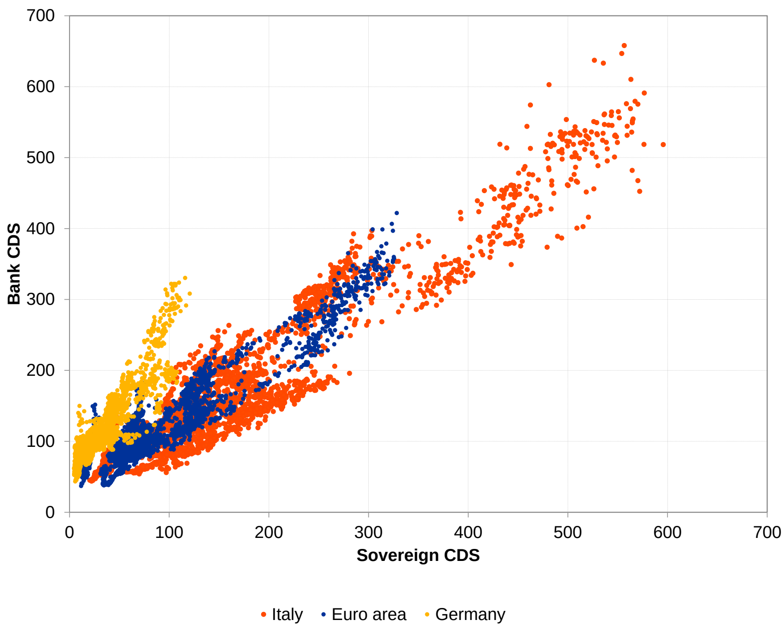
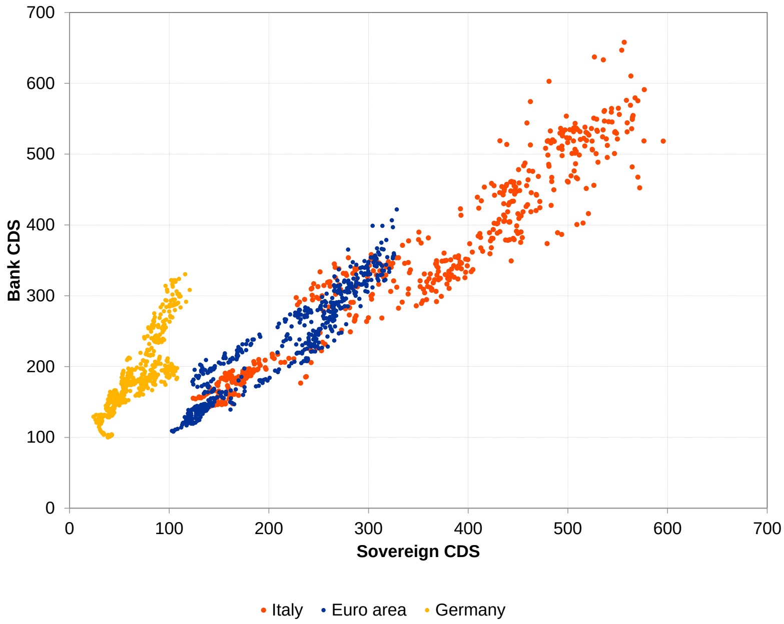


Figure 3: Business daily observations of sovereign and bank CDS, 2011-2012, in bps



B Model parameter calibration

Table 1: Parameter Estimates

Parameters		Posterior Mode
η	Habit formation	0.788
σ_c	Intertemp. elasticity of subst.	1.673
σ_l	Labor disutility	0.683
r_β	Rate of time preference	0.093
ξ_E^R	Calvo lottery, lending rate	0.461
φ	Cap. utilization adj. cost	0.667
ϕ	Investment adj. cost	3.914
γ	Trend productivity	0.141
α	Capital share	0.326
λ_e	Employment adj. cost	0.877
$\overline{L}$	Employment shift	-0.338
α_p	Calvo lottery, price setting	0.643
ξ_p	Indexation, price setting	0.188
μ_p	Price markup	1.484
α_w	Calvo lottery, wage setting	0.428
ξ_w	Indexation, wage setting	0.205
$\overline{\pi}$	SS inflation rate	0.513
ρ	Interest rate smoothing	0.905
r_π	Taylor rule coef. on inflation	1.681
$r_{\Delta Y}$	Taylor rule coef. on Δ(output)	0.111
$r_{\Delta\pi}$	Taylor rule coef. on Δ(inflation)	0.083
AR or ARMA coefficients of exogenous shock processes		
ρ_a	AR(1) Technology	0.898
ρ_I	AR(1) Inv. Technology	0.803
ρ_g	AR(1) Gov. spending	0.989
ρ_b	AR(1) Preference	0.017
ρ_p	AR(1) Price markup	0.984
η_p	MA(1) Price markup	0.862
ρ_w	AR(1) Wage markup	0.954
ρ_{σ_e}	AR(1) entrepr. risk	0.917
ρ_{R_G}	AR(1) Gov. bond valuation	0.981
$\rho_{a,g}$	Corr(Tech.,Gov. Spend.)	0.648
Standard deviations of exogenous shock processes		
$\sigma_{\epsilon_t^a}$	Technology	0.789
$\sigma_{\epsilon_t^I}$	Inv. Technology	3.658
$\sigma_{\epsilon_t^g}$	Gov. spending	1.752
$\sigma_{\epsilon_t^b}$	Preference	2.105
$\sigma_{\epsilon_t^p}$	Price markup	0.133
$\sigma_{\epsilon_t^w}$	Wage markup	0.13
$\sigma_{\epsilon_t^{\sigma_e}}$	Entrepreneurs risk	4.259
$\sigma_{\epsilon_t^{R_G}}$	Gov. bond valuation	1.109
$\sigma_{\epsilon_t^r}$	Policy rate	0.09

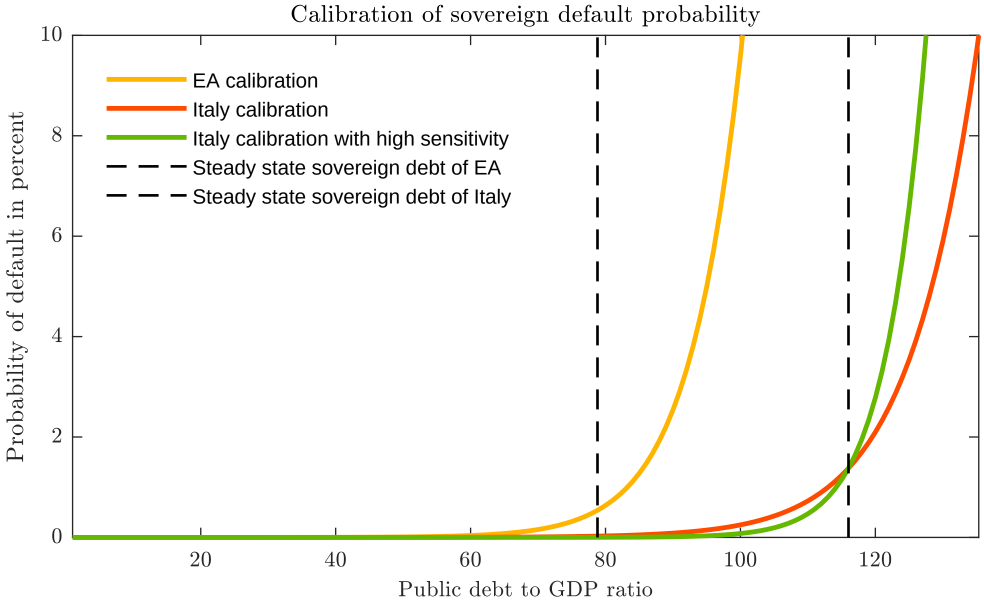
Table 2: Calibrated Parameters

Parameters		Value
Price and wage setting		
μ_w	Wage markup	1.50
ψ	Kimball goods aggregator parameter	10
ψ_w	Kimball labour aggregator parameter	10
Technology		
δ	Fixed capital stock depreciation rate	0.025
Entrepreneurs		
μ_e	monitoring costs	0.10
σ_e	std idiosyncratic entrepreneur risk	0.30
χ_e	seizability rate	0.50
ζ_e	Survival probability for entrepreneurs	0.99
Ψ_E	Tranfers to new entrepreneurs (percentage of assets)	0
Banks		
$\mu_E^R - 1$	Lending rate monopolistic margin in basis points	15.00
ζ_b	Survival probability for bankers	0.95
σ_b	std idiosyncratic bank risk	0.03
χ_b	Regulatory penalty	0.40
ν_b	Regulatory bank capital requirement	0.08
ν_g	Regulatory constraint on gov. bonds	0
Ψ_B	Tranfers to new bankers (percentage of assets)	0.10
Government sector and debt market		
$\frac{G^\star}{Y}$	Share of gov. expenditures to output	0.18
$\frac{B_G}{4Y}$	Share of outstanding gov. bonds to output (annual)	0.7781
η_1	location of logistic distr. of gov. default prob.	16
η_2	scale of logistic distr. of gov. default prob.)	0
ϕ_T	lump-sum tax sensitivity to debt-to-GDP ratio	0.1
ρ_T	AR(1) lump-sum tax	0
$\frac{\kappa_B^g}{\kappa_B^l}$	Share of bank holdings of gov. bond to loans	0.12
$\frac{B_H}{4Y}$	Households target gov. bond holdings	0.27
τ_g	Geometric decay factor for coupons	0.02
c_g	Coupon rate	0.04
$\frac{\chi_H}{100}$	Portfolio adj. cost for households	5.50
$\frac{\chi_B}{100}$	Portfolio adj. cost for bankers	0.50

Table 3: Calibrations under different scenarios

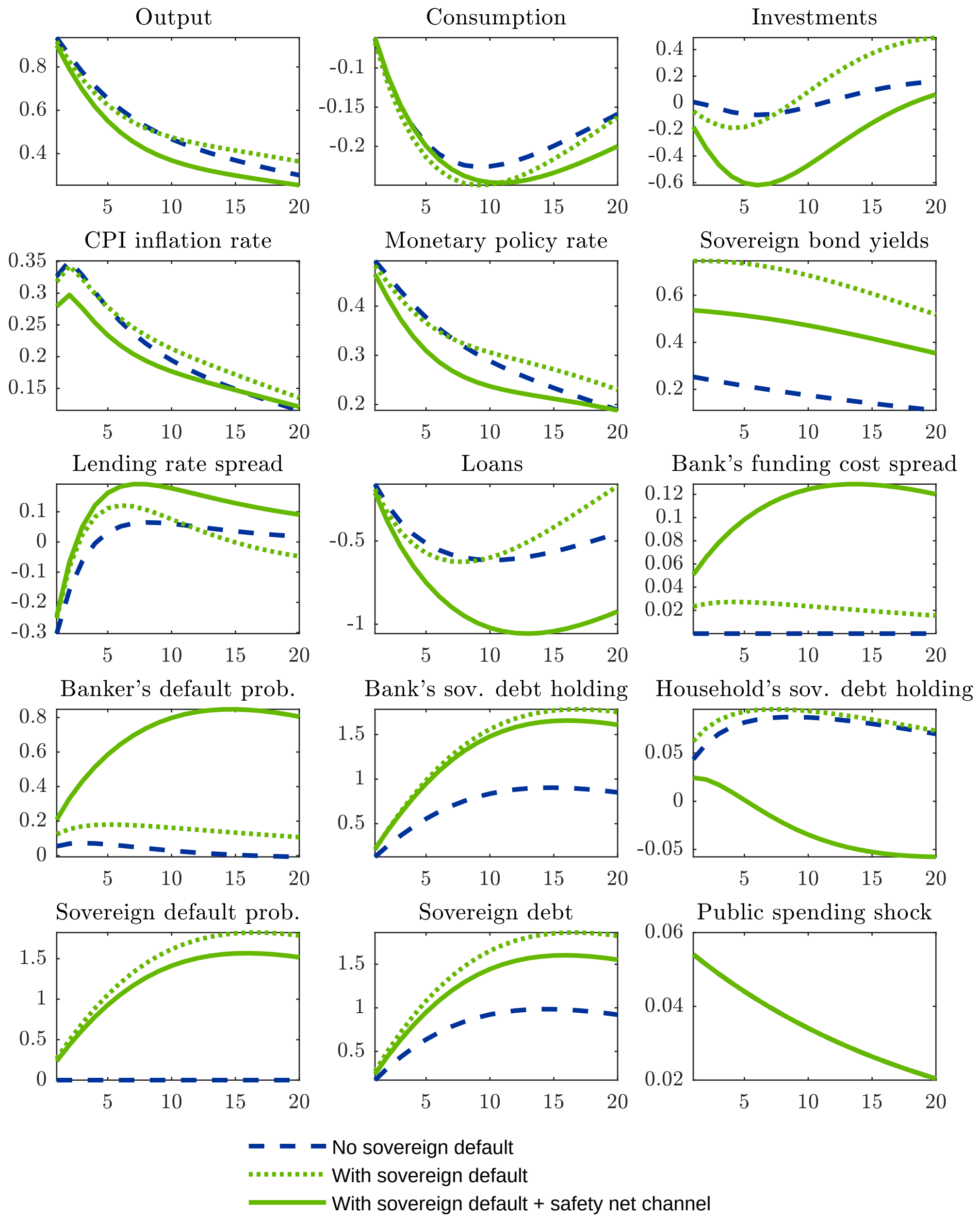
	$\frac{B_G}{4Y}$	η_1	η_2	Λ_Ψ	$p_B^{\xi_G}$	$\frac{\kappa_B^g}{\kappa_B^l}$	ν_b
No sov. default	0.7781	16	0	0.15	0	0.12	0.08
Sov. default	1.1502	25	18	0.15	0	0.12	0.08
Sov. default + safety net channel	1.1502	25	18	0.15	0.5	0.12	0.08
Sov. default + safety net channel, high sovereign bond exposure	1.1502	25	18	0.15	0.5	0.30	0.08
Sov. default + safety net channel, weak bank capitalisation	1.1502	25	18	0.15	0.5	0.12	0.0425

Figure 4: Logistic function for sovereign's probability of default



C 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. Sovereign debt and bank's and household's sovereign debt holding is expressed as percentage point deviation of the ratio to annual GDP. The default probability of bankers and the sovereign is denoted in annual percentage point deviations. The shock process is displayed in terms of difference to the steady state. All other variables are presented in annual percentage point deviations. The lending rate and bank's funding cost is shown as spread w.r.t the policy rate.

Figure 6: Public spending shock: fragile banks with high sovereign bond exposure

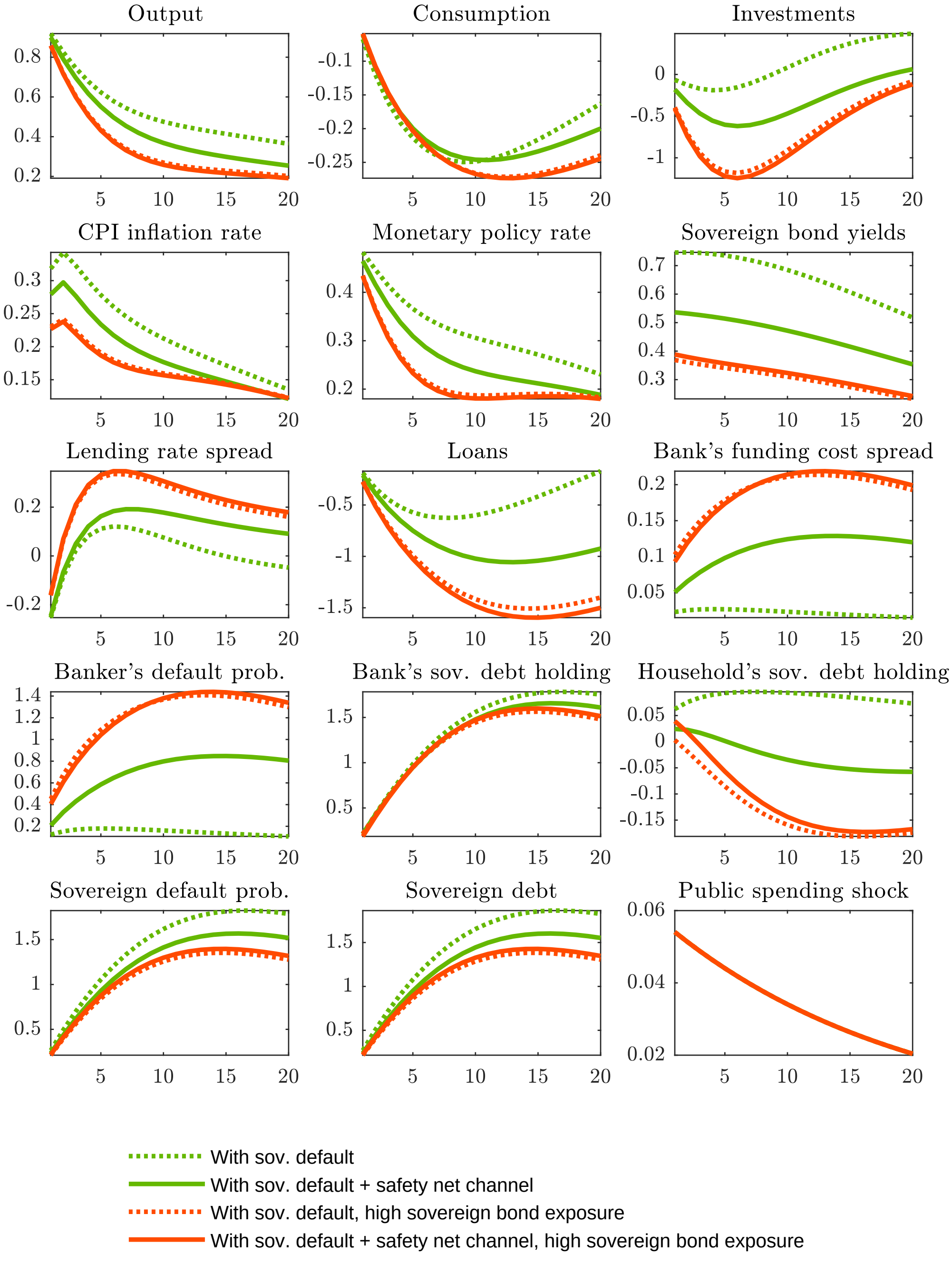


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Figure 7: Public spending shock: fragile banks with low capital requirements

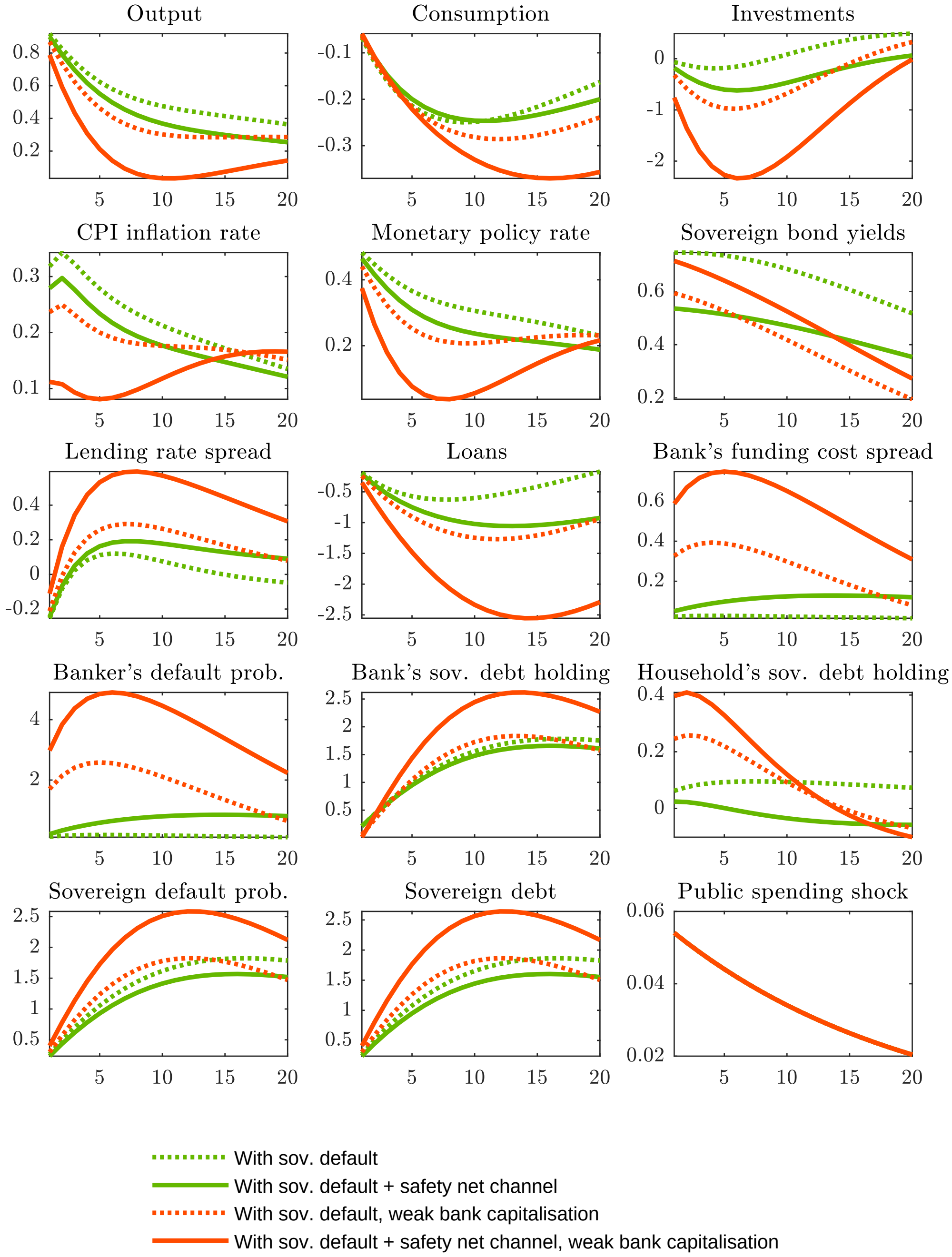

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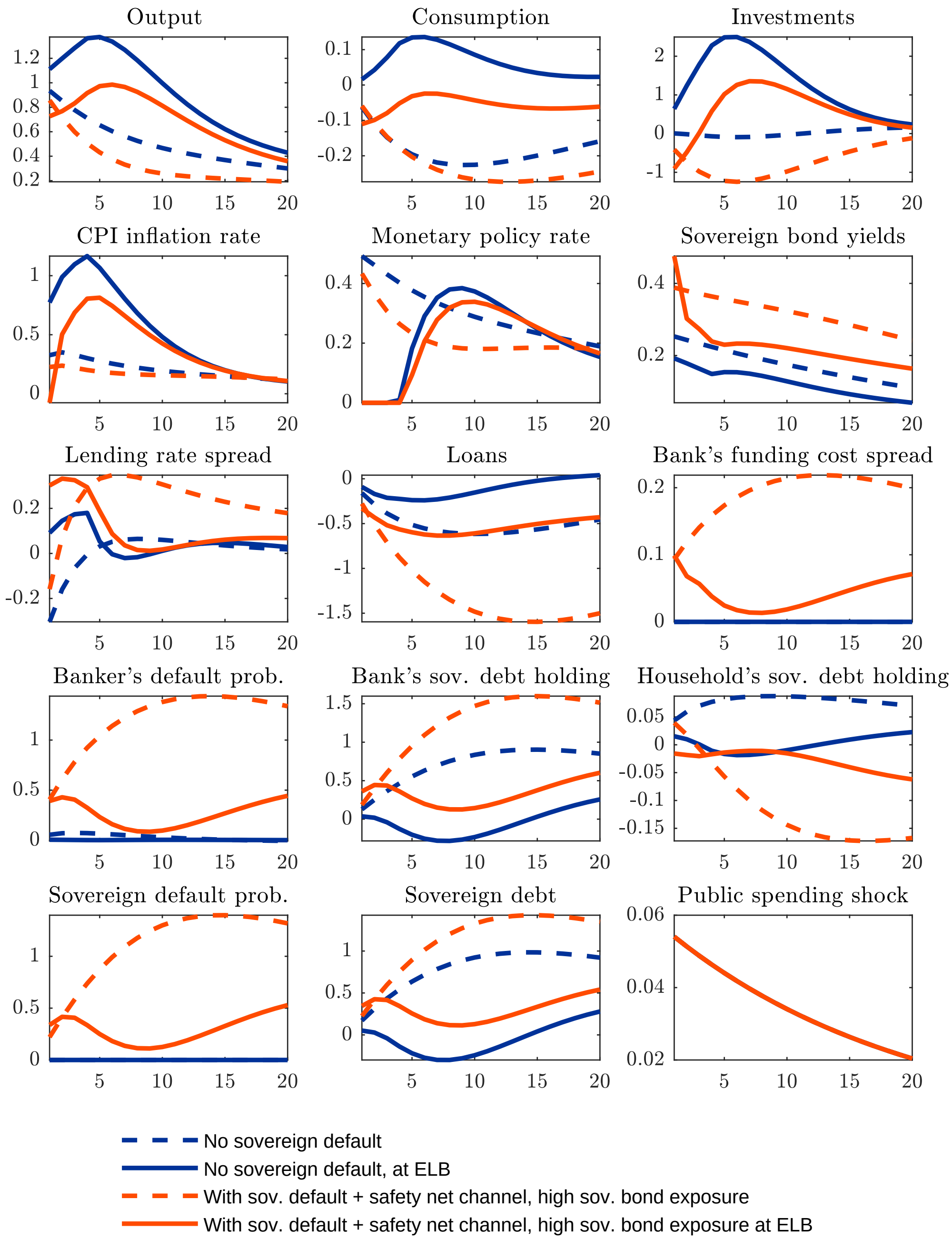
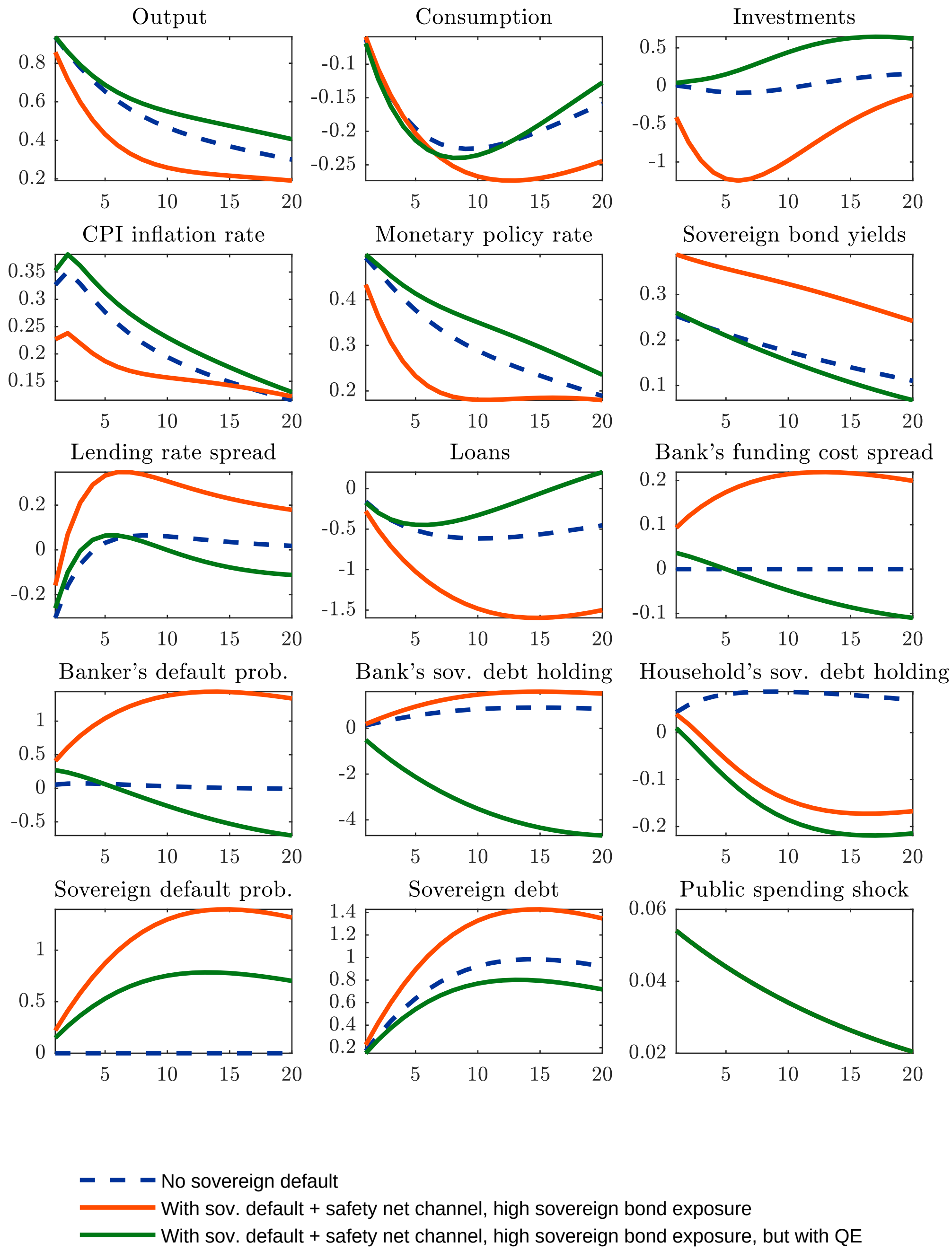
Figure 8: Public spending shock: monetary policy rate at the Effective Lower Bound



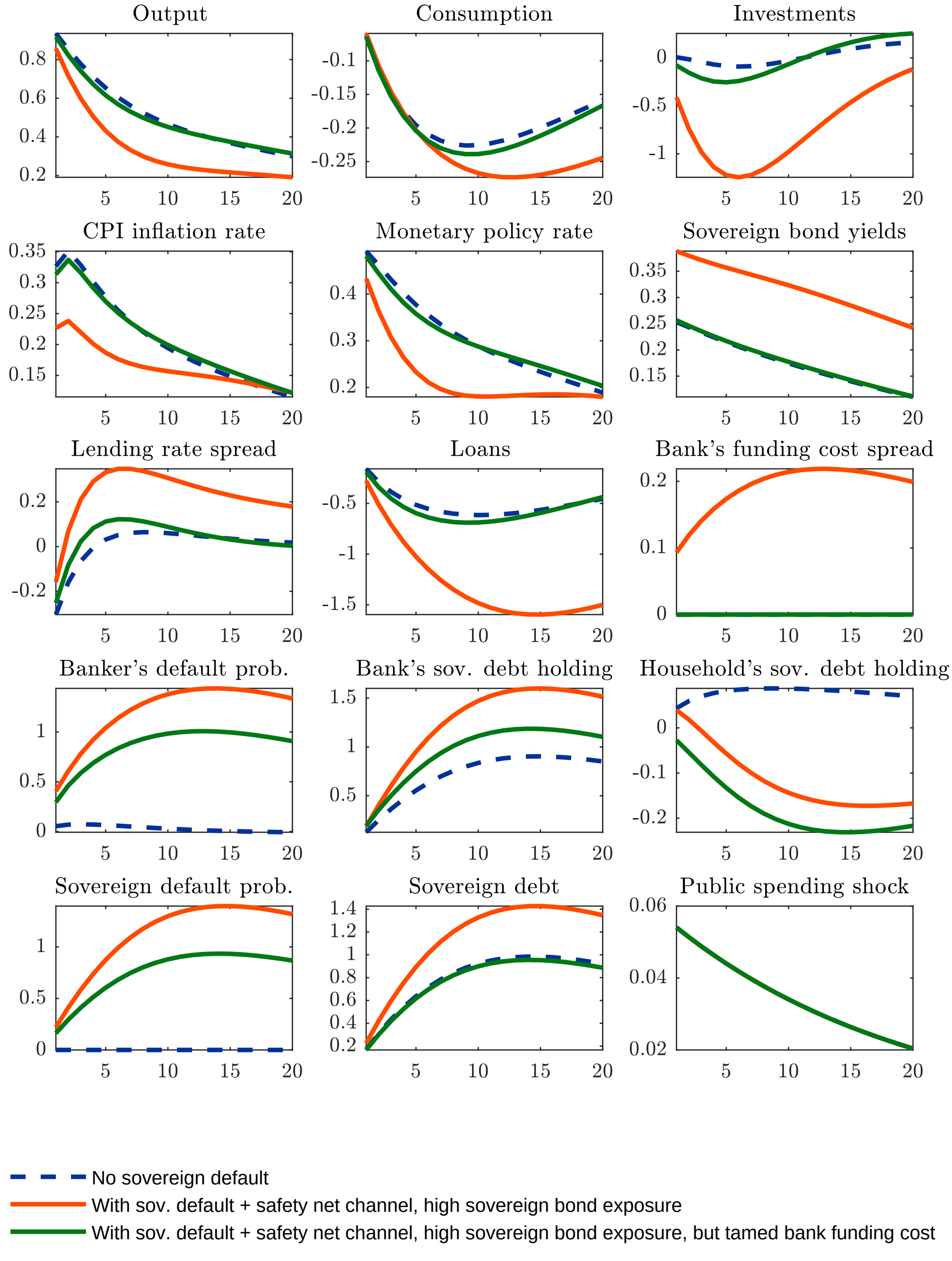
Notes: Impulse responses refer to the variable's reaction after an unanticipated increase in government spending by 1% of steady state GDP. Horizontal axis: in quarters. Vertical axis: Output, consumption, investments and loans are expressed in percentage deviations from steady-state baseline. Sovereign debt and bank's and household's sovereign debt holding is expressed as percentage point deviation of the ratio to annual GDP. The default probability of bankers and the sovereign is denoted in annual percentage point deviations. The shock process is displayed in terms of difference to the steady state. All other variables are presented in annual percentage point deviations. The lending rate and bank's funding cost is shown as spread w.r.t the policy rate.

Figure 9: Public spending shock: central bank sovereign bond-buying programme



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. Sovereign debt and bank's and household's sovereign debt holding is expressed as percentage point deviation of the ratio to annual GDP. The default probability of bankers and the sovereign is denoted in annual percentage point deviations. The shock process is displayed in terms of difference to the steady state. All other variables are presented in annual percentage point deviations. The lending rate and bank's funding cost is shown as spread w.r.t the policy rate.

Figure 10: Public spending shock: central bank shielding bank's funding costs



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. Sovereign debt and bank's and household's sovereign debt holding is expressed as percentage point deviation of the ratio to annual GDP. The default probability of bankers and the sovereign is denoted in annual percentage point deviations. The shock process is displayed in terms of difference to the steady state. All other variables are presented in annual percentage point deviations. The lending rate and bank's funding cost is shown as spread w.r.t the policy rate.

Table 4: Fiscal multiplier of government spending

PV(dY/dG)	Impact	4 qtrs	10 qtrs	19 qtrs
No sov. default	0.94	0.87	0.83	0.82
Sov. default	0.92	0.84	0.81	0.82
Sov. default + safety net channel	0.90	0.79	0.72	0.70
Sov. default + safety net channel, high sovereign bond exposure	0.86	0.70	0.59	0.56
Sov. default + safety net channel, weak bank capitalisation	0.79	0.53	0.36	0.32

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.

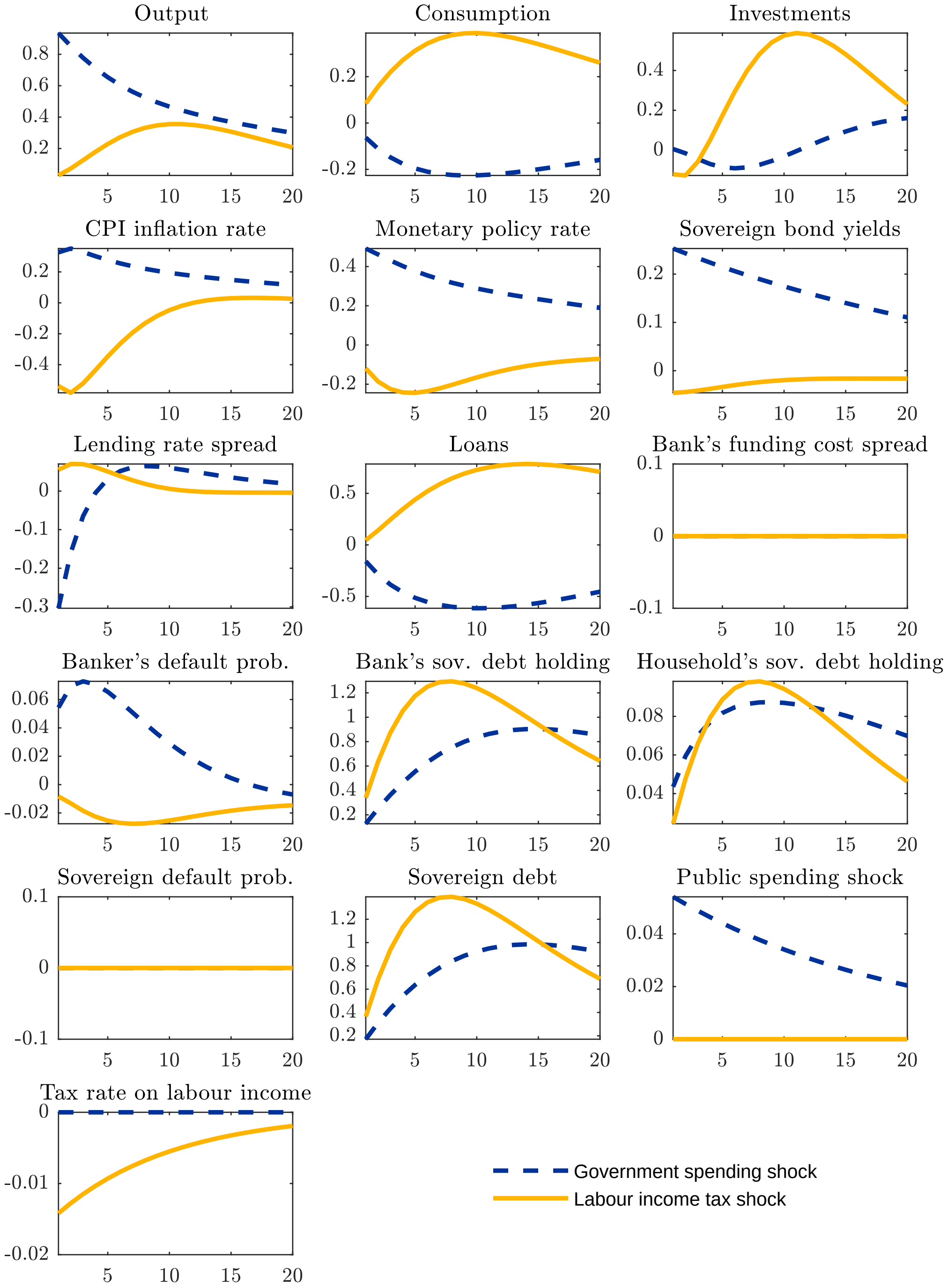
Table 5: Fiscal multiplier of government spending at the ELB

PV(dY/dG)	Impact	4 qtrs	10 qtrs	19 qtrs
No sov. default	0.94	0.87	0.83	0.82
No sov. default, at ELB	1.11	1.39	1.50	1.46
Sov. default + safety net channel, high sov. bond exposure	0.86	0.70	0.59	0.56
Sov. default + safety net channel, high sov. bond exposure at ELB	0.73	0.92	1.08	1.08

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. In ELB simulations, the monetary policy rate is fixed for four periods at the steady-state value.

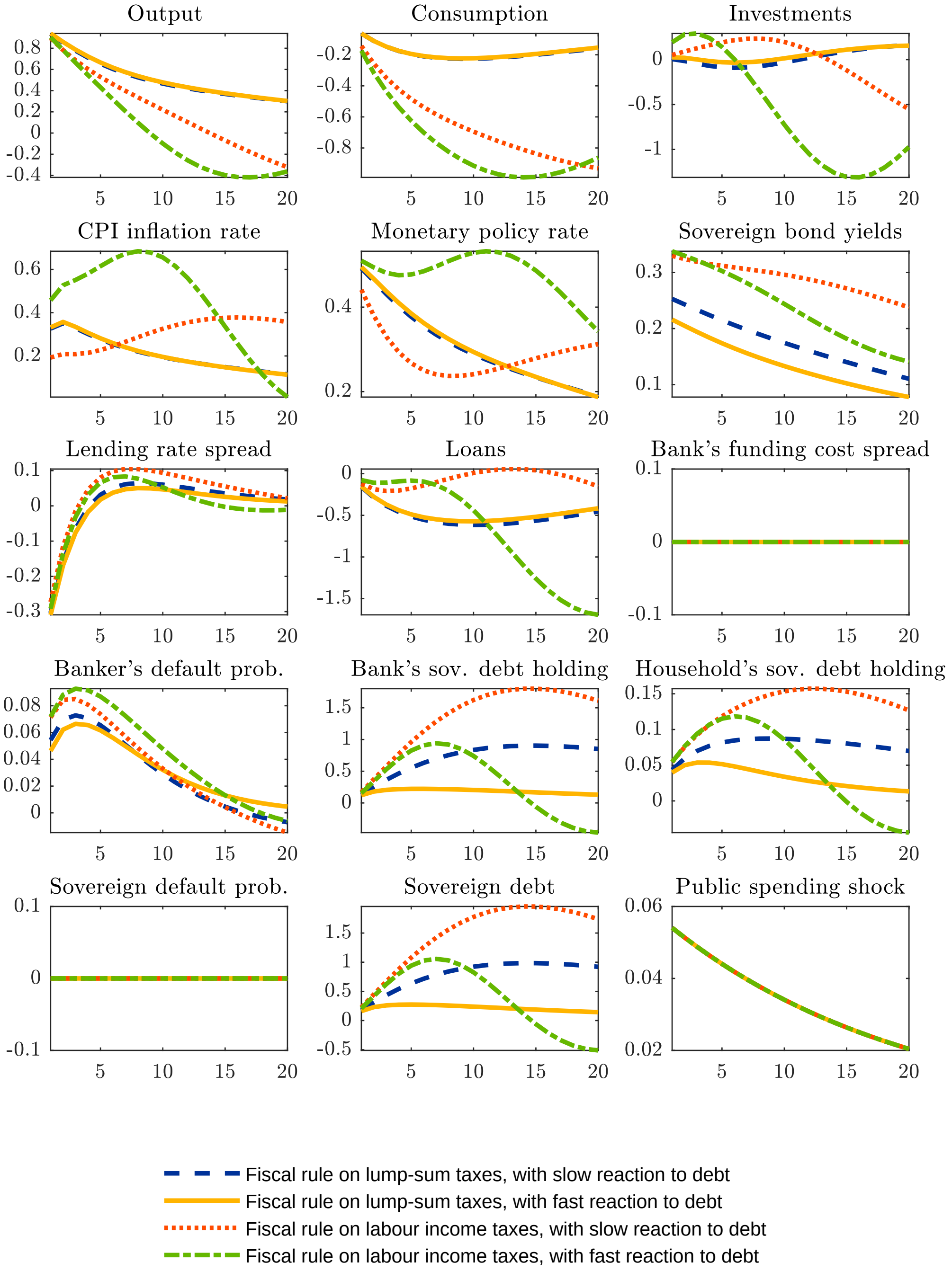
D Background simulations

Figure 11: Design of fiscal policy intervention: government spending vs taxation



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. Sovereign debt and bank's and household's sovereign debt holding is expressed as percentage point deviation of the ratio to annual GDP. The default probability of bankers and the sovereign is denoted in annual percentage point deviations. The shock process is displayed in terms of difference to the steady state. All other variables are presented in annual percentage point deviations. The lending rate and bank's funding cost is shown as spread w.r.t the policy rate.

Figure 12: Design of fiscal policy intervention: debt stabilization rule



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. Sovereign debt and bank's and household's sovereign debt holding is expressed as percentage point deviation of the ratio to annual GDP. The default probability of bankers and the sovereign is denoted in annual percentage point deviations. The shock process is displayed in terms of difference to the steady state. All other variables are presented in annual percentage point deviations. The lending rate and bank's funding cost is shown as spread w.r.t the policy rate.

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