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Abstract

We develop a dynamic stochastic general equilibrium model of a monetary union and employ it to study in an integrated manner different macrofinancial disturbances and related policy options. The model is calibrated to the euro area, comprises two regions subject to real, nominal and financial rigidities, and features microfounded regional banking sectors and portfolio selection mechanisms allowing for empirically-consistent properties. Among the questions to which we devote our analysis are the transmission of conventional and unconventional monetary policy, the effects of private- and government-sector default risk, the implications of different macroprudential policies, the endogenous emergence of country risk premia in a context of cross-border financial flows, and the stabilising properties of joint sovereign debt issuance.

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CONTENTS

1 Introduction

Spurred by the global financial crisis, the past decade brought to the forefront of the dynamic stochastic general equilibrium (DSGE) literature a closer consideration of the implications of macrofinancial disturbances and the role of financial intermediation. In the present work we investigate in an integrated manner several of the disturbances and policy responses that came to characterise the global financial crisis and the subsequent European debt crisis, that continued to evolve in connection with the covid-19 pandemic, and that may re-emerge in future contexts.

We restrict our analysis to a monetary union calibrated to the euro area. Consistently with the fact that there is neither perfect insurance between the constituent economies of the euro area, nor within those economies, our model comprises two regional blocs set to mimic a "core" and a "periphery", each home to two types of households, one of which is credit constrained. The disturbances we consider include default shocks in the different private sectors of the economy, shifts in public sector credit risk, changes to macroprudential policies and international capital flights in connection with changes in risk attitudes. We also consider the transmission and effects of two policy responses with macroeconomic stabilisation potential: unconventional monetary policy and the introduction of a common sovereign debt instrument.

The structure of our calibrated DSGE model is enriched with a number of financial frictions and mechanisms that assign a relevant macroeconomic role to credit, credit risk, financial intermediation and international capital flows. Among the more standard features of the model we have the fact that households are split into patient and impatient types, with the former owning the corporate sector and saving in the form of deposits, and the latter borrowing from domestic banks subject to a collateral constraint that is linked to their expected housing wealth. A similar collateral constraint is also included for entrepreneurs linking corporate loan amounts to the expected value of their gross operating profits and capital stock. We borrow an inertia mechanism from Iacoviello (2015) whereby outstanding household and corporate loans evolve slowly over time and introduce soft loan-in-advance constraints (LIA) for households and firms that link the use of bank loans to household and corporate investment, respectively.

The non-financial corporate sector is structured along a vertical production chain, as in Canova et al. (2015), allowing for the introduction of nominal, real and financial rigidities, as well as other relevant features, at different stages of the production process. At the first stage of production, entrepreneurs employ labour and physical capital to produce an intermediate good subject to real investment adjustment costs as in Christiano et al. (2005), as well as to the aforementioned LIA and collateral constraints. Intermediaries acquire the entrepreneurial production, differentiate it and sell the different varieties to wholesale aggregator firms subject to staggered pricing as in Calvo (1983). Product differentiation allows for the introduction of market power in a monopolistic competition setting, as well as for the existence of fixed costs that can offset intermediaries' operating margins. Final goods producers introduce international trade into the model by combining the output of wholesalers in both regions to produce a final good that is used for private and public consumption, as well as for investment purposes. Finally, housebuilders conduct housing investment by transforming a part of the final good into the economy's housing stock subject to investment adjustment costs and to decreasing returns to scale.

Among our more innovative contributions are the modeling of the banking sector and the associated mechanisms for portfolio selection and cross-border financial flows. Motivated by the experience of the 2007-08 financial crisis, there has been much progress in the past decade in rendering financial intermediation a relevant mechanism for originating, transmitting and amplifying shocks in a DSGE context. One dimension along which modeling approaches differ is as to their degree of microfoundation. On one end of the range we can find financial sectors that are described by a set of empirically-flexible reduced-form equations that are not explicitly derived from optimising agent behaviour, of which Gourinchas et al. (2016) is a relatively recent example. On the other end of the range, one can find deeply microfounded banking sectors, of which Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) are seminal examples. The latter class of models, however, typically relies on a highly stylised description of the workings of financial intermediation and often requires strong assumptions as to structure of the underlying economy, the types of shocks that originate financial disturbances or as regards agent behaviour and the timing of their decisions.

Our modeling of the banking sector is microfounded on standard firm theory whereby zero-measured bank managers maximise a discounted dividend stream on behalf of bank owners under a standard principal-agent friction that implies that the time horizon of managers is more myopic than that of owners. Banks are subject to a capital ratio constraint that is consistent with real-world regulatory requirements imposed by supervisory authorities, as well as a deviation cost built around banks' leverage ratio. That cost assumes that banks target a steady-state leverage ratio, a behavioural device also found in Kollmann et al. (2013), although under a different specification. The target leverage ratio is based on the well-accepted notion that banks behave as if holding (too much) capital is costly, as well as on the possibility of market pressure mechanisms for banks holding too little capital.

There are a number of DSGE models of the euro area that comprise more than one region within the currency union, and where each region is endowed with its own banking sector. Among these types of models one could highlight Poutineau and Vermandel (2015, 2017), Bokan et al. (2018) and Pariès et al. (2019). A general difference with respect to the existing literature is the wide range of macrofinancial simulations allowed for by the model structure presented in this paper, as exemplified in Section 4. Other differences include the avoidance of some pragmatic, though not necessarily realistic, devices, which are used to impart relevance to macrofinancial mechanisms. These devices include: significant adjustment costs to financial assets; banks' maximisation object being something other than the summation of discounted dividends; bank owners or managers representing a distinct and sizable share of the population; or autonomous depreciation of bank capital, a financial variable. We also opt to work with consolidated regional banking sectors rather than with different types of banks, as is for example the case of Poutineau and Vermandel (2015), or of the workhorse DSGE model described in Coenen et al. (2018). This is in part motivated by Europe's tradition of universal banking and by a desire to avoid a pattern of bank specialisation that has no clear counterpart in the actual structure of the European banking industry. However, our model implementation is such that the study of interbank lending disturbances remains possible both along domestic and cross-border dimensions.

The transmission of monetary policy in our model is effected via a perfectly competitive banking sector and is modeled in an explicit manner. Banks have access to a central bank deposit facility, with the monetary authority controlling the policy rate on this facility. Banks' no-arbitrage pricing reflects changes in the policy rate, thereby transmitting conventional monetary policy to borrowers, depositors and the broader economy. As regards unconventional monetary policy, the monetary authority is empowered to purchase government bonds from banks at the market price and to swap them for reserves held at the deposit facility.

An important feature of our model is the inclusion of portfolio management mechanisms whereby (risk-adjusted) portfolio yields are maximised subject to investor preferences and the prevailing financial environment. In our setup, bank head offices decide steady-state investment amounts and define competitive interest rates for their portfolio of government bonds and interbank loans. These are communicated to portfolio managers, along with investment preferences (or guidelines). Portfolio managers are then tasked with allocating investment across regions based on the whole information set provided by head offices. In the spirit of the preferred habitat theory introduced by Modigliani and Sutch (1966), financial asset price formation is thus the result of two forces in our model: the competitive cost-based, no-arbitrage pricing of head offices, and the investor preference-influenced decisions of portfolio managers. Besides helping to determine asset prices and allocations, the interplay of portfolio managers in both regions has an important role in determining relative country risk, as this will be the relative premium demanded for cross-border interbank loans in order to ensure sufficient external funding. As such, differently from more mechanistic approaches for ensuring external balance described in Schmitt-Grohé and Uribe (2003),[1] country risk is an implicit market equilibrium mechanism in our model, resulting from the supply and demand of international funds, and determined by the interplay of investors and other general equilibrium forces.

The previously-described model design renders it particularly suitable for the assessment of three types of policies. The first are macroprudential policies, which we translate into included model features such as capital requirements and loan-to-value ratios. The second are monetary policies, particularly as regards unconventional measures such as asset purchases. The third is the introduction of different forms of common sovereign debt instruments, a topic which has gained renewed relevance given the current initiatives for large, temporary issuance by the European Union on behalf of Member States in the wake of the recent pandemic crisis.[2] Common sovereign debt instruments have been mainly analysed from the viewpoint of their credit risk properties - see, e.g., ESRB High-Level Task Force on Safe Assets (2018), Leandro and Zettelmeyer (2019) and Monteiro (2023) - or of these properties in interaction with a banking sector, as in Brunnermeier et al. (2017). A full-blown general equilibrium analysis of common sovereign debt instruments is still missing in the literature. The first and, to our knowledge, only attempts at modeling such instruments in a DSGE framework are Badarau et al. (2021) and Jarociński and Maćkowiak (2018). However, their modeling framework is significantly more stylised than what is considered here.[3]

The remainder of this paper is organised as follows: Section 2 provides a detailed model description; Section 3 discusses the calibration of the model; Section 4 simulates the model dynamics in response to standard macroeconomic shocks, different monetary and financial shocks, macroprudential policy changes and the introduction of a common debt instrument; while Section 5 concludes and provides avenues for future research.

2 The model economy

The model economy is discretised to quarterly frequency and comprises two regions in a monetary union: a "periphery" with measure $0 < n < 1$ and a "core" with measure $1 - n$. The following subsections describe the periphery bloc, which can also be understood as the "domestic" region from the viewpoint of our analysis. The description of the core region is analogous to that of the periphery.

2.1 The household sector

The economy is populated with savers, which are indexed by s and have measure $0 < \omega_s < 1$, and borrowers, which are indexed by b and have measure $1 - \omega_s$. Both household types share similar preferences but differ as to their intertemporal discount factors $0 < \beta_b < \beta_s < 1$ and asset ownership. The more patient households own the entire corporate sector and save in the form of bank deposits while the comparatively impatient households borrow in the form of bank loans.

2.1.1 Saver households

The representative saver household maximises a discounted stream of expected utility by choosing in each period t how much to consume (C_s), how much housing capital to own (H_s), how much time to work (N_s) and how much to save (D_s):

[1] Such as risk premia being set in a dedicated equation as function of external debt, or the imposition of portfolio adjustment costs.

[2] This is namely the case of the NextGenerationEU and the SURE initiatives.

[3] For instance, Badarau et al. (2021) do not include a banking sector nor other features found in fully developed models, such as capital accumulation. Jarociński and Maćkowiak (2018)) consider only an area-wide banking sector and their common debt instrument (which is akin to undefaultable central bank liabilities) is unlike the most common proposals.

$$\max_{\{C_{s,t},H_{s,t},N_{s,t},D_{s,t}\}} E_0 \sum_{t=0}^{\infty} \beta_s^t \left[\frac{\left(C_{s,t} - h\bar{C}_{s,t-1}\right)^{1-\chi}}{1-\chi} + \nu_s^h \frac{H_{s,t}^{1-\chi}}{1-\chi} - \nu_s^n \frac{N_{s,t}^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where $0 < h < 1$ captures external habits in consumption, $\bar{C}_s$ is the aggregate consumption of savers, $\chi > 0$ is the coefficient of relative risk aversion, $\nu^h, \nu^n > 0$ are the relative (dis)utility weights of housing services and hours worked, respectively, and $\varphi > 0$ is the inverse of the Frisch elasticity of labour supply. The budget constraint of savers is given by

$$P_t(C_{s,t} + T_{s,t} + AC_{H_s,t}) + P_t^H(H_{s,t} - (1-\delta_H)H_{s,t-1}) + D_{s,t} = R_{s,t}^D D_{s,t-1} + W_t N_{b,t} + DIV_{s,t} \tag{2}$$

where P denotes the price level of final goods, AC_{H_s} a real cost from adjusting the housing stock, $T > 0$ a lump-sum tax, P^H the price of housing, $0 < \delta_H < 1$ the depreciation rate of the housing stock, R^D the gross return rate on deposits, W the nominal wage rate and DIV the aggregate net dividends paid out by the corporate sector.

The inclusion of AC_{H_s} seeks to capture housing transaction costs, broadly defined. It reflects, inter alia, the costs associated with searching and moving into new housing, as well as possible transaction taxes. One of its implications is that, for a given total housing stock H in the economy, changes in ownership between savers and borrowers do not happen in a frictionless manner. Housing adjustment costs are governed by intensity parameter $s_{H_s} > 0$ and take the following form:

$$AC_{H_s,t} = \frac{s_{H_s}}{2}\left(H_{s,t} - H_{s,t-1}\right)^2 \tag{3}$$

2.1.2 Borrower households

The representative borrower household faces a similar lifetime utility maximisation problem, although it optimises on loans from domestic banks (L_b) rather than on deposits:

$$\max_{\{C_{b,t},H_{b,t},N_{b,t},L_{b,t}\}} E_0 \sum_{t=0}^{\infty} \beta_b^t \left[\frac{\left(C_{b,t} - h\bar{C}_{b,t-1}\right)^{1-\chi}}{1-\chi} + \nu_b^h \frac{H_{b,t}^{1-\chi}}{1-\chi} - \nu_b^n \frac{N_{b,t}^{1+\varphi}}{1+\varphi} \right] \tag{4}$$

Borrowers are subject to an intertemporal budget constraint,

$$\begin{aligned} P_t\left(C_{b,t} + T_{b,t} + AC_{H_b,t}\right) + P_t^H\left(H_{b,t} - (1-\delta_H)H_{b,t-1}\right) + \varepsilon_t^b R_{b,t-1} L_{b,t-1} + P_t LIA_{b,t} \\ = L_{b,t} + W_t N_{b,t} \end{aligned} \tag{5}$$

where R_b represents the gross nominal interest rate on bank loans, $0 < \varepsilon^b \leq 1$ the complement of the loan default rate and LIA_b real costs from deviating from a LIA constraint. They are also subject to housing adjustment costs, as in the case of saver households:

$$AC_{H_b,t} = \frac{s_{H_b}}{2}\left(H_{b,t} - H_{b,t-1}\right)^2 \tag{6}$$

When lending to households, banks impose a collateral constraint that limits the loaned amounts to a fraction of the expected housing wealth. Thus

$$L_{b,t} \leq \rho_b \Pi_t L_{b,t-1} + (1-\rho_b)\left(\gamma_t^b E_t \frac{P_{t+1}^H (1-\delta_H) H_{b,t}}{R_{b,t}}\right) \tag{7}$$

where the $0 < \gamma_t^b < 1$ parameter governs the loan-to-value ratio and is allowed to vary as a function of exogenous shocks. In order to capture the empirical fact that loan amounts change only slowly over time, we include $0 < \rho_b < 1$ as an inertia parameter and allowing for the updating of the associated past nominal loan amounts at the inflation rate Π_t. It is worth noting that Equation (7) assumes that banks compute housing wealth in present value terms, considering the expected evolution of house prices, the size of the housing stock and the riskiness of the mortgage loan as reflected in the interest rate. A change in any of these factors implies a change in loan amounts and produces a "financial accelerator" type of mechanism.

Finally, borrower households are subject to a soft LIA constraint governed by intensity parameter s_b which makes it costly for them to deviate from the steady-state housing-wealth-to-loan ratio:[4]

$$LIA_{b,t} = \frac{s_b}{2}\left(\frac{P_t^H H_{b,t}}{L_{b,t}} - \frac{P^H H_b}{L_b}\right)^2 \tag{8}$$

Equation (8) represents a soft constraint in the sense that a relative dearth of credit makes it more difficult (though not impossible) for indebted households to expand or sustain their nominal housing stock. In that sense, it differs from a traditional cash-in-advance constraint, where cash balances necessarily need to be greater or equal than a given nominal consumption amount. While Equation (8) is technically built around an optimal housing wealth-to-loans ratio, it can be interpreted as capturing the role of mortgage credit for housing investment. As such, credit scarcity can be costly for households as they may need to search harder for mortgage loans or be facing a constrained banking sector that is passing on to borrowers higher-than-usual loan appraisal and monitoring costs. Conversely, a credit boom stimulates housing demand. Ultimately, the soft LIA constraint sharpens the specificity of bank loans as primarily funding housing rather than consumption, reflecting the empirical fact that loans to households are by and large mortgage loans.

The household LIA constraint and its corporate counterpart discussed in the next subsection are one the main macrofinancial rigidities of the model, imparting a relevant role to financial factors. Together with banks' target leverage ratio given by Equation (34) in Subsection 2.3, these constraints ascribe a role to credit that is consistent with the micro studies quoted in Subsection 3, in terms of credit's effect on investment and prices. Figure 1 in Annex D illustrates these points by showing how the macroeconomic impact of household default is progressively augmented by the inclusion of the main macrofinancial frictions of the model.

2.2 The non-financial corporate sector

The non-financial corporate sector is vertically organised, comprising entrepreneurs, intermediaries, wholesalers, final goods producers and housebuilders. This structure allows to easily track the introduction of key macroeconomic features and rigidities, which are gradually integrated at different stages of the production process.

The different types of firms are deemed to behave competitively and to be price takers. This can be understood as a consequence of the assumption that, at each stage of production, there is continuum of firms, with none able to yield market power. The exception are wholesale firms who operate in a monopolistically competitive environment due to the fact that each one offers a differentiated product. In the model description below this continuum of firms is indexed in the case of wholesalers, but firm-level indices are otherwise omitted to keep the notation lighter.

[4] Here and elsewhere, the suppression of the t subscript from a variable in an equation denotes that we are considering the steady-state value of that variable.

2.2.1 Entrepreneurs

Entrepreneurs maximise the expected discounted value of a profit stream $\Omega_{e,t}$ where the choice variables are bank loan amounts L_e, investment levels I_e and the two production factors, capital (K_t) and labour (N_t):

$$\max_{\{L_{e,t},I_{e,t},K_t,N_t\}} E_0 \sum_{t=0}^{\infty} \beta_e^t \lambda_{s,t} \Omega_{e,t} \tag{9}$$

Entrepreneurs' stochastic discount rate incorporates that of firm-owning households, $\lambda_{s,t}$. At the same time, the constant discount factor β_e is assumed to be lower than β_s, reflecting a principal-agent friction whereby managers' time horizon with a firm is shorter than that of the (infinitely-lived dynasty of) firm owners. This relative impatience of entrepreneurs to pay out dividends ensures that they will wish to borrow to the maximum possible extent in a neighbourhood of the model's steady state.

The in-period profit is given by

$$\Omega_{e,t} = P_t^X X_t + L_{e,t} - \left(P_t I_{e,t} + \varepsilon_t^e R_{e,t-1} L_{e,t-1} + W_t N_t + P_t LIA_{e,t}\right) \tag{10}$$

where X is a real amount produced and P^X its price, P is the final goods price at which investment goods can be acquired and transformed into physical capital, R_e is the gross nominal interest rate on corporate loans, $0 < \varepsilon^e \leq 1$ is the complement of the corporate loan default rate, N is the total labour supplied by both types of households and LIA_e are the real costs from deviating from a LIA constraint.

Entrepreneurial production technology is Cobb-Douglas:

$$X_t = \varepsilon_t^z \left(K_{t-1}\right)^{\alpha} \left(N_t\right)^{1-\alpha} \tag{11}$$

where ε_t^z accounts for exogenous shocks to total factor productivity (TFP) and $0 < \alpha < 1$ is the share of capital income in total entrepreneurial production.

The law of motion of physical capital is given by

$$K_t = I_{e,t}\left[\varepsilon_t^{I_k} - S^k\left(I_{e,t}, I_{e,t-1}\right)\right] + \left(1 - \delta_k\right) K_{t-1} \tag{12}$$

where $\varepsilon_t^{I_k}$ takes the value of one in the steady-state, while allowing for exogenous shocks that modify investment efficiency, $0 < \delta_k < 1$ is the capital depreciation rate and $S^k \geq 0$ is an investment adjustment cost governed by intensity parameter s_k:

$$S^k\left(I_{e,t}, I_{e,t-1}\right) = \frac{s_k}{2}\left(\frac{I_{e,t}}{I_{e,t-1}} - 1\right)^2 \tag{13}$$

It is worth noting that the fact that entrepreneurs choose both I_e and K is a shorthand way of introducing capital goods production into the economy. This approach is equivalent to an alternative one found in the DSGE literature whereby independent capital goods producers acquire and transform final goods into physical capital.

Similarly to borrowing households, entrepreneurs face a collateral constraint linking the maximum value of their loans to the expected discounted value of their gross operating surplus ($P^X X - WN$) and capital stock:

$$L_{e,t} \leq \rho_e \Pi_t L_{e,t-1} + (1-\rho_e)\left(\gamma_t^e E_t \frac{(P_{t+1}^X X_{t+1} - W_{t+1}N_{t+1}) + (1-\delta_k)Q_{e,t+1}K_t}{R_{e,t}}\right) \tag{14}$$

In the previous inequation, $0 < \rho_e < 1$ is an inertia parameter, Q_e is the price of capital and $0 < \gamma_t^e < 1$ governs the loan-to-value ratio of entrepreneurial firms, which is allowed to vary over time in response to exogenous shocks.

Finally, entrepreneurs are subject to a soft LIA constraint of the form

$$LIA_{e,t} = \frac{s_e}{2}\left(\frac{Q_{e,t}K_t}{L_{e,t}} - \frac{Q_e K}{L_e}\right)^2 \tag{15}$$

where $s_e > 0$ governs the overall intensity of the constraint. According to Equation (15), a relative scarcity of corporate lending increases the cost of sustaining or expanding the capital stock. This may be because of increased search costs for other forms of funding (e.g., equity investment from saver households), because of the lower quality of the investment incurred by liquidity-constrained firms, or for other reasons such as those previously discussed when considering the problem of borrower households. Conversely, relatively abundant credit incentivises the expansion of the capital stock (or may otherwise prove costly if not backed by sufficient collateral).

As discussed in the previous subsection, the LIA constraint, together with bank's target leverage ratio introduced in Subsection 2.3, augment the macroeconomic impact of credit, bringing it in line with evidence from micro studies. The role of these two macrofinancial rigidities is illustrated in Figure 2 of Annex D.

2.2.2 Intermediary firms

Intermediary firms, together with wholesale firms discussed in the next subsection, allow for the introduction of market power, fixed costs and nominal rigidities in the model, the latter via a mechanism of staggered prices. A continuum of intermediaries indexed by $i \in [1, n]$ acquires the production X of entrepreneurs at price P^X and differentiates it into a continuum of i varieties, with each intermediary selling its variety to wholesalers at a price P_i^Y and incurring fixed costs F_i. The maximisation problem of a given intermediary i is thus

$$\max_{\widetilde{P}_{i,t}^Y} E_0 \sum_{t=0}^{\infty} \beta_s^t \lambda_{s,t}\left(P_{i,t}^Y Y_{i,t} - P_t^X X_{i,t} - F_i\right) \tag{16}$$

subject to wholesalers' demand for Y_i. It can be observed that the stochastic discount rate of intermediary firms coincides with that of their owners.

What makes intermediaries' optimisation problem dynamic and allows for the introduction of price rigidities is the fact that only a randomly-determined fraction of firms $1-\phi$ is allowed to revise their prices in any given period. The remaining $0 < \phi < 1$ fraction is stuck with a price previously set, though updated at the steady-state inflation rate. Thus, $\widetilde{P}_{i,t}^Y$ denotes the optimal chosen price whenever an intermediary has the opportunity of revising it. $\widetilde{P}_{i,t}^Y$ can be shown to be

$$\widetilde{P}_{i,t}^{Y} = \frac{\theta}{\theta - 1} \frac{E_t \sum_{l=0}^{\infty} (\phi\beta_s)^l \lambda_{s,t+l} \left(\Pi^l\right)^{-\theta} P_{t+l}^{X} \left(P_{t+l}^{Y}\right)^{\theta} Y_{t+l}}{E_t \sum_{l=0}^{\infty} (\phi\beta_s)^l \lambda_{s,t+l} \left(\Pi^l\right)^{1-\theta} \left(P_{t+l}^{Y}\right)^{\theta} Y_{t+l}} \tag{17}$$

where θ is a product differentiation parameter presented in the next subsection. P_t^Y can be shown to evolve as

$$P_t^Y = \left[(1-\phi)\left(\widetilde{P}_{z,t}^{Y}\right)^{1-\theta} + \phi\left(\left(\Pi_t\right)^{-1}\Pi P_{t-1}^{Y}\right)^{(1-\theta)}\right]^{\frac{1}{1-\theta}} \tag{18}$$

2.2.3 Wholesalers

Wholesalers acquire the product varieties i produced by intermediaries and aggregate them into a composite good Y that can be used as an input for the production of the domestic final good (Y_D), or otherwise exported (Y_{M^*}). The wholesalers' problem is to minimise total expenditure,

$$\min_{Y_{i,t}} \int_0^n P_{i,t}^{Y} Y_{i,t} di \tag{19}$$

subject to a given level of output Y obtained from a Dixit-Stiglitz aggregation technology:

$$Y_t = Y_{D,t} + Y_{M^*,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\theta}} \int_0^n \left(Y_{i,t}\right)^{\frac{\theta-1}{\theta}} dz\right]^{\frac{\theta}{\theta-1}} \tag{20}$$

The $\theta > 0$ parameter is the elasticity of substitution among varieties, conferring differentiation-based market power to intermediary firms.

2.2.4 Final goods producers

Firms producing final goods combine domestic wholesale production Y_D acquired at price P^Y with wholesale production imported from the foreign region, Y_M^*, which is acquired at price P^{Y^*}.[5] Final goods producers minimise total expenditure,

$$\min_{Y_{D,t}, Y_{M,t}^*} P_t^Y Y_{D,t} + P_t^{Y^*} Y_{M,t}^* \tag{21}$$

subject to a constant elasticity of substitution (CES) production technology,

$$Z_t = \left[\left(1-\omega^M\right)^{\frac{1}{\nu}} \left(Y_{D,t}\right)^{\frac{\nu-1}{\nu}} + \left(\omega^M\right)^{\frac{1}{\nu}} \left(Y_{M,t}^*\right)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} \tag{22}$$

where ω_M is an input share parameter and ν the CES parameter.

2.2.5 Housebuilders

Housebuilders acquire final goods for housing investment purposes, I_h, and use them as inputs to change the overall housing stock. Their optimisation problem is to choose investment levels to maximise a stream of profits discounted at the firm owners' rate,

[5] Here and elsewhere, an asterisk signals a foreign economy variable, or one that is traded across borders.

$$\max_{\{I_{h,t}\}} E_0 \sum_{t=0}^{\infty} \beta_s^t \lambda_{s,t} \left(P_t^H \Xi_t - P_t I_{h,t} \right) \tag{23}$$

subject to a housebuilding technology exhibiting decreasing returns to scale and investment adjustment costs:

$$\Xi_t = H_t - (1 - \delta_H) H_{t-1} = \left(s_{h_0} - S^h \left(I_{h,t}, I_{h,t-1} \right) \right) I_{h,t}^{\gamma} \tag{24}$$

$$S^h \left(I_{h,t}, I_{h,t-1} \right) = \frac{s_{h_1}}{2} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right)^2 \tag{25}$$

The $0 < \delta_H < 1$ parameter denotes the depreciation rate of the housing stock, $0 < \gamma < 1$ is a technological parameter governing the degree of decreasing returns to scale and $s_{h_0} > 0$ is a technological parameter calibrated in such a way as to ensure that the usual capital law of motion holds in the steady state. I.e, $H_t = (1 - \delta_H) H_{t-1} + I_{h,t}$ whenever $H_t = H_{t-1} = H$ and $I_{h,t} = I_h$. Parameter $s_{h_1} \geq 0$ governs the intensity of the investment adjustment costs.

The fact that housebuilding is subject to decreasing returns to scale can be motivated by the existence of a production factor in fixed supply, e.g. land, while investment adjustment costs is a standard feature describing real economies.

2.3 Banks

Each region is home to a consolidated banking sector f that operates competitively. Banks grant loans to households (L_h), to entrepreneurs (L_e) and to domestic (IB_f) and foreign banks (IB_f^*). Banks also hold a portfolio of domestic (B_f) and foreign sovereign bonds (B_f^*) and can access a deposit facility (CB_t) with the common central bank, which completes the description of the asset side of their balance sheets. On the funding side, banks take deposits (D_h) and obtain equity financing (K_f) from saver households, while also funding themselves in the domestic and cross-border interbank market (IBF_f).

It should be noted that domestic interbank loans are necessarily in zero net supply in each region, with the gross outstanding long and short positions canceling each other out when considering the banking sector in consolidated terms. For this reason, IB_f is not taken into account when considering the consolidated assets and liabilities of the regional banking sectors. However, domestic interbank lending can still be usefully included in the model in order to study the effects of interbank default and to enable portfolio selection mechanisms, as will be presently seen. In fact, the impact of interbank default is linked to the gross outstanding amounts of interbank exposures, as are any capital requirements associated with interbank lending.

As regards the deposit facility of the central bank, it serves two important purposes. First, it is the means through which the monetary authority enacts its conventional monetary policy. By setting the policy rate R^{EA} on this facility, interest rates in the wider economy are affected via banks' no-arbitrage asset pricing conditions. Second, the presence of a deposit facility allows us to study the effect of other forms of monetary policy. For instance, reserve requirements can be modeled as mandatory amounts held by banks in the deposit facility,[6] while asset purchase programmes can be modeled as a swap of government bonds (or private-sector loans) for central bank reserves.

[6]This, in fact, similar to how CB_t is modeled in the present version of the model, i.e., as exogenously determined by the central bank.

Another key interest rate affecting economy-wide dynamics will be the weighted average rate paid by banks on their interbank funding portfolio IBF_f, which will affect the interest rate paid on depositors (i.e., the other form of debt-based funding banks can resort to) via a no-arbitrage relationship.[7] The average rate on IBF_f will also be the means via which country risk premia can affect an economy's funding costs, as discussed in Subsection 2.3.2.

An important characteristic of the model is that bank head offices price government bonds as well as domestic and foreign interbank loans in a competitive manner taking into account i) the risk-free rate (as given by the deposit facility), ii) the credit risk of each exposure and iii) the respective capital requirements, as interacted with the general conditions of the bank, such as the tightness of the leverage ratio constraint. Bank head offices do not decide, however, the exact proportions of domestic and foreign assets to be held in each of these categories. Instead, they communicate their pricing and investment preferences (in terms of desired steady-state regional asset shares and willingness to substitute across regions) to bond and interbank portfolio managers, which can be understood as separate divisions within the bank. This approach merges the notion of risk- and cost-based, no-arbitrage pricing (conducted by head offices) with preferred habitat effects (introduced by portfolio managers), so that the resulting asset price formation reflects both forces. It allows us to pin down portfolio allocations that reflect observable data and to generate financial flows that are empirically consistent.

Banks take into account the stochastic discount factor of firm owners and maximise the expected present value of dividends, which are equal to net income ($NI_{f,t}$) minus changes in bank capital ($\Delta K_{f,t}$):

$$\max_{\left\{L_{h,t},L_{e,t},B_{f,t},B^*_{f,t},IB_{f,t},IB^*_{f,t},CB_{f,t},D_{h,t},IBF_{f,t}\right\}} E_0 \sum_{t=0}^{\infty} \beta_f^t \lambda_{s,t} \left(NI_{f,t} - \Delta K_{f,t}\right) \tag{26}$$

with

$$\begin{aligned} NI_{f,t} = {} & \left(\varepsilon_t^b R_{b,t-1} - 1\right) L_{h,t-1} + \left(\varepsilon_t^e R_{e,t-1} - 1\right) L_{e,t-1} \\ & + \left(\varepsilon_t^B R_{t-1} - 1\right) B_{f,t-1} + \left(\varepsilon_t^{B^*} R^*_{t-1} - 1\right) B_{f,t-1} + \left(\varepsilon_t^{ib} R^{IB}_{f,t-1} - 1\right) IB_{f,t-1} \\ & + \left(\varepsilon_t^{ib^*} R^{IB^*}_{f,t-1} - 1\right) IB^*_{f,t-1} + \left(R^{EA}_{t-1} - 1\right) CB_{f,t-1} - \left(R_{s,t-1} - 1\right) D_{h,t-1} \\ & - \left(\varepsilon_t^{ib} R^{IBF}_{f,t-1} - 1\right) IBF_{f,t-1} - P_t AC_{K,t} \end{aligned} \tag{27}$$

and

$$\begin{aligned} K_{f,t} &= L_{h,t} + L_{e,t} + B_{f,t} + B^*_{f,t} + IB_{f,t} + IB^*_{f,t} + CB_{f,t} - D_{h,t} - IBF_{f,t} \\ &= L_{h,t} + L_{e,t} + B_{f,t} + B^*_{f,t} + IB^*_{f,t} + CB_{f,t} - D_{h,t} - IB_{f^*,t} \end{aligned} \tag{28}$$

where the second equality of Equation (28) follows from the fact that $IB_{f,t}$ is in zero net supply. In the previous equations $0 < \beta_f < \beta_s$ is the constant discount factor; R and R^* denote the gross nominal yield on domestic and foreign bonds, respectively; $0 < E_t[\varepsilon^B_{t+1}] \leq 1$ is the complement of the expected loss on sovereign bond holdings; $0 < \varepsilon^{ib} \leq 1$ is the complement of the interbank loan default rate; R_f^{IB} and $R_f^{IB^*}$ are the gross interest rates charged on domestic and foreign interbank

[7] This is readily seen in Equation (91) in Appendix B.

lending, respectively;[8] R_f^{IBF} is the average gross interest rate paid on interbank borrowing; and AC_K is the real cost from deviating from a target leverage ratio.

It should be recalled that, in the absence of unexpected shocks, the expected loss rates on mortgage, corporate and interbank loans coincide with actual loss rates due to the operation of the law of large numbers in conjunction with the assumption of the existence of an infinity of private-sector agents. However, given that a government is a single entity, government default is a binomial event. As such, ε_t^B captures the underlying credit risk of the government, as given by the ex ante expected loss on the exposure, rather an actual ex post loss rate. Whether ε_t^B materialises in actual losses is dependent on the sovereign actually defaulting, a scenario which can be modeled as being governed by a "sunspot" variable, with ε_t^B taking the value 1 in the absence of default.

It should also be noted at this stage that a share $0 \leq \omega^f \leq 1$ of banks is assumed to be locked into a strategic game with their home sovereign, whereby their dominant strategy is to increase their exposure to the latter whenever domestic sovereign risk increases. This game is illustrated in Appendix A and is based on the idea that, for highly-exposed banks, increasing domestic bond holdings when confronted with higher credit risk premia is a one-way bet: while shareholder value is always fully wiped out in the event of sovereign default, the higher premia can be pocketed in as extra income in case there is no default. Therefore, such ω^f share of highly-exposed banks consider the actual costs of credit risk, as given by the associated capital requirements discussed below, but not the potential costs, as given by the actual losses in the case of a credit event. This model feature allows us to capture the empirical phenomenon whereby periphery banks reinforced their sovereign home bias during the euro area sovereign debt crisis. It carries no particular implications for the description of the banking sector laid out in this subsection, but leads to two different first order conditions for B_f depending on whether bank $f \in \omega^f$ or not.[9]

In line with the Basel III/IV provisions as set out in the Capital Requirements Regulation and Directive (CRRD) for European Union Member States, banks obey a regulatory constraint whereby their level of capital needs to be equal to or greater than their capital requirements, $KR_{f,t}$, as defined in the CRRD and assessed by bank supervisory authorities:

$$K_{f,t} \geq KR_{f,t} \tag{29}$$

where KR_t is defined as

$$KR_{f,t} = \rho_f \Pi_t KR_{f,t-1} + (1 - \rho_f)(RWA_{f,t} + EL_{f,t}) \tag{30}$$

and

$$RWA_{f,t} = \eta_t^{L_h} L_{h,t} + \eta_t^{L_e} L_{e,t} + \eta_t^B \left(B_{f,t} + B_{f,t}^*\right) + \eta_t^{IB} \left(IB_{f,t} + IB_{f,t}^*\right) \tag{31}$$

Equation (30) computes capital requirements as the sum of a banks' risk weighted assets (RWA_f) and unrecognised expected losses EL_f. RWA are, for their part, computed as bank exposures multiplied by their respective risk weights $\eta \geq 0$. The inclusion of the $0 < \rho_f < 1$ parameter allows for a degree of inertia in adjusting bank capital, which can reflect leniency or inattention on the part of the supervisory authority.

[8] As discussed in Subsection 2.3.2, the return on interbank lending also includes a relative country risk premium e. However, as this premium is determined subsequently by the bank portfolio managers, we not consider it in the optimization problem of head offices, which is why e is omitted from Equation (27).

[9] See Equations (83) and (84) of Appendix B.

It should be noted that Equations (30) and (31) express risk weights in effective form, meaning that they already incorporate a bank's minimum regulatory capital ratio[10] as well as any other capital add-ons, including those that bank management may wish to apply as part of their internal capital adequacy assessment process. In the case of the latter add-ons, the bank may be operating discretionarily above minimum capital requirements, implying that the ρ_f parameter can then partly reflect a smoothing behaviour by bank managers.

In line with the CRRD, bank capital should also cover for unrecognised expected losses and impairments, which justifies the inclusion of the EL_f term.[11] The computation of $EL_{f,t}$ is therefore as follows:

$$\begin{aligned} EL_{f,t} = E_t \Bigg[& (1-\varepsilon_{t+1}^{b})(1-\eta_t^{L_h})L_{h,t} + (1-\varepsilon_{t+1}^{e})(1-\eta_t^{L_e})L_{e,t} \\ & + (1-\eta_t^{B})B_{f,t}\left(\omega^{HFT}\left(1-\frac{\bar{R}_t}{R_t}\right) + (1-\omega^{HFT})(1-\varepsilon_{t+1}^{B})\right) \\ & + (1-\eta_t^{B})B_{f,t}^{*}\left(\omega^{HFT}\left(1-\frac{\bar{R}_t^{*}}{R_t^{*}}\right) + (1-\omega^{HFT})(1-\varepsilon_{t+1}^{B^*})\right) \\ & + (1-\eta_t^{IB})\left((1-\varepsilon_{t+1}^{ib})IB_{f,t} + (1-\varepsilon_{t+1}^{ib^*})IB_{f,t}^{*}\right)\Bigg] \end{aligned} \quad (32)$$

I.e., capital requirements due to unrecognised expected losses on a given exposure equal that part of the exposure not already covered by bank capital, $(1-\eta)$, times the expected default rate $(1-\varepsilon_{t+1})$ on any such part. In the case of government bonds a refinement is introduced. Given that bonds are tradable securities, they can either be held for trading (HFT) or held to maturity (HTM), implying different accounting treatments. In particular, the share of bonds that is HFT, ω^{HFT}, is subject to impairments whenever the yield currently demanded by market participants R_t is higher than the average promised interest rate on those bonds, $\bar{R}_t$, as set in the past when the bonds were originally issued.[12]

Given Equations (28), (30), (31) and (32), we have that Inequation (29) is equivalent to:

[10] As such, if a bank's (core equity) tier 1 ratio is set at 10.5% and the credit risk weight on a given exposure is set at 50%, then the effective risk weight on that exposure is set at 10.5% × 50% = 5.25%.

[11] Impairments are born of the difference between the book value of exposures, as included e.g. in Equation (28), and their fair value, which needs to account for changes in the present value in the case of securities held for trading, or of expected losses in the case of debt exposures held to maturity. These expected losses and impairments, being unaccounted for elsewhere in the model, must be recognised for capital requirements purposes in Equation (30).

[12] The distinction between HFT and HTM allows for the study of the macroeconomic impact of accounting choices and makes for more realistic modeling, but has no major implications for model dynamics.

$$
\begin{aligned}
D_{h,t}+IB_{f^*,t} \leq \rho_f \Pi_t \big(& D_{h,t-1}+IB_{f^*,t-1}-L_{h,t-1}-L_{e,t-1}-B_{f,t-1}-B^*_{f,t-1}-IB^*_{f,t-1}-CB_{f,t-1}\big) \\
& + L_{h,t} + L_{e,t} + B_{f,t} + B^*_{f,t} + IB^*_{f,t} + CB_{f,t} \\
- (1-\rho_f) \Bigg(& \eta_t^{L_h} L_{h,t} + \eta_t^{L_e} L_{e,t} + \eta_t^{B}\left(B_{f,t} + B^*_{f,t}\right) + \eta_t^{IB}\left(IB_{f,t} + IB^*_{f,t}\right) \\
& + E_t \Bigg[(1-\varepsilon^b_{t+1})(1-\eta_t^{L_h}) L_{h,t} + (1-\varepsilon^e_{t+1})(1-\eta_t^{L_e}) L_{e,t} \\
& + (1-\eta_t^B) B_{f,t} \left(\omega^{HFT}\left(1 - \frac{\bar{R}_t}{R_t}\right) + (1-\omega^{HFT})(1-\varepsilon^B_{t+1}) \right) \\
& + (1-\eta_t^B) B^*_{f,t} \left(\omega^{HFT}\left(1 - \frac{\bar{R}^*_t}{R^*_t}\right) + (1-\omega^{HFT})(1-\varepsilon^{B^*}_{t+1}) \right) \\
& + (1-\eta_t^{IB}) \left((1-\varepsilon^{ib}_{t+1}) IB_{f,t} + (1-\varepsilon^{ib^*}_{t+1}) IB^*_{f,t} \right) \Bigg] \Bigg)
\end{aligned} \tag{33}
$$

Besides being subject to a regulatory constraint expressed in Equation (33), banks find it costly to deviate from a target (steady-state) leverage ratio:

$$
\begin{aligned}
AC_{K,t} &= \frac{a_K}{2} \left(\frac{Assets_{f,t}}{K_{f,t}} - \frac{Assets_f}{K_f} \right)^2 \\
&= \frac{a_K}{2} \left(\frac{Liabilities_{f,t}}{K_{f,t}} - \frac{Liabilities_f}{K_f} \right)^2 \\
&= \frac{a_K}{2} \left(\frac{Liabilities_{f,t}}{KR_{f,t}} - \frac{Liabilities_f}{KR_f} \right)^2 \\
&= \frac{a_K}{2} \left(\frac{D_{h,t} + IB_{f^*,t}}{\rho_f \Pi_t KR_{f,t-1} + (1-\rho_f)(RWA_{f,t} + EL_{f,t})} - \frac{D_h + IB_{f^*}}{KR_f} \right)^2
\end{aligned} \tag{34}
$$

where the second equality follows from the fact that $Assets_{f,t} = K_{f,t} + Liabilities_{f,t}$, the third equality from the fact that β_f is calibrated in such a way that Inequation (29) holds with equality in a neighbourhood of the steady state, and the fourth equality from Equation (30).[13]

One the one hand, Equation (34) reflects banks' disinclination to hold too much capital relative to total assets. This is consistent with the well-established observation in the banking literature according to which banks behave as if capital is costly. Besides the usual corporate finance argument that debt can boost the risk-adjusted return on equity by increasing the tax shield, there are also bank-specific reasons that may render debt a cheaper funding alternative when compared with capital. These include the possibility of banks enjoying pricing power in the market for deposits, as well as that of government bail-outs, the latter (partly) protecting bank's creditors, including depositors, who may therefore accept a lower rate of remuneration.

On the other hand, too little capital relative to total assets may also prove costly for banks via the unflattering effect it may have on a bank's solvency position when compared with its peers. For these reasons, Equation (34) postulates a target steady-state leverage ratio from which banks avoid deviating according to intensity parameter $a_K > 0$.

[13] The autoregressive term $\rho_f \Pi_t KR_{f,t-1}$ is assumed to be taken as given by banks in their intertemporal optimization problem. This assumption, which does not materially affect the model structure, avoids introducing unnecessary algebraic complication in banks' first order conditions.

The target leverage ratio constitutes, together with the LIA constraints, the main macrofinancial mechanism of the model. When this set of financial rigidities is entirely removed, the banking sector plays a largely neutral role and does not particularly amplify the impact of financial disturbances, in the line with macroeconomic modeling tradition predating the global financial crisis. Figures 1 and 2 in Annex D illustrate the role of the target leverage ratio in the context of default shocks in the household and corporate sectors.

2.3.1 Banks' bond portfolio manager

Banks' head offices communicate to bond portfolio managers i) competitively-priced bond yields $\tilde{R_f}$ and $\tilde{R}^*_f$, as given by Equations (83), (84), and (85) in Appendix B, as well as ii) their geographical investment preferences in terms of an investment share parameter $0 < \omega_f^B < 1$ and willingness to reallocate their bond holdings across regions in response to yield differentials, $\sigma_f^B > 0$. Portfolio managers maximise a weighted average of "excess" gross returns on domestic $(R/\tilde{R_f})$ and foreign $(R^*/\tilde{R}^*_f)$ bonds under a CES framework incorporating the aforementioned preferences:

$$\max_{B_{f,t},B^*_{f,t}} \left(\left(\omega_f^B\right)^{\frac{1}{\sigma_f^B}} \left(\frac{R_t}{\tilde{R}_{f,t}} B_{f,t}\right)^{\frac{\sigma_f^B-1}{\sigma_f^B}} + \left(1-\omega_f^B\right)^{\frac{1}{\sigma_f^B}} \left(\frac{R^*_t}{\tilde{R}^*_{f,t}} B^*_{f,t}\right)^{\frac{\sigma_f^B-1}{\sigma_f^B}} \right)^{\frac{\sigma_f^B}{\sigma_f^B-1}} \tag{35}$$

subject to

$$\begin{gathered} B_{f,t} + B^*_{f,t} = BP_{f,t} \Leftrightarrow \\ P_t^B \frac{R_t}{\tilde{R}_{f,t}} B_{f,t} + P_t^{B^*} \frac{R^*_t}{\tilde{R}^*_{f,t}} B^*_{f,t} = BP_{f,t} \end{gathered} \tag{36}$$

where B_f denotes domestic government bonds held by domestic banks; B^*_f their holdings of foreign government bonds; BP_f their total sovereign bond holdings; $\tilde{R}_{f,t}$ are cost-based, competitively-priced interest rates resulting from banks' optimisation problem (as presented in Subsection 2.3); R_t are final market interest rates; $P_t^B = \frac{\tilde{R}_{f,t}}{R_t}$ is the "one-period" normalised price of the bond;[14] and $P_t^{B^*} = \frac{\tilde{R^*_{f,t}}}{R^*_t}$.

It is additionally assumed that competitive pressures imply that there are no excess yields on average in the steady state:

$$\frac{\frac{R}{\tilde{R}_f} B_f + \frac{R^*}{\tilde{R}^*_f} B^*_f}{BP_{f,t}} = R^{BP} = 1 \tag{37}$$

It should be noted that, in pricing government bonds, banks' head offices and their portfolio managers help determine required quarterly returns in a market equilibrium each period. This does not mean, however, that government bonds are in general one-period securities. As discussed in Subsection 2.4, the average duration of government bonds is calibrated to available evidence. However, as bonds are tradable securities, market participants freely exchange and reprice outstanding bonds every period.

[14] I.e., a price reflecting the "excess" quarterly yield of a bond. This differs from the usual definition of a bond's price, which reflects the required yield to maturity.

2.3.2 Banks' interbank loan portfolio manager

As in the case of government bonds, banks' head offices transmit to interbank loan portfolio managers their investment preferences in terms of geographical portfolio shares $0 < \omega^{IB} < 1$ and elasticity of substitution among regions $\sigma_f^{IB} > 0$. As regards the pricing of interbank loans to domestic (IB_f) and foreign banks ($IB^*_{f,t}$), head offices first determine the respective competitive interest rates, as per Equations (86) and (87) of Appendix B. The latter pricing equations take into account two forms of default-related costs: i) expected loss rates in the following period - which, given a continuum of banks, will be exactly realised by the law of large numbers - and ii) costs from holding capital against those expected losses. The assessment of default-related costs allows head offices to produce net, default-corrected yields for domestic ($\tilde{R}_f^{IB}$, as given by Equation (101) in Appendix B) and foreign interbank lending ($\tilde{R}_f^{IB^*}$, as given by Equation (102)), which are transmitted to portfolio managers for aggregate return maximisation under a CES framework:[15]

$$\max_{IB_{f,t},IB^*_{f,t}} \left(\left(\omega^{IB}\right)^{\frac{1}{\sigma_f^{IB}}} \left(\tilde{R}_{f,t}^{IB} IB_{f,t}\right)^{\frac{\sigma_f^{IB}-1}{\sigma_f^{IB}}} + \left(1-\omega^{IB}\right)^{\frac{1}{\sigma_f^{IB}}} \left(\frac{\tilde{R}_{f,t}^{IB^*}}{e_t} IB^*_{f,t}\right)^{\frac{\sigma_f^{IB}-1}{\sigma_f^{IB}}} \right)^{\frac{\sigma_f^{IB}}{\sigma_f^{IB}-1}} \tag{38}$$

subject to

$$\begin{gathered} IB_{f,t} + IB^*_{f,t} = IBP_{f,t} \Leftrightarrow \\ P_{f,t}^{IB} \tilde{R}_{f,t}^{IB} IB_{f,t} + P_{f,t}^{IB^*} \frac{\tilde{R}_{f,t}^{IB^*}}{e_t} IB^*_{f,t} = IBP_{f,t} \end{gathered} \tag{39}$$

where $e_t > 0$ is a relative country risk premium $P_{f,t}^{IB} = \frac{1}{\tilde{R}_{f,t}^{IB}}$, $P_{f,t}^{IB^*} = \frac{e_t}{\tilde{R}_{f,t}^{IB^*}}$ and IBP_f are the total interbank lending amounts approved by head offices.

Domestic interbank loans, which are in zero net supply from the viewpoint of the consolidated domestic banking sector, are modeled as a share ib_f of domestic loans to the household and corporate sectors, and admit exogenous shocks:

$$IB_{f,t} = ib_f \times (L_{h,t} + L_{e,t})\, \varepsilon_t^{IB_f} \tag{40}$$

Two aspects should be discussed regarding the workings of the interbank portfolio management mechanism. The first relates to the relative country risk premium e_t. This premium is assumed not to exist in the steady state (i.e., e is calibrated to 1). However, it emerges as an external equilibrium mechanism whenever a region's demand for interbank loans exceeds the other region's willingness to supply them. As will be seen in Section 4 this will often occur when a region's net foreign asset (NFA) position deteriorates with respect to the other region. However, differently from other approaches found in the literature, the link between country risk and the NFA is not mechanistically set in a dedicated equation, but is rather the result of the interplay between supply and demand for international funding. Besides relative NFA positions, among the key drivers of country risk is the willingness of portfolio managers to reallocate interbank lending across regions in response to relative returns, as given by the CES parameter σ_f^{IB}.[16] This

[15] It is worth noting that the meaning of $\tilde{R}_f^{IB}$ and $\tilde{R}_f^{IB^*}$ is not therefore equivalent to that of $\tilde{R}_f$ and $\tilde{R}_f^*$, as the interest rates considered by interbank portfolio managers are default cost-corrected, while those considered by bond portfolio managers are not. The reason for this difference in modeling approaches is explained below.

[16] As such, allowing for time variation in the CES and share parameters as a function of exogenous shocks readily permits capturing the shifts in risk attitudes and flight-to-safety phenomena that characterised the 2009-14 sovereign debt crisis in the euro area.

formulation also constitutes an alternative to the "excess yield" approach seen in the previous subsection. The technical reason for the different modeling approaches lies in the fact that, while "excess yields" can be identified separately in each sovereign debt market, country risk premia can only be identified in relative terms in the model.

The second aspect relates to why the $\tilde{R}_f^{IB}$ variables are produced by discounting default-related costs from the competitive interest rates determined by head offices. This choice is motivated by the fact, in the presence of default risk, portfolio managers should not be guided in their portfolio choice by promised returns (R_f^{IB}), but rather by expected returns ($\tilde{R}_f^{IB}$). Otherwise, portfolio managers would tend to invest naively in the interbank loans commanding the highest promised return, notwithstanding the fact that those returns will fail to materialise in the subsequent period.

2.4 The government sector

The government raises lump-sum taxes T from each type of household in proportion to their size (as determined by ω_s), acquires a share of the final good to conduct government expenditure G, manages its outstanding debt amounts B on which it pays average gross interest $\bar{R}$, and receives the central bank profits DIV_{CB} (or, conversely, recapitalises central bank losses) each period. The government respects the following budget constraint:

$$P_t G_t + \bar{R}_{t-1} B_{t-1} = B_t + P_t T_t + DIV_{CB,t} \tag{41}$$

The final consumption expenditure of the government is constant as a fraction g of steady-state GDP, safe for exogenous expenditure shocks ε_t^{gy}:

$$\frac{G_t}{Y} = g\varepsilon_t^{gy} \tag{42}$$

Equation (42) assumes that government spending does not change in real terms, thus imparting a degree of countercyclicality and macroeconomic stabilisation role to fiscal policy. As regards tax policies, the government sets the tax-to-GDP ratio t_t to eventually stabilise the government debt-to-GDP ratio b, and also possibly in response to the business cycle and financial market conditions:

$$\ln\left(\frac{t_t}{t}\right) = t_1 \ln\left(\frac{b_{t-1}}{b}\right) + t_2 \ln\left(\frac{Y_t}{Y}\right) + t_3 \ln\left(\frac{R_t/R_t^{EA}}{R/R^{EA}}\right) + \varepsilon_t^{\zeta} \tag{43}$$

where $t_1 > 0$ is a parameter capturing the speed at which the government stabilises the debt ratio towards its steady-state value, t_2 is a parameter allowing for (counter)cyclical tax policies, $t_3 \geq 0$ is a parameter capturing governments' reaction to marginal funding costs and ε_t^{ζ} is a tax policy shock. The effect associated with the t_3 parameter is consistent with evidence from the literature (see, e.g., Meyermans (2019)) according to which euro area governments have tended to tighten fiscal policies when confronted with rising spreads. Its inclusion allows, in particular, to study the impact of the introduction of a common sovereign debt instrument on market discipline, as such instruments may alter a sovereign's marginal funding cost (see, e.g., Giudice et al. (2019)).

Total government debt is held by domestic and foreign banks:

$$B_t = B_{f,t} + B_{f^*,t} \tag{44}$$

Government default risk ε_t^B is linked to sovereign probabilities of default PD, which in turn are linked to the expected debt ratio:

$$\varepsilon_t^B = (1 - PD_{G,t} \times LGD_G) \tag{45}$$

$$PD_{G,t+1} = E_t \left[\exp\left(p_1 \left(\frac{B_{t+1}}{4 \times Y_{t+1}} \right)^{p_2} \right) - 1 + \varepsilon_t^{pd} \right] \tag{46}$$

where $0 < LGD \leq 1$ is a loss given default parameter capturing the percentage loss imposed on bondholders in the event of sovereign default, while p_1 and p_2 are curvature parameters describing the non-linear relationship between default risk and the government debt ratio.

Each period the government faces gross financing needs (GFN) associated with the roll-over of maturing bonds and, possibly, a fiscal deficit:

$$GFN_t = B_t - B_{t-1} + \frac{1}{m} B_{t-1} \tag{47}$$

where m is the average maturity of government bonds expressed in terms of quarters. New government debt linked to GFN is issued at prevailing market rates R_t and feeds into average rates as follows:

$$\bar{R}_t = \frac{\left(\frac{m-1}{m} B_{t-1}\right) \bar{R}_{t-1} + (GFN_t)\, R_t}{\frac{m-1}{m} B_{t-1} + GFN_t} \tag{48}$$

Equations (47) and (48) are based on the assumption that government bonds mature randomly with probability $1/m$ each quarter. Such a simplifying assumption, which can be found e.g. in Chatterjee and Eyigungor (2012), is a useful aggregation device allowing us to keep track of just an average and a marginal government interest rate, thus avoiding the inclusion of numerous state variables, each one linked to a particular bond issuance. At the same time, this approach allows for a gradual pass-through of marginal rates to average interest rates that is consistent with observable government bond duration. Finally, it is worth noting that exogenous term premia could be trivially included and linked to average bond duration m, although we abstract from such premia in the present version of the model.

2.5 The common monetary authority

The common monetary authority sets the policy rate R_t^{EA} on the deposit facility of the central bank in order to meet a union-wide inflation target Π^{EA} and to stabilise union-wide output Y_t^{EA} according to a Taylor rule:

$$\ln\left(\frac{R_t^{EA}}{R^{EA}}\right) = \ln\left[\left(\frac{R_{t-1}^{EA}}{R^{EA}}\right)^{\rho_R} \left(\left(\frac{\Pi_t^{EA}}{\Pi^{EA}}\right)^{\gamma_\Pi} \left(\frac{Y_t^{EA}}{Y^{EA}}\right)^{\gamma_Y} \right)^{1-\rho_R} \right] + \varepsilon_t^R \tag{49}$$

where

$$\Pi_t^{EA} = n\Pi_t + (1-n)\Pi_t^* \tag{50}$$

and

$$Y_t^{EA} = nY_t + (1-n)Y_t^* \tag{51}$$

The $0 < \rho_R < 1$ parameter captures the degree of policy rate smoothing, $\gamma_\Pi > 1$ and $\gamma_Y \geq 0$ are the weights attached by the monetary authority to price stability and output stabilisation, respectively, and ε_t^R is a monetary policy shock. Conventional monetary policy transmit to the wider economy mainly via the savings-consumption decision of saver households, the valuation changes it produces on banks' bond holdings and by changing the discount rate for calculating the present value of assets used as collateral by entrepreneurs and borrower households.

Besides setting the interest rate, the monetary authority can purchase government bonds held by banks and exchange them for reserves with the central bank. Asset purchases are determined exogenously in the model, and are set to zero in the steady state.

The monetary authority's balance sheet comprises reserves as liabilities and government bonds as possible assets. It produces a net income stream that is rebated to euro area governments every period according to a distribution key based on their relative economic size, as determined by n.

2.6 The balance of payments

The balance of payments identity equals the nominal trade balance $P_t TB_t$ to the sum of (the negative of) the income account and the financial account:

$$\begin{aligned} P_t TB_t = \bar{R}_{t-1} B_{f^*,t-1} + \frac{1-n}{n} e_{t-1} R^{IB}_{f^*,t-1} \varepsilon_t^{ib} IB_{f^*,t-1} + \frac{1-n}{n} B^*_{f,t} + IB^*_{f,t} + CB_{f,t} + K_{CB,t} \\ - \Bigg(\frac{1-n}{n} \bar{R}^*_{t-1} B^*_{f,t-1} + \frac{R^{IB^*}_{f,t-1}}{e_{t-1}} \varepsilon_t^{ib^*} IB^*_{f,t-1} + B_{f^*,t} + \frac{1-n}{n} IB_{f^*,t} \\ + R^{EA}_{t-1} CB_{f,t-1} + K_{CB,t-1} + DIV_{CB,t} \Bigg) \end{aligned} \tag{52}$$

where K_{CB} denotes the capital position of the central bank, a "foreign" asset owned by euro area governments. The trade balance is in turn given by exports minus imports:

$$P_t TB_t = \frac{1-n}{n} P_t^Y Y_{M^*,t} - P_t^{Y^*} Y^*_{M,t} \tag{53}$$

3 Calibration

The model parameters are calibrated based on: i) observable data for the 11 largest euro area Member States; ii) standard values from the DSGE literature; and iii) results from microeconomic studies and other relevant literature. The core region captures an aggregate comprising Germany, France, the Netherlands, Belgium, Austria and Finland. The periphery region aggregate comprises Italy, Spain, Portugal, Greece and Ireland. We use region-specific values where allowed by the data sources, and keep parameters symmetric across regions otherwise. Table 2 in Appendix D lists the model parameter values.

Parameters derived from observable data generally take 2019 as the reference year.[17] This year choice is motivated by the fact that the economic turbulence caused by the covid-19 crisis (and

[17] In some cases, parameter values are based on averages taken over 2019 and previous years, for robustness sake.

the subsequent Russian invasion of Ukraine) render data for more recent years less representative of a possible steady state. Eurostat data has been used to calibrate: the relative size n of the periphery regional bloc; the share g of government spending; the average maturity m of government debt;[18] a corporate loan-to-GDP ratio of 78% in each region through the γ^e parameter; and a housing stock-to-GDP ratio[19] of 1.53 in the periphery and of 1.65 in the core through the ν^h parameter. Data provided by the European Banking Authority (EBA) in its Q4 2019 Risk Dashboard informed the expected loss rates on household (ε^b) and corporate loans (ε^e), while the steady-state loss rate on interbank loans (ε^{ib}) was set to zero by assumption. EBA data from its 2019 Transparency Exercise informed: the risk weights η^B on sovereign bonds; the portfolio share of domestic sovereign bonds (ω_f^B); the share of sovereign bonds held for trading (ω^{HFT}); the portfolio share of domestic interbank lending (ω^{IB}); and the amount of domestic interbank lending as a percentage of corporate and household loans, ib_f. European Central Bank (ECB) data was used to set: the risk weights on household (η^{L_h}), corporate (η^{L_e}) and interbank loans (η^{IB});[20] a euro area-wide household loan-to-value ratio of 81% via the γ^b parameter;[21] and the steady-state central bank reserves as a percentage of other bank assets, cb_f.[22] The share of imports in domestic demand, ω^M, is derived from bilateral trade data for 2015 available from the OECD TiVA database. We choose to rely on trade-in-value-added data, rather than on gross trade flows, as the former is more consistent with the trade specification described in Subsection 2.2.4 and, in particular, in Equation (22), where foreign exports have no import content and are thus, in effect, in foreign value added terms. The housing transaction costs parameters s_H are region-specific and derived from Global Property Guide data.[23]

A set of parameters was calibrated based on standard values found in the DSGE literature. We relied, in particular, on three institutional workhorse DSGE models of the euro area employed by the ECB and the European Commission, and described in Coenen et al. (2018), Albonico et al. (2019) and Burgert et al. (2020). The parameters calibrated based on these models are: the capital income share α; the discount factors β_b and β_s; the Taylor rule coefficients γ_Π, γ_Y and ρ_R; the capital depreciation rate δ_k; the consumption habits parameter h; the CES of intermediate good varieties θ; the CES of imports ν; the weight of hours worked in the utility function ν^n; the corporate investment adjustment costs s_k;[24] the Calvo price stickiness parameter ϕ; the inverse of the Frisch elasticity of labour supply φ;[25] the constant relative risk aversion of households χ; and the share of saver households ω_s. Some banking and construction sector parameters were informed by specialised models. As such, the DSGE model with a banking sector of Iacoviello (2015) was used to calibrate the persistence parameters ρ_b, ρ_e and ρ_f, while the DSGE model with a housing sector of Pataracchia et al. (2013) was used to calibrate the housing depreciation rate δ_H and the construction technology parameter γ.[26] We relied on Quint and Rabanal (2014) for the housing investment adjustment costs parameter s_{h_1} and for the CES of the interbank loan portfolio σ_f^{IB}.[27]

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[18] For Austria, the source was the OeBFA.

[19] The value of the housing stock is net of land value.

[20] Equality of steady-state inflation rates across regions requires (via Equation (109) in conjunction with other steady-state equations) that η^{IB} be the same in both regions. For this reason, we use euro area-wide rather than region-specific values for η^{IB}.

[21] As per the loan-to-value ratio at origination derived from the 2019 SSM credit underwriting data collection exercise and published in Lang et al. (2020).

[22] Given that the model's steady state does not include central bank asset purchases, the calibration of reserves was based on average figures taken from 2001 to 2013 (the year preceding the introduction of the ECB's asset purchase programme).

[23] Source: `http://www.globalpropertyguide.com/transaction-costs`. Consistent with Equations (3) and (6), each s_{H_s} and s_{H_b} corresponds to half of a "round-trip", with regional figures calculated as dwelling value-weighted averages of national figures.

[24] For s_k, we rely on the original estimation of the model described in Coenen et al. (2018), i.e. the NAWM model of Christoffel et al. (2008), whose parameter value is closer to those typically found in the wider literature.

[25] Our choice for φ sits between the somewhat higher figures found in the aforementioned models, and the lower values found in Smets and Wouters (2003) and Quint and Rabanal (2014).

[26] The value of the γ parameter is also consistent with land representing 25% of total housing-related wealth, a figure broadly in line with empirical estimates.

[27] While Quint and Rabanal (2014) use a different approach for determining international risk premia - namely a reduced-form equation linking risk premia to the foreign debt ratio -, their estimated parameter κ_B can be

Non-DSGE literature and microeconomic studies informed a subset of parameters, notably those influencing the financial dynamics of the model. The parameter governing the strength of the penalty from deviating from target bank capital ratios, a_K, was derived from literature on the effects of regulatory changes to bank capital requirements. In fact, the latter provide natural experiments where banks are temporarily dislodged from their target capital ratios by having to adjust to new (usually higher) target ratios.[28] In order to set the value of a_K we simulate the effect on loan supply of a 1 pp increase in capital requirements that is progressively incorporated by banks into a new target capital ratio. Under our calibration, such a shock reduces bank loans by 1.5% in the first 9 months, and by 2% on average during the first three years, in line with the results for European banks of Mésonnier and Monks (2015) and Maurin and Toivanen (2012).[29]

Among the parameters derived from the non-DSGE literature are also those governing the strength of the LIA constraints, s_b and s_e. As regards the corporate LIA parameter s_e, it was calibrated so that a credit supply shock reducing corporate lending by an average of 1% in the first year produces a reduction of approximately 0.8% in corporate investment and in the corporate investment ratio (I_e/K) during that period. This co-movement is consistent with the range of results found in the literature, such as those in Degryse et al. (2019) for Belgium, Cingano et al. (2016) for Italy, Amiti and Weinstein (2018) for Japan and Claessens et al. (2014) for recessions associated with credit crunches.[30] As regards the LIA parameter of households, s_b, it was calibrated by drawing on Favara and Imbs (2015), Bayoumi and Melander (2008) and Claessens et al. (2014). Under our parameter choice a 1% positive shock to household lending leads to an average increase in house prices of approximately 0.2% in the first year.[31]

The CES of bank's bond portfolio, σ_f^B, was set so that the model mimics the estimated impact of central bank asset purchases on bond prices. Under our calibration, acquiring 10% of euro area government debt lowers annual yields by 24 bps, equivalent to the value found by Altavilla et al. (2015) in their event study (one-day change) for the euro area.[32] This figure is on the lower end of available estimates for the euro area.[33] However, the particular circumstances under which asset purchases have taken place may have potentiated their effect, motivating the selection of a conservative figure.

The share of banks locked in a strategic game with the domestic sovereign, ω^f, was calibrated

mapped to σ_f^{IB} on account of the latter's role in generating country risk in our model.

[28]It is worth noting that, as mentioned in European Central Bank (2015), DSGE models with a banking sector tend to underestimate the transition costs to higher capital requirements when compared to micro studies. At the same time, some DSGE models may arguably overestimate the long-run impact of hikes in capital requirements by failing to distinguish between short-run and long-run effects. Our modeling strategy imposes consistency with micro studies, while our simulation strategy in Subsection 4.4 purges long-run effects from short-term transition costs. We return to the discussion of the distinction between short-run and long-run effects of macroprudential policy in that subsection.

[29]Our calibrated impact sits towards the lower end of the range found in the literature. For instance, it is weaker than that estimated in Aiyar et al. (2014) and in Noss and Toffano (2016) for UK banks, or that estimated by Brun et al. (2013) for French banks. However, given that such microeconomic studies often cover periods of economic fragility that can potentiate the immediate negative effects of an increase in capital requirements, we find it preferable to focus on the lower end of available estimates.

[30]The results found in the literature need to be translated into terms that are comparable among themselves and with the model. For instance, credit shocks in Degryse et al. (2019) where translated from standard deviations to percentage changes, and the regression results of Cingano et al. (2016) were applied to the in-model K/L_e ratio. Different horizons also complicate the comparisons. As such, while we considered co-movements during the first year, the horizons considered in Cingano et al. (2016) and Claessens et al. (2014) are longer.

[31]This figure is somewhat higher than the 0.12% found in Favara and Imbs (2015) for the US, but considerably lower than the approximately one-to-one co-movement between credit and house prices found by Claessens et al. (2014) for recessions associated with credit crunches. As regards Bayoumi and Melander (2008), our calibration produces results that are: i) approximately twice the estimated long-run impact on spending in residential investment of a one monetary unit increase in lending and ii) approximately half the same estimated impact when the variable of concern is spending on durable goods.

[32]Here and elsewhere, results were made comparable by considering asset purchases in percentage of total debt.

[33]For instance, it is lower than the effect found over a two-day window in the same paper by Altavilla et al., or the results in Andrade et al. (2016), De Santis (2020) and Monteiro and Vasicek (2019). As regards estimates for US, our simulated impact is close to that of Vayanos and Vila (2021), and somewhat stronger than that implied by the results in Krishnamurthy and Vissing-Jorgensen (2012).

so as to reproduce the home bias dynamics observed during the European sovereign debt crisis. As such, under our calibration a 1 pp increase in sovereign debt spreads is associated with a 3.65% increase in the relative share of domestic sovereign bond holdings.[34]

The value of the sovereign risk curvature parameters, p_1 and p_2, was adapted from the analysis in Monteiro and Vasicek (2019). The values of the tax rule parameters t_1 and t_3 were, in turn, derived from the fiscal reaction function literature. Concretely, t_1 was set so that a 1 pp increase in the government debt-to-GDP ratio elicits a 0.05 pp increase in the government's primary balance as a percentage of GDP. This sensitiveness is consistent with the average estimates found in the literature review conducted by Checherita-Westphal and Žďárek (2017). As regards t_3, it was set so that a 1 pp increase in the government bond spread elicits a 0.3 pp increase in the primary balance, consistently with the results in Meyermans (2019), and in Mauro et al. (2015) for the post-World War II period.

The relative value of the discount factors β are such that all borrowing constraints bind in a neighbourhood of the steady state. In particular, the discount factor of entrepreneurs, β_e, was set below that of saver households and bankers, and has a value similar to that of Breuss et al. (2015). In addition, β_f was set so that banks earn a real return on equity of 9% in the steady state, in line with estimates for the cost of equity of euro area banks.[35]

A small number of parameters are assumed, or follow their own rationale. Quarterly steady-state government debt-to-GDP ratios b are set in line with the Maastricht Treaty reference figure of 60% in the core region, and consistently with an assumed 90% annual ratio in the periphery region.[36] Target inflation rate Π^{EA} is assumed to be 2%, in line with the ECB's monetary policy strategy announced in 2021. Fixed costs F are set so that the profits of intermediary firms are zero in equilibrium. The housing investment parameter s_{h_0} is set so that a standard law of motion, $H_t = (1 - \delta_H) H_{t-1} + I_{h,t}$, applies to the housing stock in the steady state. The LGD_G parameter is set at a conventional 60%, and t_2 is set to zero by assumption, so that real government expenditure does not respond to the business cycle.

4 Macrofinancial dynamics

In this section we rely on a first-order approximation of our calibrated model to study the effects of i) standard monetary, fiscal and productivity shocks, ii) credit risk shocks affecting the private and government sector, iii) changes in macroprudential policy, iv) capital flights in a recession and v) an unconventional monetary policy shock. The impact from introducing a common sovereign debt instrument is also discussed, particularly in connection with point iv). As in the model description of Section 2, we assume throughout that the periphery is the domestic region. Simulated shock sizes serve merely to illustrate model dynamics and do not seek to capture empirically-identified shock magnitudes.

4.1 Expansionary monetary, fiscal and productivity shocks

We begin by examining the basic properties of the model with a simulation of three standard expansionary shocks: a 10% increase in government fexpenditure in the domestic region,[37] a 1 pp cut in the policy rate and a 1% increase in the TFP of the domestic region. The respective

[34] This is the co-movement observed in the periphery region from the first quarter of 2010 to the second quarter of 2012, based on EBA data for sovereign bond holdings (with Greece excluded from the sample due to its particular circumstances involving the restructuring of sovereign debt). While there is no similar historical experience to draw from regarding the core region, we assume the same elasticity between spreads and domestic bond holdings as that of the periphery.

[35] See, e.g., European Banking Authority (2019).

[36] Actual government debt ratios in 2019 were 73% in the core region and 116% in the periphery region.

[37] Given that government final consumption expenditure represents 19% of the GDP of the periphery, the shock is worth 1.9% of GDP. This shock size is motivated by the fact that it produces responses of an order of magnitude similar to that of the other shocks discussed in this subsection, more easily allowing for cross-shock comparisons of the impulse response function profiles.

impulse response functions (IRFs) are plotted in Figure 3 of Appendix D for a selection of key economic variables covering the two regions, as well as the euro area aggregate.

All three shocks increase output in the domestic region, as well as in the euro area aggregate. Monetary policy loosening, being a symmetric shock, tends to produce similar responses in both regions. In particular, it boosts output, consumption and international trade on impact and in subsequent quarters. The associated internal demand expansion generates strong inflationary pressures which soon lead to a reversal in the policy rate.[38] While corporate investment reacts positively on impact, this effect is muted due to adjustment costs and the forward-looking behaviour of entrepreneurs, who anticipate the forthcoming policy rate correction.

While the shocks to domestic government expenditure and productivity are both expansionary for the domestic economy, they carry different implications for other macroeconomic variables and for the foreign economy. Due to Ricardian behaviour, crowding out effects and a tightening reaction in monetary policy, an increase in government expenditure does not boost domestic private consumption, and has a neutral effect on corporate investment on impact. The inflationary pressures it generates lead to an increase in the policy rate and a decrease in the real exchange rate (RER)[39] which, together with an internal demand-led increase in imports, produces a deterioration of the trade balance and of the NFA position. The increase in import demand helps, in turn, to provide an external trade boost in the foreign region.

As regards the productivity shock, the expansion in aggregate supply has a deflationary effect which prompts monetary policy loosening. Firms invest more to take advantage of the higher return on capital and the favourable macroeconomic environment, while the foreign economy experiences a negative competitiveness effect that increases the RER and deteriorates net exports.

In our streamlined modeling of the government sector, changes to the government debt ratio are driven by nominal growth effects, the real interest rate on government bonds and government expenditure shocks. As such, the latter has a noticeable impact on the debt ratio, bringing it from an initial 90% to approximately 92% by the end of the second year, an increase nonetheless mitigated by the strong nominal growth effect of expansionary fiscal policy. The other shocks decrease the debt ratio via positive GDP growth, an effect that is much more marked in the case of a policy rate shock which, unlike a productivity shock, has an inflationary nature.

4.2 Credit risk shocks in the private sector

Figures 4 and 5 provide an overview of the impact of an increase in the default rates of households, entrepreneurs and banks located in the domestic region in terms of the IRFs of key economic and financial variables. The increase in the default rates of households and firms is equivalent to 5% of GDP, a magnitude comparable to that observed in periphery countries during the European sovereign debt crisis. The shock to interbank default rates is also set at 5% of GDP for comparison purposes, even though such a magnitude would be unprecedented by historical standards.

Credit risk shocks have important and persistent recessionary effects in the model. Shocks to household and corporate default rates lead to a significant drop in output in the region experiencing them, with the effect being somewhat more pronounced in the case of shocks to firms. As regards interbank default shocks, the impact is shared with the foreign region, which is directly exposed to domestic banks via cross-border interbank lending. Default shocks have a net deflationary effect by impairing the functioning of the banking sector and leading to a tightening of financial conditions. In the case of interbank default shocks, the deflationary effect

[38]It should be noted that, differently from the expenditure and productivity shocks which have autoregressive parameter 0.9, the policy rate shock is assumed to have zero persistence via its autoregressive parameter. While interest rate smoothing implicit in Equation (49) lends the policy rate shock a degree of persistence, this fades away fairly quickly.

[39]We define the RER as the price level of final goods in the foreign economy relative to that of the domestic economy. I.e., $rer_t = P_t^*/P_t$.

is particularly marked at euro area level due to the strength of its transmission to the foreign region.

Household and corporate default shocks strongly impair investment levels in the domestic region through tighter financial conditions, a drop in collateral value and weakened internal demand. However, a rebound begins to take hold in the second year following the initial shock for the cases under analysis.

Default on mortgages generates bank repossession-like phenomena[40] whereby borrower households relinquish a large share of their housing stock, which is acquired by the bank-owning households in a context of depressed house prices and investment. Domestic consumption levels drop with the impact of corporate and interbank default, but remain robust in the case of household default. In the latter case, borrowers experience a consumption boost on impact from walking away from their debt commitments, but are quickly affected by the subsequent credit crunch, which depresses their consumption in a durable manner. Bank-owning savers do not experience sustained wealth losses from mortgage default due to banks' assumed ability to reprice loans following the materialisation of the default shock. On the contrary, they respond positively to a supportive decrease in policy rates. Overall, there is an economy-wide redirection away from housing investment (which is durably impaired) and into private consumption, with savers' positive consumption dynamics more than offsetting the negative consumption dynamics of borrowers.

The foreign region weathers well the purely idiosyncratic household and corporate default shocks in its trading partner. Given that it has no exposure to the affected asset classes, it incurs no default-related losses. At the same time, the foreign region benefits from a supportive drop in policy rates (which boosts investment) and from cheaper imports. In the medium term, the foreign economy temporarily gains a competitive edge over the domestic economy, which also provides a degree of support. These benign dynamics contrast with the case of interbank default, which can impair the functioning of the foreign financial sector and thus have an important negative impact on output, consumption and investment. In fact, as evidenced in comparative investment dynamics, default in the domestic banking sector can in some respects be more detrimental to the foreign region than to the domestic one, as it implies a wealth transfer from the former to the latter.

By depressing domestic demand and temporarily increasing the RER, household and corporate default shocks initially improve the trade balance, thereby lending a degree of support to the domestic economy. Interbank default shocks, however, have a more symmetric impact across economies and a weaker net impact on trade. All the default shocks increase the NFA position of the domestic economy in the first year, which in the case of household and corporate default shocks is due to the emergence of a trade surplus. Due to a sustained improvement in the NFA position, the relative country risk of the domestic economy tends to decrease when in the presence of corporate and household shocks.[41] At the same time, country risk increases with interbank default in connection with a retrenchment of cross-border interbank lending.

Focusing now on the response of interest rates, it should be noted that, given the assumed ability of banks to reprice their lending rates every period, they are able to insure themselves against loan losses stemming from heightened expected default rates in the periods following the initial shock by raising interest rates. This can be observed in Figure 5 where the interest rate on the asset class experiencing the default shock sees its nominal interest rate increase significantly, even as the monetary authority lowers the euro area-wide nominal risk-free rate in a supportive policy move. This risk premia-related increase in financial discount rates contributes, however,

[40] Such phenomena is entirely implicit in the model and does not follow from specific repossession equations. Rather, it is the result of the fact that credit-dependent borrowers find it too costly to sustain their housing stock, which is then partly released on the market.

[41] It should be noted that country risk is strictly defined in the context of the model and does not account for any form of default risk, which is covered by dedicated variables. As such, a negative performance of the domestic economy does not necessarily generate country risk, especially if it improves the NFA position.

to lower the present value of the respective collateral, thereby having a direct effect on credit provision and inducing financial accelerator dynamics. Due to the negative impact of default on inflation and bank balance sheets, real interest rates also increase in loan classes not experiencing losses, thus contributing to tighter overall financial conditions.

It should be further noted that the ability to reprice private-sector loans does not render banks immune to the costs of default. Besides suffering unexpected losses on impact, they are further constrained to adjust their solvency and leverage positions to deal with a riskier environment that is causing valuation losses on their assets and exacting higher capital requirements. This is reflected, in particular, in the regulatory need to provision for expected losses. In practice, default losses induce banks to try and support their tier 1 ratios, which can be severely affected on impact, and to adjust leverage ratios towards target values. The speed at which tier 1 ratios are to be repaired is assumed to be essentially determined by supervisory authorities, as reflected in the ρ_f parameter of Equation (30). While tier 1 ratio repair is not instantaneous, it occurs quickly in our calibration, in the first two quarters following the default shock. At the same time, the default-induced increase in capital requirements moves the leverage ratio given by Equation (34) away from its target value. The eventual adjustment of the tier 1 and leverage ratios is achieved not only via capital injections from shareholders, but also by an asset downsizing and a tightening of credit conditions, with particular incidence in the riskier asset classes (namely, the one experiencing default, and others commanding higher risk weights). The overall persistence of credit tightening effects is partly determined by the quarterly autoregressive parameter of the default shock, which was set to 0.9.

Finally, one can observe that default shocks can significantly deteriorate the government debt ratio via their strong negative impact on real and nominal growth, with this effect reversing over time as the real government interest rate turns negative (itself a consequence of the relative safety and favourable regulatory treatment of government bonds compared to other asset classes).

4.3 Credit risk shock in the sovereign sector

After having examined the effects of credit risk shocks in the private sector, we turn now to a situation where the domestic sovereign experiences heightened credit risk. This is modeled as a 1 pp increase in the quarterly probability of default, i.e., as a shock to ε_t^{pd} in Equation (46), with autoregressive parameter equal to 0.9. The results are shown in Figure 6.

An increase in domestic sovereign risk generates losses on the balance sheets of banks in the two regions, as evidenced by a drop in tier 1 ratios on impact. These losses arise both in the case of bonds held for trading (where an increase in sovereign yields lowers their market value) as well as in bonds held to maturity (where banks need to provision for higher expected losses). As in the case of private sector default risk, the effect is contractionary and deflationary, being more marked in the domestic region (where home bias in banks' bond holdings implies a larger exposure), but also directly affecting the foreign region, which is also exposed to domestic sovereign bonds. Private consumption is affected in both regions and there is a significant contraction in investment in the domestic region in the first two years. The domestic region, being the more impacted of the two, benefits from an external trade impulse, supported by a favourable RER.

As regards financial variables, tighter financial conditions mean a drop in mortgage and firm loans, as well as a heightened quarterly interest rate on domestic bonds, notwithstanding a supportive decrease in the policy rate. Because of the home bias effect discussed in Appendix A, a share of domestic banks takes advantage of the high-yield environment by significantly increasing their demand for domestic sovereign bonds, meaning that government interest rates rise less than might be expected from a pure risk-return perspective. Notwithstanding this effect, the domestic government debt ratio is durably affected by a lower real and nominal growth path, as well as by higher interest rates.

While the existence of a common European safe asset is only explicitly simulated below, in Subsection 4.5, it is worth nothing at this point that one of its effects would arguably be to prevent sudden, sharp and asymmetric increases in sovereign risk. Thus, the simulation discussed in the present subsection can also be understood as highlighting possible benefits from introducing a common safe asset, at least as regards its canonical form as a "Eurobond", where research suggests that credit risk would remain contained, even in peak crisis periods.[42]

4.4 Permanent shocks to macroprudential policy

Figures 7 and 8 depict the effects of two forms of macroprudential policy tightening: a permanent increase in tier 1 ratios and a permanent decrease in the maximum loan-to-value ratios of households and firms.

In a simulation of this nature, it is important to consider whether there are transition frictions or not. In Figure 7 the macroprudential shocks are applied to the euro area aggregate and no transition frictions are assumed, meaning that banks and borrowers internalise the new regulatory environment by updating their target capital and borrowing ratios along the transition path.[43] On the contrary, Figure 8 (which depicts macroprudential shocks in the domestic economy) assumes the existence of transition frictions, so that agents feel the full brunt of deviating from their target financial ratios on impact. After the initial shock, domestic banks and borrowers start updating these targets, so that 80% of the new capital ratios, and 20% of the new LTV ratios, are internalised by the end of the first year.[44] The new targets are assumed to be fully internalised eventually, so that the economy converges to the same steady state as that of the frictionless transition in the long run.[45,46]

The stricter macroprudential policies under consideration generally lead to lower output, consumption, capital and investment levels in the long run. At the same time, they produce short- to medium-run deflationary dynamics, that eventually turn inflationary in the case of a negative LTV shock, as the capital stock dwindles and the supply side of the economy is affected. On the financial side, tighter macroprudential policies depress steady-state loans to households and firms, while tending to increase nominal and real lending rates for the riskiest asset class (corporate loans). However, the effects are very mild in the case of a frictionless transition, and in any case in the long run: for a 1 pp increase in euro area-wide tier 1 ratios, the long-run contraction in output is 0.04% to 0.05%, depending on the concerned region. In this case, the main long-run effect of an increase in tier 1 ratios stems from the need to fund a slightly higher share of lending with bank capital (which is relatively expensive, as it needs to be remunerated at a return on equity determined by β_f), instead of with cheaply-available deposits. Effects are comparatively stronger in the case of a permanent 1% decrease in loan-to-value ratios. This is particularly true of the housing market, which experiences a negative feedback loop whereby a lack of credit depresses housing investment, and a lack of housing investment depresses mortgage lending by

[42] See Monteiro (2023).

[43] This is implemented by effectively turning off the leverage and LIA constraints, so that banks and borrowers perceive to be meeting their financial targets at all times as they settle into the new steady state.

[44] The speed of internalisation of the new capital ratios is in line with that assumed in the simulations of Mendicino et al. (2020), where the implementation of new capital requirements is essentially completed after two years. Their paper, which follows a different modeling strategy than the one presented here, provides a rare instance where a general equilibrium model is applied to study in an in-depth manner the transition and long-run implications of changes to capital requirements.

[45] The simulation is implemented in an approximate manner by assuming temporary shocks to capital requirements and LTV ratios under the usual capital ratio and LIA constraints. This approach is made possible by the fact that, as will be seen, the long-run effects of the macroprudential shocks are quite small under a frictionless transition, a situation that is thus approximately equal to having only temporary shocks.

[46] It is worth noting in this connection that one could also simulate the effects of permanent macroprudential shocks assuming that the original leverage and LIA constraints remain fully active throughout the transition *and in the new steady state*. This, however, would be theoretically inconsistent, in effect transforming business-cycle frictions into a permanent feature of the new steady state. In other words, it would imply accepting that the initial steady-state ratios used in the leverage and LIA equations are the only frictionless ones (a kind of "divine coincidence" governing the initial calibration of the model), and that any other steady state would generate a permanent drag on the economy. For this reason, we do not consider this type of simulation.

eroding the value of the housing collateral. The existence of this feedback loop means that the “multiplier” on LTV ratios is greater than one, i.e., a 1% reduction in LTV ratios leads to more than a 1% reduction in mortgage lending. On a more positive note, the redirection of household budgets away from housing supports consumption in the short to medium-run.

While the effects of macroprudential policy shifts are seen to be relatively mild in the long run, they can be potent in the short run in the presence of transition frictions. This is shown in Figure 8, where a bank capital requirements shock requiring the immediate increase of the periphery's tier 1 ratio to meet that of the core's produces a decline in the periphery's GDP of up to 0.5% in the first year. The effects of a 1% decrease in LTV ratios are less sharp on impact, but more protracted, eventually leading to a trough of -0.5% in the periphery's GDP. Both types of shock have strong negative impact on corporate investment, which is larger and more persistent in the case of an LTV shock. In the presence of transition frictions, capital ratio shocks strongly impact the interest rate and loan amounts of the riskiest asset class (i.e., firm lending), while a reduction in LTV ratios is particularly detrimental for housing investment and long-term mortgage lending (though supportive of consumption in the short term).

While the assessment in this subsection focus on the costs of macroprudential policies, it does not contradict their overall net benefit. Gauging the latter would, however, require dedicated analysis capturing, inter alia, the positive effects of macroprudential policies on prevention, absorption and recovery from adverse shocks.

4.5 Capital flights in a recession, with and without a common sovereign debt instrument

Figures 9 and 10 depict the effects of a severe recession where the domestic economy suffers a 5% fall in TFP and the government responds immediately by raising expenditure by 25%. Three scenarios are plotted: in the first one, international financial market participants respond according to their baseline investor preferences; in the second one, there is a panicked response by foreign investors, who retrench into their home markets in a capital flight; in the third scenario, there is also a capital flight by foreign investors, but the euro area is endowed with a common sovereign debt instrument, in the form of a “Eurobond”.

Capital flights are modeled as a 10 pp increase in the home bias parameter ω^{IB^*} of foreign interbank lenders, together with a sharp 99% reduction in the elasticity of substitution of interbank loans in both regions (i.e., a 99% reduction in σ^{IB} and σ^{IB^*}). Shocks to TFP, government spending and ω^{IB^*} are assumed to have a quarterly persistence of 90%.

The common sovereign debt instrument is introduced as a “canonical” Eurobond, i.e., a financial instrument that fully replaces existing national debt and is largely risk-insensitive. In practice, the Eurobond is modeled by assuming a very large elasticity of substitution between government bonds[47] and by setting portfolio investment shares equal to the shares of national debt outstanding. This modeling strategy implies that investors cannot distinguish between issuing regions, and that sovereign bond markets are fully integrated under one price. Furthermore, the periphery's probability of default, as given by Equation (46), is set so as to be insensitive to domestic debt levels, consistently with the results in Monteiro (2023).

In the baseline scenario, the support offered by an increase in government expenditure is short-lived and eventually outweighed by the severity of the productivity shock, with the domestic economy experiencing a recession as a result. However, the expenditure shock boosts imports, which provide a modest growth impulse to the foreign economy on impact. The combination of a sharply negative supply shock and a strongly positive demand shock produces strong inflationary pressures, which lead to an increase in the policy rate.

[47]This elasticity is infinite in theory, although setting it to a very high level produces equivalent results, while allowing the model to solve numerically without further modifications to its structural equations.

When a capital flight is added to the baseline scenario, the drop in output in the domestic economy sharpens further. Given foreign investors' unwillingness to fund the domestic economy, country risk shoots up, tightening domestic financing conditions. Consumption and investment drop more markedly than before, and the economy is forced to embark on an external trade-led recovery characterised by internal devaluation, a curtailment of imports and an expansion of exports. A capital flight also leads, by its very nature, to a strong retrenchment in interbank lending to the domestic economy. This forces domestic banks to also withdraw from foreign debt markets, so as to refinance the domestic economy and absorb the expansion in domestic government debt. Nominal interest rates on government bonds and interbank loans largely co-move with the policy rate, but are also driven by widening spreads between the two regions.[48] As regards the foreign economy, the sudden repatriation of capital has a overheating effect that stimulates output, consumption and inflation in the short term.

A euro area endowed with Eurobonds approximates in several respects the no capital-flight outcome explored in the first scenario, even when the interbank market is assumed to be characterised by the same level of panic seen in the second scenario. The stabilising effect of Eurobonds in a capital flight context means i) that the combined TFP and government expenditure shock remains inflationary; ii) that the drop in private consumption and housing investment is not as sharp, thus supporting welfare; and iii) that external funding remains available via the government bond market, preventing country risk from shooting up and imports from collapsing. At the same time, the presence of Eurobonds implies that the domestic region is not forced to embark on an export-led recovery, a situation which ultimately prolongs the negative effect of the crisis on output via protractedly low levels of net trade and corporate investment. Conversely, the foreign region benefits from the periphery's continued access to external funding, which props up the core's exports and output. Because of the very nature of common debt issuance, investors cannot discriminate between domestic and foreign bonds. As such, the share of periphery debt held by banks increases equally in both regions, mirroring the increasing share of periphery debt in total euro area debt brought about by the periphery's expansionary fiscal policies. It is worth noting that the fact that the model includes neither distortionary taxation nor government investment means that the benefits of Eurobonds are likely to be underestimated. In fact, by supporting continued government funding, Eurobonds mean that governments can moderate rises in distortionary taxation and cuts in public investment in a crisis context, thus helping to avert the associated negative effects on growth.

4.6 An unconventional monetary policy shock

We conclude our investigation of macrofinancial dynamics in the euro area by looking at the effects of an unconventional monetary policy (UMP) shock whereby the monetary authority acquires 10% of the outstanding government debt of each region on impact, and gradually unwinds these asset purchases thereafter at a rate of 5% per quarter. The results are shown in Figure 11.

When studying the effects of asset purchases, it is important to consider how UMP interacts with conventional Taylor rule-based monetary policy. In the illustrative simulations presently considered, UMP is deployed as a shock from the steady-state, when inflation is already at target. In such a case, policy rates cannot abide by the standard Taylor rule described in Equation (49), as monetary policy would be incongruous otherwise. I.e., it would be trying to boost inflation through asset purchases, only to see these efforts thwarted by a reactive increase in policy rates. In practice, UMP has been deployed when inflation is below target and policy rates have neared, or reached, the effective lower bound. In any case, it is useful to combine asset purchases with forward guidance whereby the monetary authority commits not to increase policy rates for an extended period of time, as was the case in advanced economies over the past decade. Concretely, we assume that the monetary authority credibly announces that the policy rate R^{EA} will remain

[48] This effect is only observable in the interbank market once we take into account that the effective cross-border lending rate of the foreign economy is $e_t \times R^{IB}_{f*,t}$, i.e., a rate that includes the country risk premium e_t.

frozen for one or two years, depending on the simulation concerned.[49,50]

Figure 11 shows the result of these simulations. Government bond purchases appreciate bond prices, lower yields and de-risk bank balance sheets, as bonds are exchanged for risk-free central bank reserves. The latter are seen to jump on impact, and to gradually decrease thereafter as asset purchases unwind. Bank balance sheets are thus strengthened through lower expected losses and valuation gains on bond holdings, which makes them pursue more expansionary credit policies, as reflected in increased lending and lower interest rates. Looser financial conditions provide, in turn, a boost to euro area inflation, consumption, investment and output. At the same time, higher nominal growth and lower interest rates improve government debt ratios. All these effects are augmented when policy rates are frozen for two years, rather than one. In such a case, however, policy rates need to react more strongly once they are allowed to rise again in order to maintain inflation expectations anchored.[51] This results in a stronger correction, observable in output, lending rates and other macroeconomic variables, in the second and third years.

5 Conclusion

We have looked at the macrofinancial dynamics of a monetary union such as the euro area through the lens of a general equilibrium model enriched with financial frictions, portfolio selection mechanisms, endogenous country risk premia, relevant and regulatory-consistent financial intermediators and a detailed modeling of government bond markets and monetary policy transmission. The characteristics of our model allow for empirically-consistent properties, and we have so calibrated it and employed it to conduct a number of experiments relating to macrofinancial shocks and policy innovations.

We have seen, in particular, how household and corporate default shocks can have a lasting depressing effect on economic activity in the region experiencing them, and be of a deflationary nature by leading to a tightening of financial conditions. They can also carry specific economic implications, with mortgage defaults leading to an eventual dislocation of the housing stock from borrowers to creditors, and with lending and interest rates reacting particularly strongly in the sector directly concerned by the loan losses. While household and corporate default shocks may have no negative effects on the trading partner economy (which sees a drop in export demand, but benefits from a cut in the policy rate), the same is not true of interbank default and of heightened sovereign risk. The latter are seen to be recessionary and deflationary forms of financial disturbance that affect financial intermediation and the real economy in both regions of the monetary union irrespective of their origin, a result that can be understood as the consequence of the direct cross-border exposures in sovereign and interbank debt markets.

We then considered the effects of macroprudential policy by simulating two types of permanent policy changes. An increase in banks' capital requirements is seen to permanently shift economies to lower output, consumption and investment paths. At the same time, it shifts loan levels downwards and the interest rate of the riskiest asset class upwards. While these effects can be potent in short run in the presence of transition frictions, they are minor in the long run and need to be weighed against the financial stability benefits that an increase in capital requirements may produce. A decrease in the maximum allowed loan-to-value ratios similarly depresses output, investment and, eventually, consumption. Its effects can be more marked in the long run than

[49] To ensure model stability and a re-anchoring of inflation expectations, agents also expect the monetary authority to take into account the cumulated deviation from the inflation target once the Taylor rule kicks in. This contrasts with the baseline specification of the Taylor rule, which considers only the contemporaneous deviation.

[50] Contrary to the previous subsections, the model is simulated in fully non-linear form and in a deterministic framework in order to handle the policy rate commitment.

[51] It should be noted that asset purchases are simulated as a shock from the steady state, when inflation is already on target. This differs from the real world application of UMP, which has typically been introduced in periods of low or negative inflation.

those of a capital ratio hike, particularly as regards the housing market, which can experience significant drops in investment and mortgage lending due to a negative feedback loop between housing collateral availability and lending for housing investment. As before, while long-run effects remain contained, the short term impact of tightening loan-to-value ratios can be potent in the presence of transition frictions.

As regards cross-border capital flights in a recession, we have seen how a panicked response of foreign investors can significantly sharpen the drop in output, consumption and investment in the economy experiencing the recession-inducing total factor productivity (TFP) shock. The disruption produced by a capital flight also tends to reverse the strong inflationary pressures from a negative TFP shock coupled with a positive government expenditure shock. Other phenomena produced by a capital flight are the forcing of the afflicted economy onto an external trade-led recovery path and a sharp increase in country risk, both of which act as external equilibrium mechanisms in a context of bilateral retrenchment in cross-border financial flows. The presence of a common sovereign debt instrument in the form of a fully-fledged "Eurobond" helps to approximate the no-capital flight outcome in some respects by facilitating the afflicted economy's access to external funding. This moderates the drop in domestic consumption, prevents deflationary dynamics from setting in and contains the increase in country risk. At the same time, the common debt instrument delays an external trade-led adjustment and prolongs the weakness in output.

Finally, we turned our attention to an unconventional monetary policy (UMP) shock whereby the monetary authority acquires sovereign bonds in the market and commits to keeping policy rates unchanged for a period of time. UMP is seen to be a powerful tool for temporarily boosting inflation and output. Eased financial conditions result in increased lending, consumption and investment, as well as lower lending rates. The policy is more potent the longer policy rates stay frozen, although inflation expectations management may require a stronger offsetting monetary policy impulse as UMP is discontinued, which can then lead to a macroeconomic correction.

As regards future avenues for model improvement and research, a less stylised representation of the government sector could be usefully developed, particularly to explore its interaction with the macrofinancial disturbances analysed in this paper. In particular, the model could profit from features such as distortionary taxation and the possibility of governments conducting investment. The inclusion of a rest of the world bloc could likewise prove useful by expanding the model's analytical scope as regards cross-border spill-overs and external stabilisation mechanisms. Finally, the empirical relevance of the model could be further improved by estimating some of the parameters with Bayesian methods applied to our calibrated "priors".

References

Aiyar, S., C. W. Calomiris, and T. Wieladek (2014): "Does Macro-Prudential Regulation Leak? Evidence from a UK Policy Experiment," *Journal of Money, Credit and Banking*, 46, 181–214.

Albonico, A., L. Calés, R. Cardani, O. Croitorov, F. D. Dio, F. Ferroni, M. Giovannini, S. Hohberger, B. Pataracchia, F. Pericoli, P. Pfeiffer, R. Raciborski, M. Ratto, W. Roeger, and L. Vogel (2019): "The Global Multi-Country Model (GM): An Estimated DSGE Model for Euro Area Countries," European Economy Discussion Paper 102, European Commission.

Altavilla, C., G. Carboni, and R. Motto (2015): "Asset purchase programmes and financial markets: lessons from the euro area," Working Paper 1864, European Central Bank.

Amiti, M. and D. E. Weinstein (2018): "How Much Do Idiosyncratic Bank Shocks Affect Investment? Evidence from Matched Bank-Firm Loan Data," *Journal of Political Economy*, 126, 525–587.

Andrade, P., J. Breckenfelder, F. De Fiore, P. Karadi, and O. Tristani (2016): "The ECB's asset purchase programme: an early assessment," Working Paper 1956, European Central Bank.

Andreeva, D. C. and T. Vlassopoulos (2019): "Home Bias in Bank Sovereign Bond Purchases and the Bank-Sovereign Nexus," *International Journal of Central Banking*, 15, 157–197.

Badarau, C., F. Huart, and I. Sangaré (2021): "Macroeconomic and policy implications of eurobonds," *International Review of Law and Economics*, 65, 105954.

Bayoumi, T. and O. Melander (2008): "Credit Matters: Empirical Evidence on U.S. Macro-Financial Linkages," Working Paper 08/169, International Monetary Fund.

Bokan, N., A. Gerali, S. Gomes, P. Jacquinot, and M. Pisani (2018): "EAGLE-FLI: A macroeconomic model of banking and financial interdependence in the euro area," *Economic Modelling*, 69, 249–280.

Breuss, F., W. Roeger, and J. in 't Veld (2015): "The stabilising properties of a European Banking Union in case of financial shocks in the Euro Area," European Economy Economic Papers 550, European Commission.

Brun, M., H. Fraisse, and D. Thesmar (2013): "The Real Effects of Bank Capital Requirements," Débats économiques et financiers, Banque de France.

Brunnermeier, M. K., S. Langfield, M. Pagano, R. Reis, S. V. Nieuwerburgh, and D. Vayanos (2017): "ESBies: safety in the tranches," *Economic Policy*, 32, 175–219.

Burgert, M., W. Roeger, J. Varga, J. in 't Veld, and L. Vogel (2020): "A Global Economy Version of QUEST: Simulation Properties," European Economy Discussion Paper 126, European Commission.

Calvo, G. A. (1983): "Staggered prices in a utility-maximizing framework," *Journal of Monetary Economics*, 12, 383–398.

Canova, F., L. Coutinho, C. Mendicino, E. Pappa, M. T. Punzi, and D. Supera (2015): "The Domestic and the International Effects of Financial Disturbances," presented at a DIW seminar on May 6, 2015: https://www.diw.de/documents/dokumentenarchiv/17/diw_01.c.503348.de/macroseminar_ss2015_canova.pdf.

Chatterjee, S. and B. Eyigungor (2012): "Maturity, Indebtedness, and Default Risk," *American Economic Review*, 102, 2674–99.

Checherita-Westphal, C. and V. Žďárek (2017): "Fiscal reaction function and fiscal fatigue: evidence for the euro area," Working Paper 2036, European Central Bank.

Christiano, L., M. Eichenbaum, and C. Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113, 1–45.

Christoffel, K., G. Coenen, and A. Warne (2008): "The New Area-Wide Model of the Euro Area: a micro-founded open-economy model for forecasting and policy analysis," Working Paper 944, European Central Bank.

Cingano, F., F. Manaresi, and E. Sette (2016): "Does Credit Crunch Investment Down? New Evidence on the Real Effects of the Bank-Lending Channel," *Review of Financial Studies*, 29, 2737–2773.

Claessens, S., M. A. Kose, and M. E. Terrones (2014): "What happens during recessions, crunches and busts?" *Economic Policy*, 24, 653–700.

Coenen, G., P. Karadi, S. Schmidt, and A. Warne (2018): "The New Area-Wide Model II: an extended version of the ECB's micro-founded model for forecasting and policy analysis with a financial sector," Working Paper 2200, European Central Bank.

De Santis, R. A. (2020): "Impact of the Asset Purchase Programme on euro area government bond yields using market news," *Economic Modelling*, 86, 192–209.

Degryse, H., O. De Jonghe, S. Jakovljević, K. Mulier, and G. Schepens (2019): "Identifying credit supply shocks with bank-firm data: Methods and applications," *Journal of Financial Intermediation*, 40, 100813.

ESRB High-Level Task Force on Safe Assets (2018): "Sovereign bond-backed securities: a feasibility study," Report, European Systemic Risk Board.

European Banking Authority (2019): "Risk Assessment Questionnaire – Summary of the Results - Autumn 2019," EBA questionnaire, European Banking Authority.

European Central Bank (2015): "The impact of the CRR and CRD IV on bank financing," Eurosystem response to the DG FISMA consultation paper, European Central Bank.

Favara, G. and J. Imbs (2015): "Credit Supply and the Price of Housing," *American Economic Review*, 105, 958–92.

Gertler, M. and P. Karadi (2011): "A model of unconventional monetary policy," *Journal of Monetary Economics*, 58, 17–34.

Gertler, M. and N. Kiyotaki (2010): "Financial Intermediation and Credit Policy in Business Cycle Analysis," in *Handbook of Monetary Economics*, ed. by B. M. Friedman and M. Woodford, Elsevier, vol. 3, chap. 11, 547–599.

Giudice, G., M. de Manuel, Z. G. Kontolemis, and D. P. Monteiro (2019): "A European Safe Asset to Complement National Government Bonds," available at SSRN: https://ssrn.com/abstract=3447173.

Gourinchas, P.-O., T. Philippon, and D. Vayanos (2016): "The Analytics of the Greek Crisis," in *NBER Macroeconomics Annual 2016, Volume 31*, National Bureau of Economic Research, NBER Chapters, 1–81.

Horvath, B., H. Huizinga, and V. Ioannidou (2015): "Determinants and Valuation Effects of the Home Bias in European Banks' Sovereign Debt Portfolios," Discussion Paper 10661, CEPR.

Iacoviello, M. (2015): "Financial business cycles," *Review of Economic Dynamics*, 18, 140–163.

Jarociński, M. and B. Maćkowiak (2018): "Monetary-fiscal interactions and the euro area's malaise," *Journal of International Economics*, 112, 251–266.

Kollmann, R., M. Ratto, W. Roeger, and J. in't Veld (2013): "Fiscal policy, banks and the financial crisis," *Journal of Economic Dynamics and Control*, 37, 387–403.

Krishnamurthy, A. and A. Vissing-Jorgensen (2012): "The Aggregate Demand for Treasury Debt," *Journal of Political Economy*, 120, 233–267.

Lang, J. H., M. Pirovano, M. Rusnák, and C. Schwarz (2020): "Trends in residential real estate lending standards and implications for financial stability," published as part of the ECB's Financial Stability Review, May 2020.

Leandro, A. and J. Zettelmeyer (2019): "Creating a Euro Area Safe Asset Without Mutualizing Risk (Much)," Working Paper 19-14, Peterson Institute for International Economics.

Maurin, L. and M. Toivanen (2012): "Risk, capital buffer and bank lending: a granular approach to the adjustment of euro area banks," Working Paper 1499, European Central Bank.

Mauro, P., R. Romeu, A. Binder, and A. Zaman (2015): "A modern history of fiscal prudence and profligacy," *Journal of Monetary Economics*, 76, 55–70.

Mendicino, C., K. Nikolov, J. Suarez, and D. Supera (2020): "Bank capital in the short and in the long run," *Journal of Monetary Economics*, 115, 64–79.

Meyermans, E. (2019): "Does market discipline enter governments' fiscal reaction functions in the euro area?" *Quarterly Report on the Euro Area*, 18, 7–21.

Modigliani, F. and R. Sutch (1966): "Innovations in Interest Rate Policy," *The American Economic Review*, 56, 178–197.

Monteiro, D. and B. Vasicek (2019): "A retrospective look at sovereign bond dynamics in the euro area," *Quarterly Report on the Euro Area*, 17, 7–26.

Monteiro, D. P. (2023): "Common sovereign debt instruments in the euro area," European economy discussion paper, European Commission, forthcoming.

Mésonnier, J.-S. and A. Monks (2015): "Did the EBA Capital Exercise Cause a Credit Crunch in the Euro Area?" *International Journal of Central Banking*, 11, 75–117.

Noss, J. and P. Toffano (2016): "Estimating the impact of changes in aggregate bank capital requirements on lending and growth during an upswing," *Journal of Banking and Finance*, 62, 15–27.

Pariès, M. D., C. Kok, and E. Rancoita (2019): "Macroprudential policy in a monetary union with cross-border banking," Working Paper 2260, European Central Bank.

Pataracchia, B., R. Raciborski, M. Ratto, and W. Roeger (2013): "Endogenous housing risk in an estimated DSGE model of the Euro Area," Economic Paper 505, European Commission.

Poutineau, J.-C. and G. Vermandel (2015): "Cross-border banking flows spillovers in the Eurozone: Evidence from an estimated DSGE model," *Journal of Economic Dynamics and Control*, 51, 378–403.

——— (2017): "Global banking and the conduct of macroprudential policy in a monetary union," *Journal of Macroeconomics*, 54, 306–331, banking in Macroeconomic Theory and Policy.

Quint, D. and P. Rabanal (2014): "Monetary and Macroprudential Policy in an Estimated DSGE Model of the Euro Area," *International Journal of Central Banking*, 10, 169–236.

Saka, O. (2018): "Domestic banks as lightning rods? Home bias during the eurozone crisis," Working Document 2018/03, Centre for European Policy Studies.

Schmitt-Grohé, S. and M. Uribe (2003): "Closing small open economy models," *Journal of International Economics*, 61, 163–185.

Smets, F. and R. Wouters (2003): "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, 1, 1123–1175.

Vayanos, D. and J.-L. Vila (2021): "A Preferred-Habitat Model of the Term Structure of Interest Rates," *Econometrica*, 89, 77–112.

Appendix A Heightened home bias as a strategic outcome

One of the empirical observations resulting from the European sovereign debt crisis was the increase in the home bias of the sovereign debt portfolios of banks located in "periphery" euro area countries. As documented in Horvath et al. (2015), Saka (2018) and Andreeva and Vlassopoulos (2019), periphery countries increased their exposure to domestic sovereigns as the spreads of the latter began to rise in 2010. This behaviour can be understood as the rational result of a non-cooperative strategic game between banks and the domestic sovereign, where the weakly dominant strategy of banks is to increase exposure amounts.

Table 1: Payoff matrix of a game between a bank and its domestic sovereign

		Government	
		Default	Not default
Bank	Increase exposure	$(max(-100, 0) = \underline{0}, -1200)$	**($\underline{\mathbf{10}}$, $\underline{\mathbf{-900}}$)**
	Not increase exposure	$(max(-50, 0) = \underline{0}, -1000)$	$(5, \underline{-900})$

Note: The underlined payoffs indicate the optimal strategic responses; the payoff in bold type indicates the Nash equilibrium.

To see this, consider the stylised payoff matrix in Table 1 of a bank that is already highly exposed and does not consider decreasing its level of exposure. As the sovereign probability of default (and therefore bond yields) increase, the bank can opt to maintain its exposure or increase it. Because the initial exposure level is already very high, it will go bankrupt in the event of sovereign default, whatever it chooses to do. While bank losses are larger for a highly exposed bank, the payoff of shareholders is always zero in the event of sovereign default due to their limited liability. However, if the bank increases its exposure and the government does not default, then it can pocket bigger profits from the higher yields applied to a larger asset base. This makes increasing its exposure a one-way bet or, in game-theoretic terms, a weakly dominant strategy.

At the same time, the government faces a higher economic and social cost of default if its domestic banks have increased their exposure, as it may need to bail them out at larger recapitalisation needs, or otherwise face a highly impaired banking system.[52]

[52]This effect may even tip the government towards the decision of not defaulting, although the payoffs in Table 1 were set so that not defaulting is already the government's dominant strategy.

Appendix B Dynamic conditions of the model

This appendix presents the dynamic conditions of the model as derived from agents' optimisation problems. All variables are expressed in real terms. As such, nominal variables which appear in upper case in the main text are here expressed in lower case to denote that they have been deflated by the final goods price level of the respective region (e.g., $d_{s,t} \equiv \frac{D_{s,t}}{P_t}$, $d^*_{s,t} \equiv \frac{D^*_{s,t}}{P^*_t}$, $p^Y_t \equiv \frac{P^Y_t}{P_t}$ and $p^{Y^*}_t \equiv \frac{P^{Y^*}_t}{P^*_t}$). Likewise, lower case interest rates are expressed in real terms (e.g., $r^D_{s,t} \equiv \frac{R^D_{s,t}}{\Pi_t}$). The real exchange rate is defined as $rer_t \equiv \frac{P^*_t}{P_t}$ and therefore evolves as $rer_{t+1} = \frac{\Pi^*_t}{\Pi_t} rer_t$. The stochastic discount factor is expressed in real terms as $\Lambda_{s,t} \equiv P_t \lambda_{s,t}$. Lagrange multipliers ξ have been normalised by dividing by λ_s. The different β discount factors have been calibrated in such a way that all constraints bind in a neighbourhood of the steady state. The conditions presented hereunder focus on the domestic economy, with those for the foreign economy following by analogy.

The first order conditions of **saver households** are:

$$\Lambda_{s,t} = (C_{s,t} - hC_{s,t-1})^{-\chi} \tag{54}$$

$$\frac{\nu^h_s H^{-\chi}_{s,t}}{\Lambda_{s,t}} + \beta_s E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left((1-\delta_H) p^H_{t+1} + s_{H_s} (H_{s,t+1} - H_{s,t}) \right) \right] = p^H_t + s_{H_s} (H_{s,t} - H_{s,t-1}) \tag{55}$$

$$w_t = \frac{\nu^n_s N^{\varphi}_{s,t}}{\Lambda_{s,t}} \tag{56}$$

$$\beta_s E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} r^D_{s,t} \right] = 1 \tag{57}$$

$$C_{s,t} + t_t Y_t + AC_{H_s,t} + p^H_t (H_{s,t} - (1-\delta_H) H_{s,t-1}) + d_{s,t} = r^D_{s,t-1} d_{s,t-1} + w_t N_{b,t} + div_{s,t} \tag{58}$$

where t_t denotes the tax-to-GDP ratio.

The first order conditions of **borrower households** are:

$$\Lambda_{b,t} = (C_{b,t} - hC_{b,t-1})^{-\chi} \tag{59}$$

$$\frac{\nu^h_b H^{-\chi}_{b,t}}{\Lambda_{b,t}} + (1-\delta_H)(1-\rho_f)\left(\gamma^b_0 \epsilon^{\iota b}_t\right) \xi_{b,t} E_t \left[\frac{p^H_{t+1}}{r_{b,t}} \right] + \beta_b E_t \left[\frac{\Lambda_{b,t+1}}{\Lambda_{b,t}} \left((1-\delta_H) p^H_{t+1} + s_{H_b} (H_{b,t+1} - H_{b,t}) \right) \right] = p^H_t + s_{H_b} (H_{b,t} - H_{b,t-1}) + s_b p^H_t \left(\frac{p^H_t H_{b,t}}{l_{b,t}} - \frac{p^H H_b}{l_b} \right) \tag{60}$$

$$w_t = \frac{\nu_b^n N_{b,t}^{\varphi}}{\Lambda_{b,t}} \tag{61}$$

$$1 - \xi_{b,t} = \beta_b E_t \left[\frac{\Lambda_{b,t+1}}{\Lambda_{b,t}} \left(\varepsilon_{t+1}^b r_{b,t} - \rho_f \xi_{b,t+1} \right) \right] \tag{62}$$

$$l_{b,t} = \rho_f l_{b,t-1} + (1 - \rho_f) \left(\left(\gamma_0^b \epsilon_t^{\iota b} \right) E_t \frac{p_{t+1}^H (1 - \delta_H) H_{b,t}}{r_{b,t}} \right) \tag{63}$$

$$C_{b,t} + t_t Y_t + AC_{H_b,t} + p_t^H \left(H_{b,t} - (1 - \delta_H) H_{b,t-1} \right) + \varepsilon_t^b r_{b,t-1} l_{b,t-1} + LIA_{b,t} = l_{b,t} + w_t N_{b,t} \tag{64}$$

where $\xi_{b,t}$ denotes the Lagrange multiplier associated with the collateral constraint.

The first order conditions of **entrepreneurs** are:

$$1 = q_{e,t} \left(\varepsilon_t^{I_k} - \frac{s_k}{2} \left(\frac{I_{e,t}}{I_{e,t-1}} - 1 \right)^2 - s_k \left(\frac{I_{e,t}}{I_{e,t-1}} - 1 \right) \frac{I_{e,t}}{I_{e,t-1}} \right) + \beta_e E_t \left[q_{e,t+1} \frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} s_k \left(\frac{I_{e,t+1}}{I_{e,t}} - 1 \right) \left(\frac{I_{e,t+1}}{I_{e,t}} \right)^2 \right] \tag{65}$$

$$q_{e,t} = \beta_e E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left(\alpha p_{t+1}^X \left(Y_{t+1} + \frac{1}{\theta - 1} Y \right) K_t^{-1} + q_{e,t+1} (1 - \delta_k) \right) \right] + (1 - \rho_e) \epsilon_t^{\iota e} \gamma_0^e \frac{\xi_{e,t}}{r_{e,t}} E_t \left[\alpha p_{t+1}^X \left(Y_{t+1} + \frac{1}{\theta - 1} Y \right) K_t^{-1} + q_{e,t+1}(1 - \delta_k) \right] + s_e \left(\frac{q_{e,t} K_t}{l_{e,t}} - \frac{q_e K}{l_e} \right) \frac{q_{e,t}}{l_{e,t}} \tag{66}$$

$$w_t = p_t^X (1 - \alpha) \frac{Y_t + \frac{1}{\theta - 1} Y}{N_t} \tag{67}$$

$$1 - \xi_{e,t} + s_e \left(\frac{q_{e,t} K_t}{l_{e,t}} - \frac{q_e K}{l_e} \right) \frac{q_{e,t}}{l_{e,t}^2} = \beta_e E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} \left(\varepsilon_{t+1}^e r_{e,t} - \rho_e \xi_{e,t+1} \right) \right] \tag{68}$$

$$K_t = I_{e,t} \left[\varepsilon_t^{I_k} - \frac{s_k}{2} \left(\frac{I_{e,t}}{I_{e,t-1}} - 1 \right)^2 \right] + (1 - \delta_k) K_{t-1} \tag{69}$$

$$l_{e,t} = \rho_e l_{e,t-1} + (1 - \rho_e) \times \left(\epsilon_t^{\iota e} \gamma_0^e E_t \frac{\left(p_{t+1}^X \left(Y_{t+1} + \frac{1}{\theta - 1} Y \right) - w_{t+1} N_{t+1} \right) + q_{e,t+1} (1 - \delta_k) K_t}{r_{e,t}} \right) \tag{70}$$

where q_e denotes the Lagrange multiplier associated with Equation (12),[53] and X_t has been substituted by the following intermediate goods condition:

$$Y_t + \frac{1}{\theta - 1} Y = \varepsilon_t^z \left(K_{t-1}\right)^{\alpha} \left(N_t\right)^{1-\alpha} = X_t \tag{71}$$

Condition (71) is, in turn, based on calibrating the level of fixed costs F so that the profits of monopolistically competitive wholesalers are zero in the steady-state equilibrium. Thus

$$F = \frac{1}{\theta - 1} Y \tag{72}$$

The first order conditions of **intermediaries**, **wholesalers** and **final goods firms** yield:

$$\varpi_t \equiv \phi \beta_s (\Pi)^{-\theta} E_t \left[\Pi_{t+1}^{\theta} \varpi_{t+1}\right] + \Lambda_{s,t} p_t^X \left(p_t^Y\right)^{\theta} Y_t \tag{73}$$

$$\psi_t \equiv \phi \beta_s (\Pi)^{1-\theta} E_t \left[\Pi_{t+1}^{\theta-1} \psi_{t+1}\right] + \Lambda_{s,t} \left(p_t^Y\right)^{\theta} Y_t \tag{74}$$

$$p_t^Y = \left[(1-\phi)\left(\frac{\theta}{\theta-1}\frac{\varpi_t}{\psi_t}\right)^{1-\theta} + \phi\left(\left(\Pi_t\right)^{-1} \Pi p_{t-1}^Y\right)^{(1-\theta)}\right]^{\frac{1}{1-\theta}} \tag{75}$$

$$Y_{M,t}^{*} = \omega_M \left(rer_t \, p_t^{Y^*}\right)^{-\nu} Z_t \tag{76}$$

$$1 = \left(1 - \omega_F\right) \left(p_t^Y\right)^{1-\nu} + \omega_F \left(rer_t \, p_t^{Y^*}\right)^{1-\nu} \tag{77}$$

The first order conditions of **housebuilders** are:

$$H_t = \left(1 - \delta_H\right) H_{t-1} + \left(s_{h_0} - S^h \left(I_{h,t}, I_{h,t-1}\right)\right) I_{h,t}^{\gamma} \tag{78}$$

$$\begin{aligned} & p_t^H \gamma \left(s_{h_0} - \frac{s_{h_1}}{2}\left(\frac{I_{h,t}}{I_{h,t-1}} - 1\right)^2\right) I_{h,t}^{\gamma-1} - p_t^H s_{h_1} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1\right) \frac{I_{h,t}^{\gamma}}{I_{h,t-1}} + \\ & \qquad \beta_s E_t \left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}} p_{t+1}^H s_{h_1} \left(\frac{I_{h,t+1}}{I_{h,t}} - 1\right) \frac{I_{h,t+1}^{\gamma+1}}{I_{h,t}^2}\right] = 1 \end{aligned} \tag{79}$$

As regards the dynamic conditions of **banks**, first define

$$AC'_{K,t} = a_K \left(\frac{d_{h,t} + ib_{f^*,t}}{\rho_f kr_{f,t-1} + (1-\rho_f)(rwa_{f,t} + el_{f,t})} - \frac{d_h + ib_{f^*}}{kr_f}\right) \tag{80}$$

First order conditions are then:

[53] q_e can thus be interpreted as the shadow price of capital (normalised by the price of the final good).

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^{L_h}+E_t\left[1-\varepsilon_{t+1}^b\right](1-\eta_t^{L_h})\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^{L_h}+E_t\left[1-\varepsilon_{t+1}^b\right](1-\eta_t^{L_h})\right)}{(kr_{f,t})^2}$$
$$=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^b r_{b,t}-\rho_f\xi_{f,t+1}\right)\right] \quad (81)$$

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^{L_e}+E_t\left[1-\varepsilon_{t+1}^e\right](1-\eta_t^{L_e})\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^{L_e}+E_t\left[1-\varepsilon_{t+1}^e\right](1-\eta_t^{L_e})\right)}{(kr_{f,t})^2}$$
$$=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^e r_{e,t}-\rho_f\xi_{f,t+1}\right)\right] \quad (82)$$

For the $(1-\omega^f)$ share of banks that are not locked in a strategic game with their sovereigns the first order condition with respect to B_f is:

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^{B}+E_t\left[1-\varepsilon_{t+1}^B\right](1-\eta_t^{B})\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^{B}+E_t\left[1-\varepsilon_{t+1}^B\right](1-\eta_t^{B})\right)}{(kr_{f,t})^2}$$
$$=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^B \tilde{r}_{f,t}^B-\rho_f\xi_{f,t+1}\right)\right] \quad (83)$$

For the ω^f share of banks that are locked in a strategic game with their sovereigns (see Appendix A), changes in the magnitude of potential sovereign losses (as captured by time variation in the ε_{t+1}^B factor in Equation (27)) are ignored and the first order condition is:

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^{B}+E_t\left[1-\varepsilon_{t+1}^B\right](1-\eta_t^{B})\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^{B}+E_t\left[1-\varepsilon_{t+1}^B\right](1-\eta_t^{B})\right)}{(kr_{f,t})^2}$$
$$=\beta_f \varepsilon^B E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\tilde{r}_{f,t}^B-\rho_f\xi_{f,t+1}\right)\right] \quad (84)$$

As such, Equations (83) and (84) are identical as regards their left-hand side (which captures *actual* sovereign risk-related costs, as expressed in capital requirements), but differ as regards their right-hand side (which captures *potential* costs that are dependent on the realisation of ε_{t+1}^B).

The first order condition with respect to B_f^* is the same for both types of banks:

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^B+E_t\left[1-\varepsilon_{t+1}^{B^*}\right](1-\eta_t^B)\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^B+E_t\left[1-\varepsilon_{t+1}^{B^*}\right](1-\eta_t^B)\right)}{(kr_{f,t})^2}$$
$$=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^{B^*}\tilde{r}_{f,t}^{B^*}-\rho_f\xi_{f,t+1}\right)\right] \quad (85)$$

The remaining first order conditions of banks are:

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^{IB}+E_t\left[1-\varepsilon_{t+1}^{ib}\right](1-\eta_t^{IB})\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^{IB}+E_t\left[1-\varepsilon_{t+1}^{ib}\right](1-\eta_t^{IB})\right)}{(kr_{f,t})^2}$$
$$=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^{ib}r_{f,t}^{IB}-\rho_f\xi_{f,t+1}\right)\right] \quad (86)$$

$$1-\xi_{f,t}\left(1-(1-\rho_f)\left(\eta_t^{IB}+E_t\left[1-\varepsilon_{t+1}^{ib^*}\right](1-\eta_t^{IB})\right)\right)$$
$$-AC'_{K,t}\frac{(d_{h,t}+ib_{f^*,t})(1-\rho_f)\left(\eta_t^{IB}+E_t\left[1-\varepsilon_{t+1}^{ib^*}\right](1-\eta_t^{IB})\right)}{(kr_{f,t})^2}$$
$$=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(\varepsilon_{t+1}^{ib^*}r_{f,t}^{IB^*}-\rho_f\xi_{f,t+1}\right)\right] \quad (87)$$

$$1-\xi_{f,t}=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\left(r_t^{EA}-\rho_f\xi_{f,t+1}\right)\right] \quad (88)$$

$$1-\xi_{f,t}+\rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right]-\frac{AC'_{K,t}}{kr_t}=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}r_{s,t}\right] \quad (89)$$

$$1-\xi_{f,t}+\rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right]-AC'_{K,t}\frac{\left(1-\omega_t^{IB}\right)}{kr_t}=\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\varepsilon_{t+1}^{ib}r_{f,t}^{IBF}\right] \quad (90)$$

where Equations (89) and (90) are combined so that

$$\frac{1-\xi_{f,t}+\rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right]-\frac{AC'_{K,t}}{kr_t}}{1-\xi_{f,t}+\rho_f\beta_f E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\xi_{f,t+1}\right]-AC'_{K,t}\frac{\left(1-\omega_t^{IB}\right)}{kr_t}}=\frac{E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}r_{s,t}\right]}{E_t\left[\frac{\Lambda_{s,t+1}}{\Lambda_{s,t}}\varepsilon_{t+1}^{ib}r_{f,t}^{IBF}\right]} \quad (91)$$

$$\omega_s d_{s,t} + rer_t \frac{1-n}{n} ib_{f^*,t} \leq \rho_f \big(\omega_s d_{s,t-1} + rer_{t-1} \frac{1-n}{n} ib_{f^*,t-1} - (1-\omega_s) l_{b,t-1} - l_{e,t-1}$$
$$- bp_{f,t-1} - ib^*_{f,t-1} - cb_{f,t-1}\big) + (1-\omega_s) l_{b,t} + l_{e,t} + bp_{f,t} + ib^*_{f,t} + cb_{f,t}$$
$$- (1-\rho_f) \Bigg(\eta_t^{L_h} (1-\omega_s) l_{b,t} + \eta_t^{L_e} l_{e,t} + \eta_t^B bp_{f,t} + \eta_t^{IB} \left(ib_{f,t} + ib^*_{f,t} \right)$$
$$+ E_t \Bigg[(1-\varepsilon^b_{t+1})(1-\eta_t^{L_h})(1-\omega_s) l_{b,t} + (1-\varepsilon^e_{t+1})(1-\eta_t^{L_e}) l_{e,t}$$
$$+ (1-\eta_t^B) b_{f,t} \left(\omega^{HFT} \left(1 - \frac{\bar{r}_t}{r_t} \right) + (1-\omega^{HFT})(1-\varepsilon^B_{t+1}) \right)$$
$$+ (1-\eta_t^B) rer_t \frac{1-n}{n} b^*_{f,t} \left(\omega^{HFT} \left(1 - \frac{\bar{r}^*_t}{r^*_t} \right) + (1-\omega^{HFT})(1-\varepsilon^{B^*}_{t+1}) \right)$$
$$+ (1-\eta_t^{IB}) \left((1-\varepsilon^{ib}_{t+1}) ib_{f,t} + (1-\varepsilon^{ib^*}_{t+1}) ib^*_{f,t} \right) \Bigg] \Bigg) \quad (92)$$

Risk weights are allowed to vary in response to exogenous shocks:

$$\eta_t^{L_h} = \left(\eta_0^{L_h} \varepsilon_t^{\iota L_h} \right) \quad (93)$$

$$\eta_t^{L_e} = \left(\eta_0^{L_e} \varepsilon_t^{\iota L_f} \right) \quad (94)$$

$$\eta_t^{B} = \left(\eta_0^{B} \varepsilon_t^{\iota B} \right) \quad (95)$$

$$\eta_t^{IB} = \left(\eta_0^{IB} \varepsilon_t^{\iota IB} \right) \quad (96)$$

The relation between $D_{h,t}$ and $D_{s,t}$ is

$$D_{h,t} = \omega_s D_{s,t} \quad (97)$$

The relation between $L_{h,t}$ and $L_{b,t}$ is

$$L_{h,t} = (1-\omega_s) L_{b,t} \quad (98)$$

As regards the first order conditions of **banks' bond portfolio managers**, it is assumed that they are instructed by head offices to consider the steady state values of total bond holdings (bp_f) and average excess returns (R_f^{BP}) as given, and to respond only to the prevailing excess returns for each bond ($\frac{R_t}{\tilde{R}_{f,t}}$ and of $\frac{R^*_t}{\tilde{R}^*_{f,t}}$).[54] As such

[54]This assumption implies that an increase in excess returns on a given bond tends to increase not only the relative portfolio weight of that bond, but also the absolute exposure to it. Otherwise, an increase in the relative portfolio weight of a bond experiencing heightened excess returns could be achieved in a context of reduced total sovereign exposures, which would imply poor empirical properties, namely as regards the home bias effect discussed in Appendix A.

$$b_{f,t} = \omega_f^B bp_f \left(\frac{\frac{R_t}{\tilde{R}_{f,t}}}{R_f^{BP}} \right)^{\sigma_f^B} \tag{99}$$

where $\tilde{R}$ is given by Equation (83) for a mass ω^f of banks and by Equation (84) for a mass $(1-\omega^f)$ of banks.

$$rer_t \frac{1-n}{n} b^*_{f,t} = \left(1-\omega_f^B\right) bp_f \left(\frac{\frac{R^*_t}{\tilde{R}^*_{f,t}}}{R_f^{BP}} \right)^{\sigma_f^B} \tag{100}$$

As regards **banks' interbank loan portfolio managers**, they maximise returns under a CES framework taking into account default risk-adjusted yields required by head offices. These are obtained from Equations (86) and (87) by discounting all default risk-related costs:

$$\tilde{r}_f^{IB} = E_t \Bigg[\varepsilon^{ib}_{t+1} r^{IB}_{f,t} - \xi_{f,t} (1-\rho_f)(1-\varepsilon^{ib}_{t+1})(1-\eta^{IB}_t) + AC'_{K,t}(d_{h,t} + ib_{f^*,t})(1-\rho_f) \frac{\left(1-\varepsilon^{ib}_{t+1}\right)(1-\eta^{IB}_t)}{(kr_{f,t})^2} \Bigg] \tag{101}$$

$$\tilde{r}_f^{IB^*} = E_t \Bigg[\varepsilon^{ib^*}_{t+1} r^{IB^*}_{f,t} - \xi_{f,t} (1-\rho_f)(1-\varepsilon^{ib^*}_{t+1})(1-\eta^{IB}_t) + AC'_{K,t}(d_{h,t} + ib_{f^*,t})(1-\rho_f) \frac{\left(1-\varepsilon^{ib^*}_{t+1}\right)(1-\eta^{IB}_t)}{(kr_{f,t})^2} \Bigg] \tag{102}$$

A first order condition is:

$$ib^*_{f,t} = (1-\omega^{IB}) ibp_{f,t} \left(\frac{\tilde{R}^{IB^*}_{f,t}}{e_t R^{IBP}_{f,t}} \right)^{\sigma_{IB}} \tag{103}$$

where

$$R^{IBP}_{f,t} = \frac{1}{\left(\omega_f^{IB} \left(\frac{1}{\tilde{R}^{IB}_{f,t}} \right)^{1-\sigma^{IB}} + \left(1-\omega_f^{IB}\right) \left(\frac{e_t}{\tilde{R}^{IB^*}_{f,t}} \right)^{1-\sigma^{IB}} \right)^{\frac{1}{1-\sigma^{IB}}}} \tag{104}$$

Equivalently for the interbank portfolio managers of the foreign economy, a first order condition is:

$$ib_{f^*,t} = (1-\omega^{IB^*}) ibp_{f^*,t} \left(\frac{e_t \tilde{R}^{IB}_{f^*,t}}{R^{IBP}_{f^*,t}} \right)^{\sigma_{IB^*}} \tag{105}$$

Appendix C Selected steady-state equations

This appendix presents some of the main steady-state conditions of the model.

From Equation (57) we obtain

$$R_s = \frac{\Pi}{\beta_s} \tag{106}$$

From Equation (88):

$$\xi_f = \frac{1 - \beta_f \frac{R^{EA}}{\Pi}}{1 - \rho_f \beta_f} \tag{107}$$

From Equations (86) and (88):

$$R_f^{IB} = sp_{ib}^{EA} R^{EA} \tag{108}$$

where

$$sp_{ib}^{EA} = \frac{1 - \xi_f \left(1 - \rho_f \beta_f - (1 - \rho_f)\eta_0^{IB}\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right)} \tag{109}$$

From Equations (91) and (109), we have that

$$R_s = sp_s^{EA} R^{EA} \tag{110}$$

where

$$sp_s^{EA} = sp_{ib}^{EA} \tag{111}$$

From the Equations (106) and (110) we have that

$$\frac{R^{EA}}{\Pi} = \frac{1}{\beta_s sp_s^{EA}} \tag{112}$$

$$\frac{R^{EA}}{\Pi^*} = \frac{1}{\beta_s^* sp_s^{EA*}} \tag{113}$$

and therefore

$$\frac{\Pi^*}{\Pi} = \frac{\beta_s^* sp_s^{EA*}}{\beta_s sp_s^{EA}} \tag{114}$$

Note that, given a steady-state inflation rate Π, Equations (107) and (112) jointly determine ξ_f and R^{EA}.

From Equations (81) and (88):

$$R_b = sp_b^{EA} R^{EA} \tag{115}$$

where

$$sp_b^{EA} = \frac{\left(1 - \xi_f \left(1 - \rho_f \beta_f - (1-\rho_f) \left(\eta_0^{L_h} + (1-\varepsilon_0^b)(1-\eta_0^{L_h})\right)\right)\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right) \varepsilon_0^b} \tag{116}$$

From Equations (82) and (88):

$$R_e = sp_e^{EA} R^{EA} \tag{117}$$

where

$$sp_e^{EA} = \frac{\left(1 - \xi_f \left(1 - \rho_f \beta_f - (1-\rho_f) \left(\eta_0^{L_e} + (1-\varepsilon_0^e)(1-\eta_0^{L_e})\right)\right)\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right) \varepsilon_0^e} \tag{118}$$

From Equations (83) and (88):

$$\tilde{R}_f = sp_{B_f}^{EA} R^{EA} \tag{119}$$

where

$$sp_{B_f}^{EA} = \frac{\left(1 - \xi_f \left(1 - \rho_f \beta_f - (1-\rho_f) \left(\eta_0^{B} + (1-\varepsilon_0^B)(1-\eta_0^{B})\right)\right)\right)}{\left(1 - \xi_f \left(1 - \rho_f \beta_f\right)\right) \varepsilon_0^B} \tag{120}$$

From Equation (92):

$$\begin{aligned} \omega_s d_s + rer \frac{1-n}{n} ib_{f^*} = &+ \varepsilon_0^b \left(1 - \eta_0^{L_h}\right)(1-\omega_s) l_b + \varepsilon_0^e \left(1 - \eta_0^{L_e}\right) l_e \\ &+ \left(\omega^{HFT} + \varepsilon_0^{BP} \left(1 - \omega^{HFT}\right)\right) \left(1 - \eta_0^B\right) bp_f + cb_f + \varepsilon_0^{ib^*} \left(1 - \eta_0^{IB}\right) ib_f^* \\ &- \left(\eta_t^{IB} + (1-\eta_t^{IB})(1-\varepsilon_0^{ib})\right) ib_f \end{aligned} \tag{121}$$

where ε_0^{BP} is the steady state of the complement of the expected loss on the bond portfolio, which is given by

$$E_t\left[\varepsilon_{t+1}^{BP}\right] = \frac{b_{f,t}}{bp_{f,t}} E_t\left[\varepsilon_{t+1}^{B}\right] + rer_t \frac{1-n}{n} \frac{b_{f,t}^*}{bp_{f,t}} E_t\left[\varepsilon_{t+1}^{B^*}\right] \tag{122}$$

From Equation (7) we have that

$$l_b = \gamma_0^b \frac{p^H (1-\delta_H) H_b}{r_b} \tag{123}$$

Likewise, from Equation (14) we obtain

$$\frac{l_e}{Y} = \gamma_0^e \frac{\alpha p^Y + (1-\delta_k) q_e \frac{K}{Y}}{r_e} \tag{124}$$

From Equation (62) we obtain

$$\xi_b = \frac{1 - \frac{\varepsilon_0^b s p_b^{EA} \beta_b}{s p_s^{EA} \beta_s}}{1 - \rho_b \beta_b} \tag{125}$$

From Equation (68) we obtain

$$\xi_e = \frac{1 - \frac{\varepsilon_0^e s p_e^{EA} \beta_e}{s p_s^{EA} \beta_s}}{1 - \rho_e \beta_e} \tag{126}$$

From Equation (65) we have

$$q_e = 1 \tag{127}$$

Differentiation-based market power of branding firms yields the following markup condition:

$$p^Y = \frac{\theta}{\theta - 1} p^X \tag{128}$$

Taking into account Equation (72) and the production function of wholesalers, we have

$$Y = \frac{\theta - 1}{\theta} X \tag{129}$$

From Equation (66) we have

$$\frac{K}{Y} = \frac{\alpha p^Y}{r^K} \tag{130}$$

Where r^K is defined as

$$r^K = \frac{q_e \left(1 - \beta_e (1 - \delta_k)\right) - (1 - \rho_e) \frac{\xi_e}{r_e} \gamma_0^e (1 - \delta_k)}{\beta_e + (1 - \rho_e) \gamma_0^e \frac{\xi_e}{r_e}} \tag{131}$$

From Equation (12) we have

$$\frac{I_e}{Y} = \delta_k \frac{K}{Y} \tag{132}$$

From Equation (67) we have

$$\frac{N}{Y} = \frac{(1-\alpha)}{w} p^Y \tag{133}$$

From the Equations (11), (129) and (133) we have

$$w = (1-\alpha) p^Y \frac{\theta - 1}{\theta} \left(\frac{K}{N}\right)^{\alpha} \tag{134}$$

Given that

$$\frac{K}{N} = \frac{\frac{K}{Y}}{\frac{N}{Y}} = \frac{\alpha w}{(1-\alpha) r^K} \tag{135}$$

We have that

$$w = \left(\frac{1-\alpha}{\alpha}\right) \frac{\left(\frac{\theta-1}{\theta} \alpha p^Y\right)^{\frac{1}{1-\alpha}}}{\left(r^K\right)^{\frac{\alpha}{1-\alpha}}} \tag{136}$$

From Equation (61) we have

$$N_b = \left(\frac{w}{\nu_b^n \left((1-h) C_b\right)^{\chi}}\right)^{\frac{1}{\varphi}} \tag{137}$$

From Equations (54) and (55) we have

$$H_s = \left(\frac{\nu_s^h}{\left(1 - \beta_s \left(1 - \delta_H\right)\right) p_t^H}\right)^{\frac{1}{\chi}} (1-h) C_s \tag{138}$$

Likewise, from Equations (59) and (60) we have

$$H_b = \left(\frac{\nu_b^h}{\left(1 - \beta_b \left(1 - \delta_H\right) \left(1 + \gamma_0^b \left(1 - \rho_b\right) \frac{\xi_f}{\beta_b r_b}\right)\right) p_t^H}\right)^{\frac{1}{\chi}} (1-h) C_b \tag{139}$$

From Equation (79) we have

$$p^H = \frac{1}{\gamma s_{h_0} I_h^{\gamma - 1}} \tag{140}$$

From Equation (67) together with Equations (56) and (61) we have

$$\frac{(1-\alpha) p^Y}{w} Y^{1+\frac{\chi}{\varphi}} \;=\; \omega_s \left(\frac{w}{\nu_s}\right)^{\frac{1}{\varphi}} \left(\frac{(1-h) C_s}{Y}\right)^{-\frac{\chi}{\varphi}} + (1-\omega_s) \left(\frac{w}{\nu_b}\right)^{\frac{1}{\varphi}} \left(\frac{(1-h) C_b}{Y}\right)^{-\frac{\chi}{\varphi}} \tag{141}$$

The trade balance is obtained by subtracting imports from exports:

$$\frac{TB}{Y} = \frac{1-n}{n}\omega_M^* rer^v \left(p^Y\right)^{1-\nu}\left(\frac{C^*}{Y^*}+\frac{I^*}{Y^*}+g^*\right)\frac{Y^*}{Y} - \omega_M\left(rer^* p^{Y^*}\right)^{1-\nu}\left(\frac{C}{Y}+\frac{I}{Y}+g\right) \tag{142}$$

Let $\bar{\omega}_f^B$ and $\bar{\omega}_f^{B^*}$ denote the steady-state bond portfolio shares of banks. From Equation (44) and the steady-state bond portfolio weights of banks, we have

$$\frac{1-n}{n} rer\,\frac{b_f^*}{Y} = \frac{\left(1-\bar{\omega}_f^{B^*}\right)\left(1-\bar{\omega}_f^B\right)}{\bar{\omega}_f^B-(1-\bar{\omega}_f^{B^*})}\left(\frac{\bar{\omega}_f^{B^*}}{1-\bar{\omega}_f^{B^*}}b-\frac{1-n}{n}rer\,b^*\frac{Y^*}{Y}\right) \tag{143}$$

$$\frac{b_{f^*}}{Y} = \frac{\left(1-\bar{\omega}_f^{B^*}\right)\left(1-\bar{\omega}_f^B\right)}{\bar{\omega}_f^B-(1-\bar{\omega}_f^{B^*})}\left(\frac{\bar{\omega}_f^B}{1-\bar{\omega}_f^B}\frac{1-n}{n}rer\,b^*\frac{Y^*}{Y}-b\right) \tag{144}$$

From the previous two equations, and taking into account the steady-state bond portfolio shares, we have

$$\frac{b_f}{Y} = \frac{\bar{\omega}_f^B}{1-\bar{\omega}_f^B}\frac{1-n}{n}rer\,\frac{b_f^*}{Y} \tag{145}$$

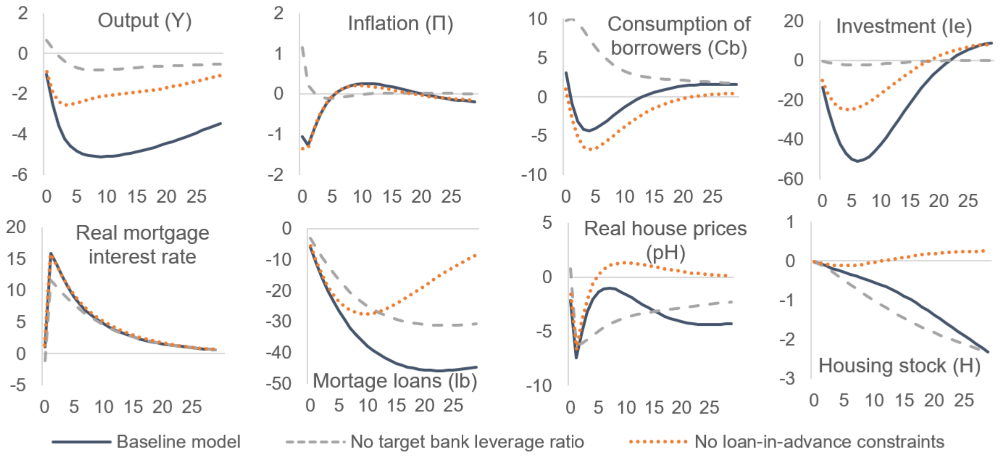
$$\frac{b_{f^*}^*}{Y} = \frac{\bar{\omega}_f^{B^*}}{1-\bar{\omega}_f^{B^*}}rer^{-1}\frac{n}{1-n}\frac{b_{f^*}}{Y} \tag{146}$$

From Equation (52) we obtain the balance of payments identity in the steady state:

$$\frac{TB}{Y} = \frac{1-n}{n}(1-r^*)\,rer\,\frac{b_f^*}{Y}+\left(1-r_f^{IB^*}\right)\frac{ib_f^*}{Y}++\left(1-r^{EA}\right)\frac{cb_f}{Y}+\left(1-\frac{1}{\Pi}\right)\frac{k_{CB}}{Y} - \left((1-r)\frac{b_{f^*}}{Y}+\frac{1-n}{n}\left(1-r_{f^*}^{IB}\right)rer\,\frac{ib_{f^*}}{Y}+\frac{div_{cb}}{Y}\right) \tag{147}$$

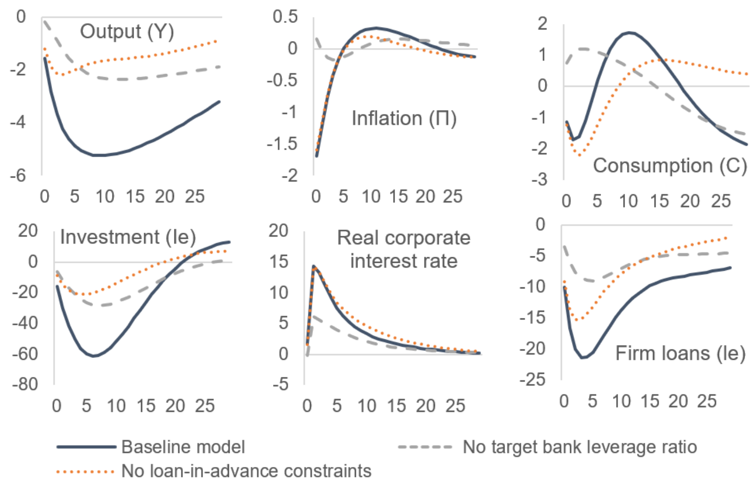
Appendix D Figures and tables

Figure 1: Impulse response functions for a credit risk shock in the household sector of the domestic region (default levels of households increase by 5% of GDP



Note: interest rates and inflation expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Shocks are assumed to have autoregressive parameter 0.9.

Figure 2: Impulse response functions for a credit risk shock in the corporate sector of the domestic region (default levels of entrepreneurs increase by 5% of GDP



Note: interest rates and inflation expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Shocks are assumed to have autoregressive parameter 0.9.

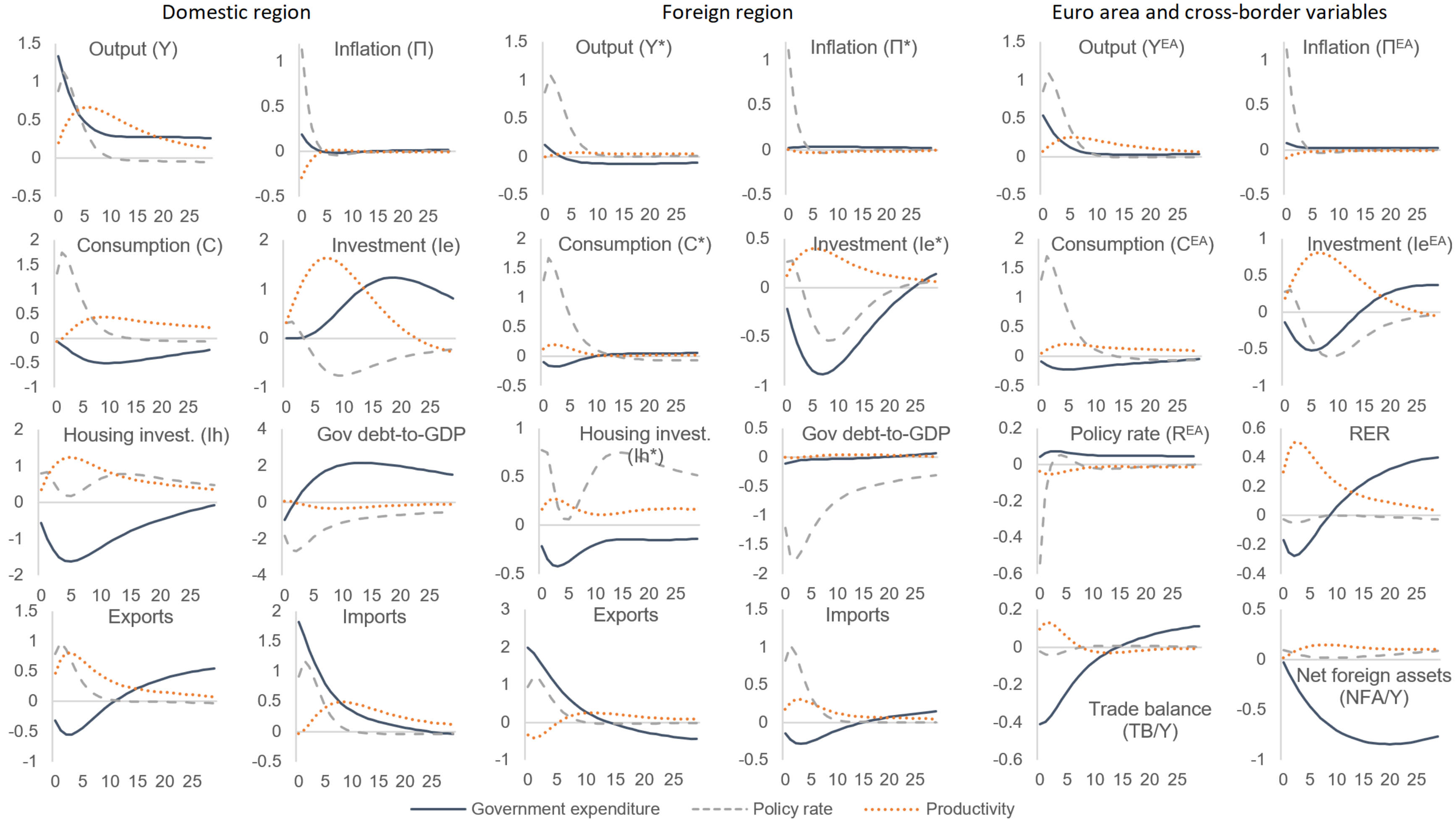
Table 2: Model parameter values

Parameter	Meaning	Value
Size parameters		
n	Size of domestic region	0.33
ω_s	Share of saver households	0.6
Preferences		
β_b	Discount factor of borrower households	0.967
β_e	Discount factor of entrepreneurs	0.97
β_f	Discount factor of bankers	0.977
β_s	Discount factor of saver households	0.997
h	Habits in consumption	0.8
ν^h	Weight of housing in utility function	0.95, 1.16
ν^n	Weight of hours worked in utility function	1
φ	Inverse of Frisch elasticity of labour supply	1
χ	Constant relative risk aversion	1
Technology		
α	Capital income share	0.35
δ_k	Capital depreciation rate	0.015
F	Fixed production costs of intermediary firms	1.268, 1.276
θ	CES of intermediate good varieties	4
ν	CES of imports	1.2
s_k	Corporate investment adjustment costs	5
ω^M	Share of imports in domestic demand (in value added)	0.18, 0.11
Housing		
δ_H	Housing depreciation rate	0.01
γ	Decreasing returns to scale in construction	0.75
s_H	Housing transaction costs	0.069, 0.073
s_{h_0}	Housing production scale parameter	0.6948, 0.7097
s_{h_1}	Housing investment adjustment costs	1.75
Banking sector		
a_K	Bank capital ratio deviation costs	0.016
cb_f	Reserves with the central bank (as % of other bank assets)	0.008, 0.013
γ^b	Household loan-to-value ratio	0.82
γ^e	Corporate loan-to-value ratio	0.32, 0.33
ε^b	Complement of steady-state loss rate on household loans	0.9988, 0.9996
ε^e	Complement of steady-state loss rate on corporate loans	0.9959, 0.9989
ε^{ib}	Complement of steady-state loss rate on interbank loans	1
η^B	Effective risk weight on sovereign bonds	0.009
η^{IB}	Effective risk weight on interbank loans	0.029
η^{L_e}	Effective risk weight on corporate loans	0.097, 0.085
η^{L_h}	Effective risk weight on household loans	0.039, 0.033
ρ_b	Autoregressive parameter of household loans	0.7
ρ_e	Autoregressive parameter of corporate loans	0.65
ρ_f	Autoregressive parameter of bank capital requirements	0.24
s_b	Soft loan-in-advance constraint of households	0.7
s_e	Soft loan-in-advance constraint of firms	11
ω^f	Share of banks locked in a strategic game with sovereign	0.154, 0.290
ω^{HFT}	Share of sovereign bonds held for trading	0.51, 0.29

Parameter	Meaning	Value
	Portfolio managers	
ib_f	Domestic interbank loans (in % of corporate and HH loans)	0.07, 0.15
σ_f^B	CES of sovereign bond holdings	164
σ_f^{IB}	CES of interbank lending	1.281, 1.767
ω_f^B	Portfolio share of domestic bonds	0.91, 0.85
ω^{IB}	Portfolio share of domestic interbank lending	0.26, 0.66
	Government	
b	Steady-state government debt (in % of quarterly GDP)	3.6, 2.4
g	Steady-state final consumption expenditure (in % of GDP)	0.19, 0.22
LGD_G	Loss given default on government bonds (in %)	0.6
m	Average sovereign bond maturity (in quarters)	34, 32
p_1	Sovereign default probability curvature parameter 1	0.0045
p_2	Sovereign default probability curvature parameter 2	3.8
t_1	Tax elasticity with respect to the government debt ratio	1.045, 0.711
t_2	Tax elasticity with respect to the output gap	0
t_3	Tax elasticity with respect to interest rate spreads	1.466, 1.327
	Monetary policy and prices	
ϕ	Calvo pricing parameter	0.8
γ_Y	Weight of output gap in Taylor rule	0.1
γ_Π	Weight of inflation in Taylor rule	2
Π^{EA}	Steady-state quarterly gross inflation rate in the euro area	1.00496
ρ_R	Policy rate smoothing	0.8

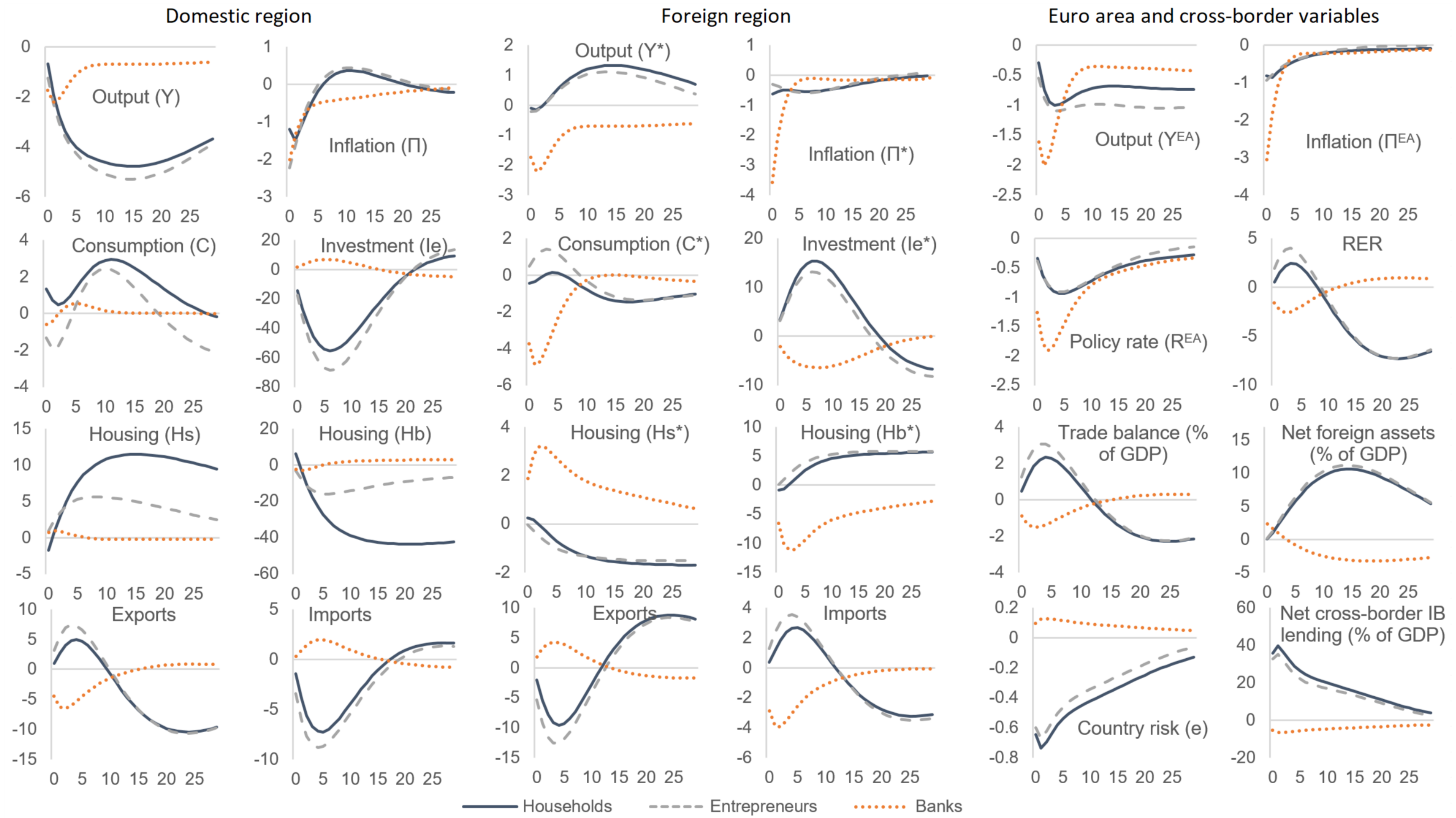
Note: When two values are shown, the first refers to the periphery (or domestic) region and the second to the core (or foreign) region.

Figure 3: Impulse response functions for expansionary shocks (10% increase in domestic government expenditure, 1 pp cut in the policy rate and 1% increase in domestic productivity)



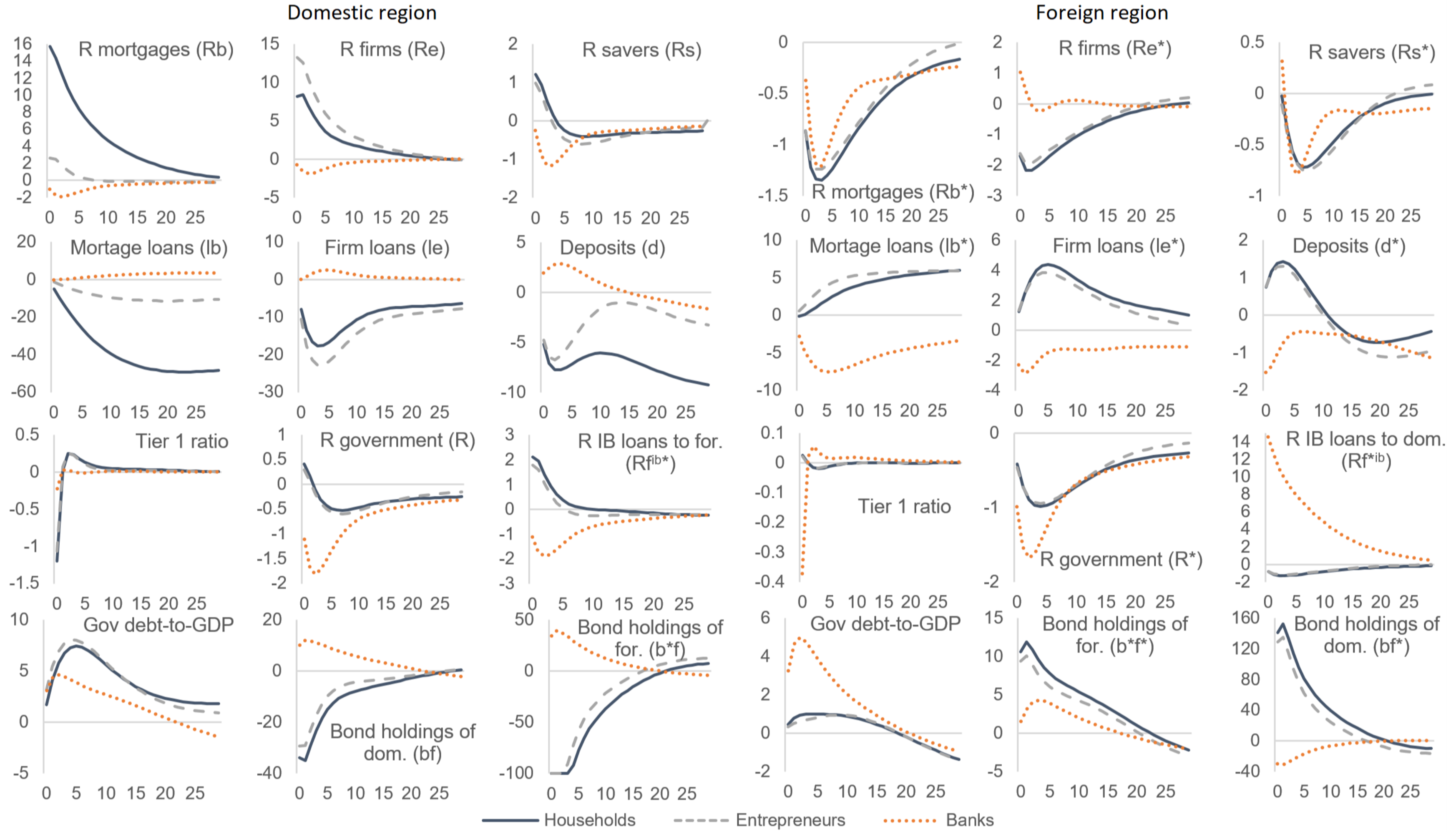
Note: interest rates, inflation, country risk and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Exports and imports in nominal terms. Shocks are assumed to have autoregressive parameter 0.9, except in the case of a monetary policy shock, which has autoregressive parameter 0.

Figure 4: Impulse response functions for credit risk shocks in the domestic private sector (default levels of households, entrepreneurs and banks increase by 5% of GDP)



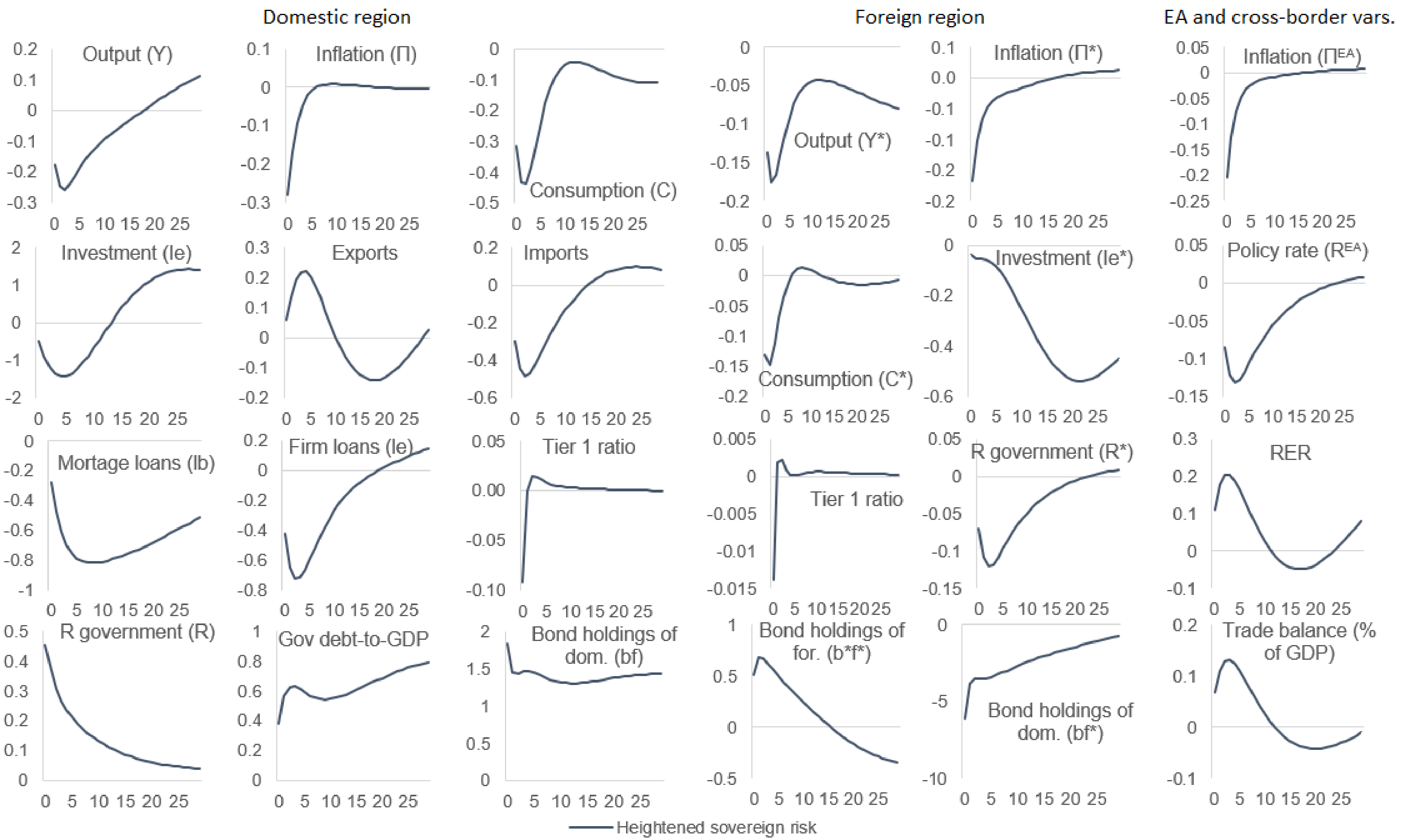
Note: interest rates, inflation, country risk, ratios and shares expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Exports and imports in nominal terms. Shocks are assumed to have autoregressive parameter 0.9.

Figure 5: Impulse response functions for credit risk shocks in the domestic private sector (default levels of households, entrepreneurs and banks increase by 5% of GDP)



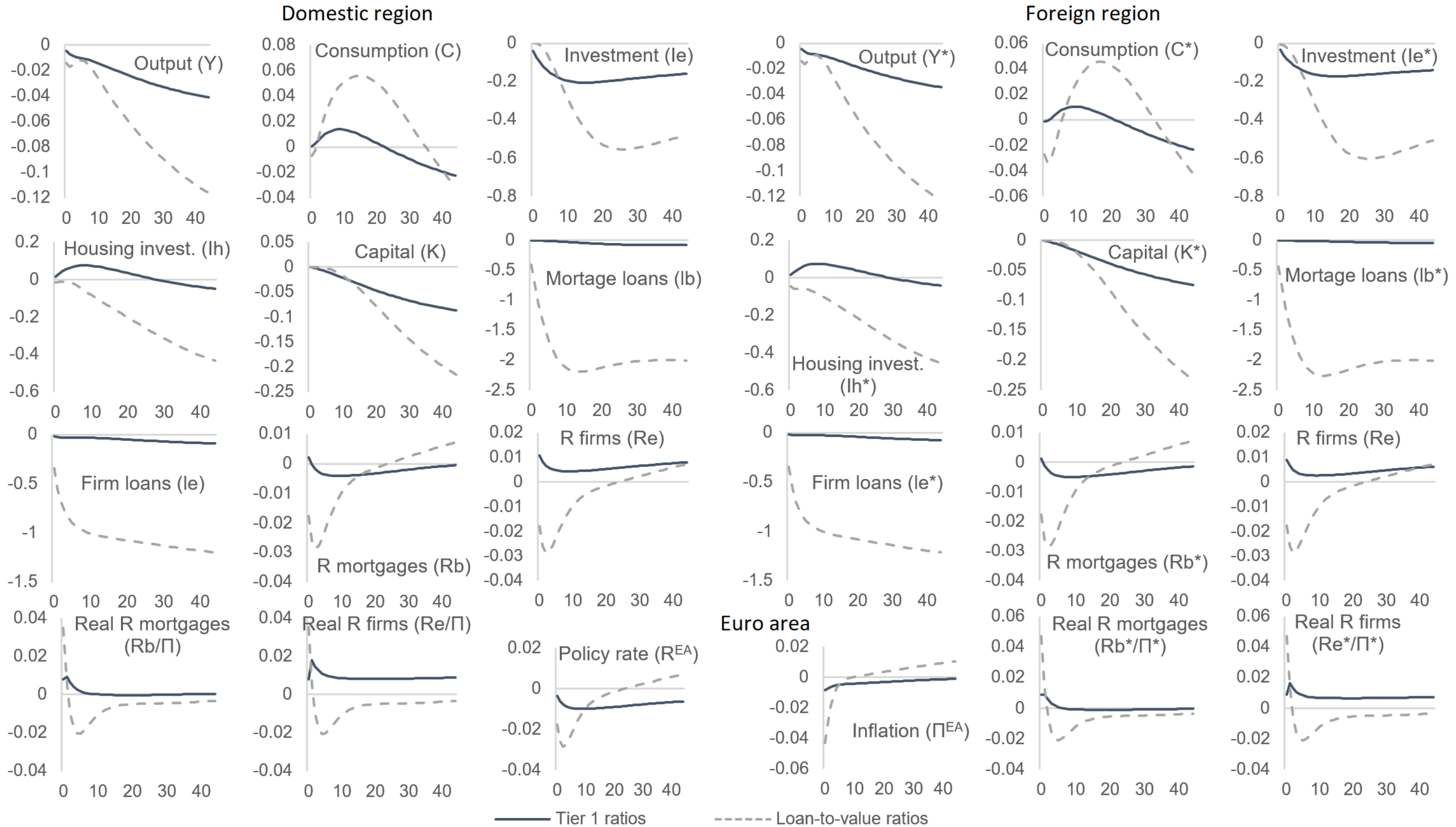
Note: interest rates and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Shocks are assumed to have autoregressive parameter 0.9.

Figure 6: Impulse response functions for a domestic sovereign risk shock (1 pp increase in quarterly probability of default)



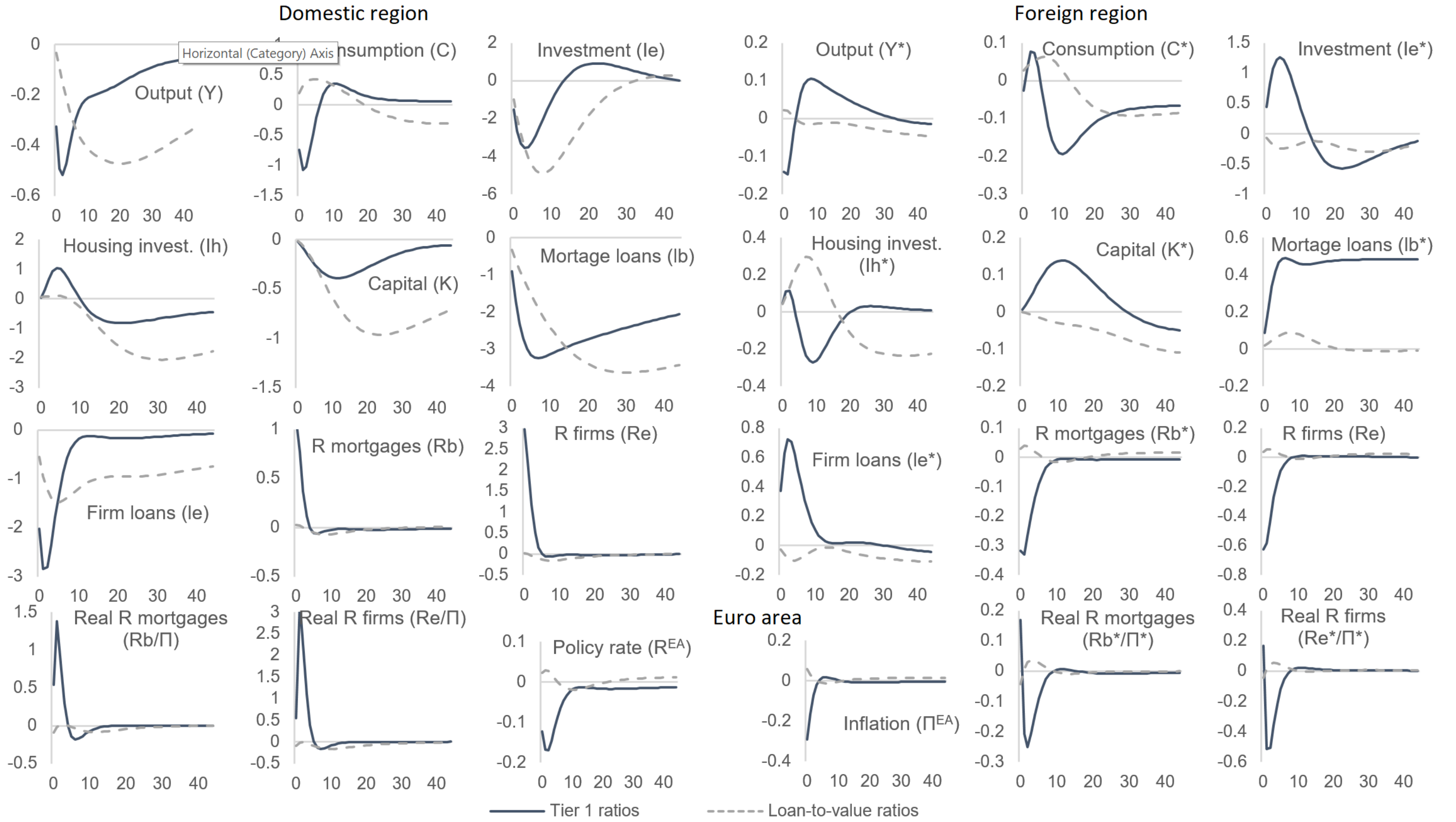
Note: interest rates and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Shocks are assumed to have autoregressive parameter 0.9.

Figure 7: Transition paths for permanent shocks to macroprudential policies in the euro area without transition frictions (1 pp increase in tier 1 ratios and 1% decrease in loan-to-value ratios)



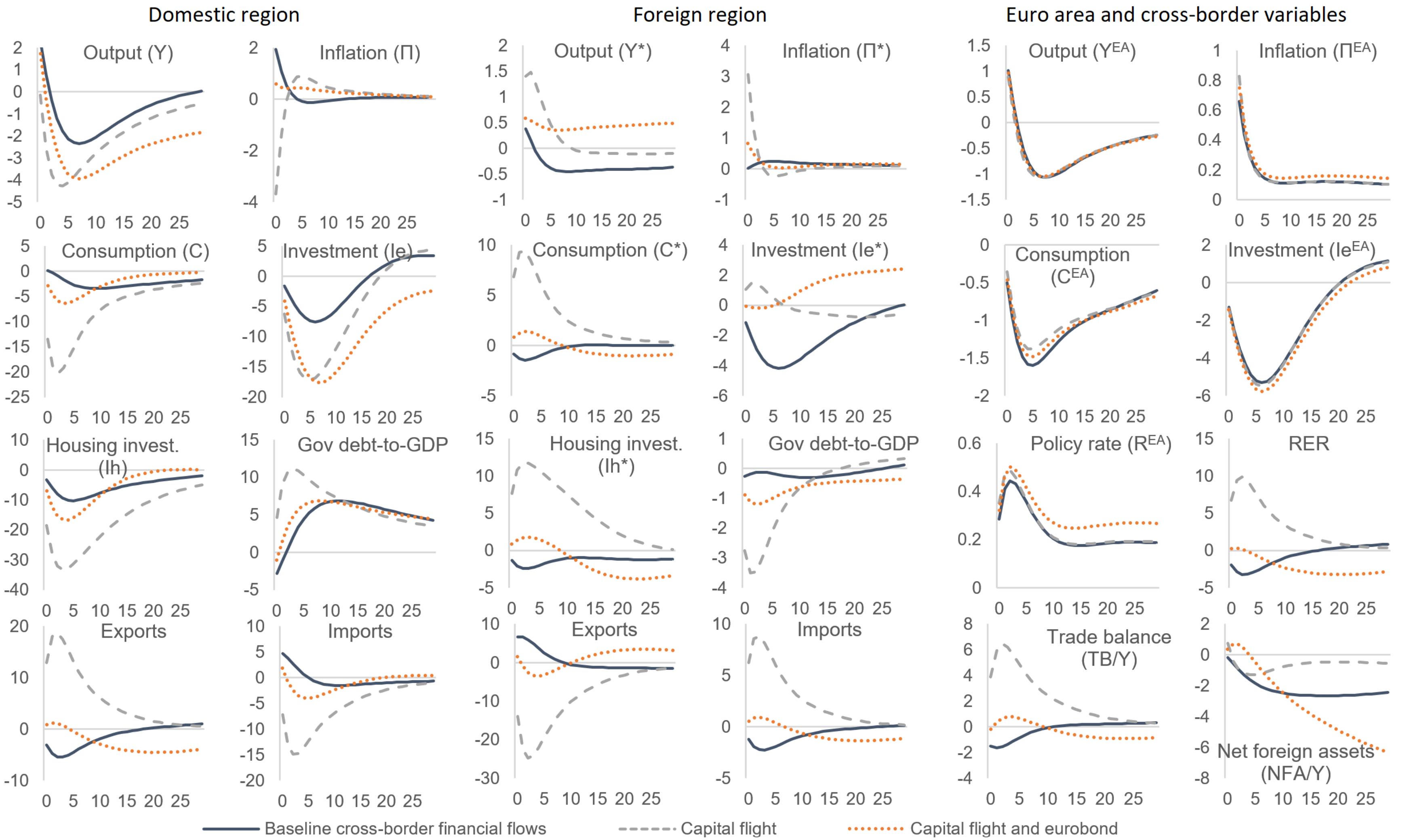
Note: interest rates and inflation expressed in percentage point change from initial steady state. All other variables expressed in percentage change from initial steady state.

Figure 8: Transition paths for permanent shocks to macroprudential policies in the domestic region, subject to transition frictions (convergence to the tier 1 ratio of core region and 1% decrease in loan-to-value ratios)



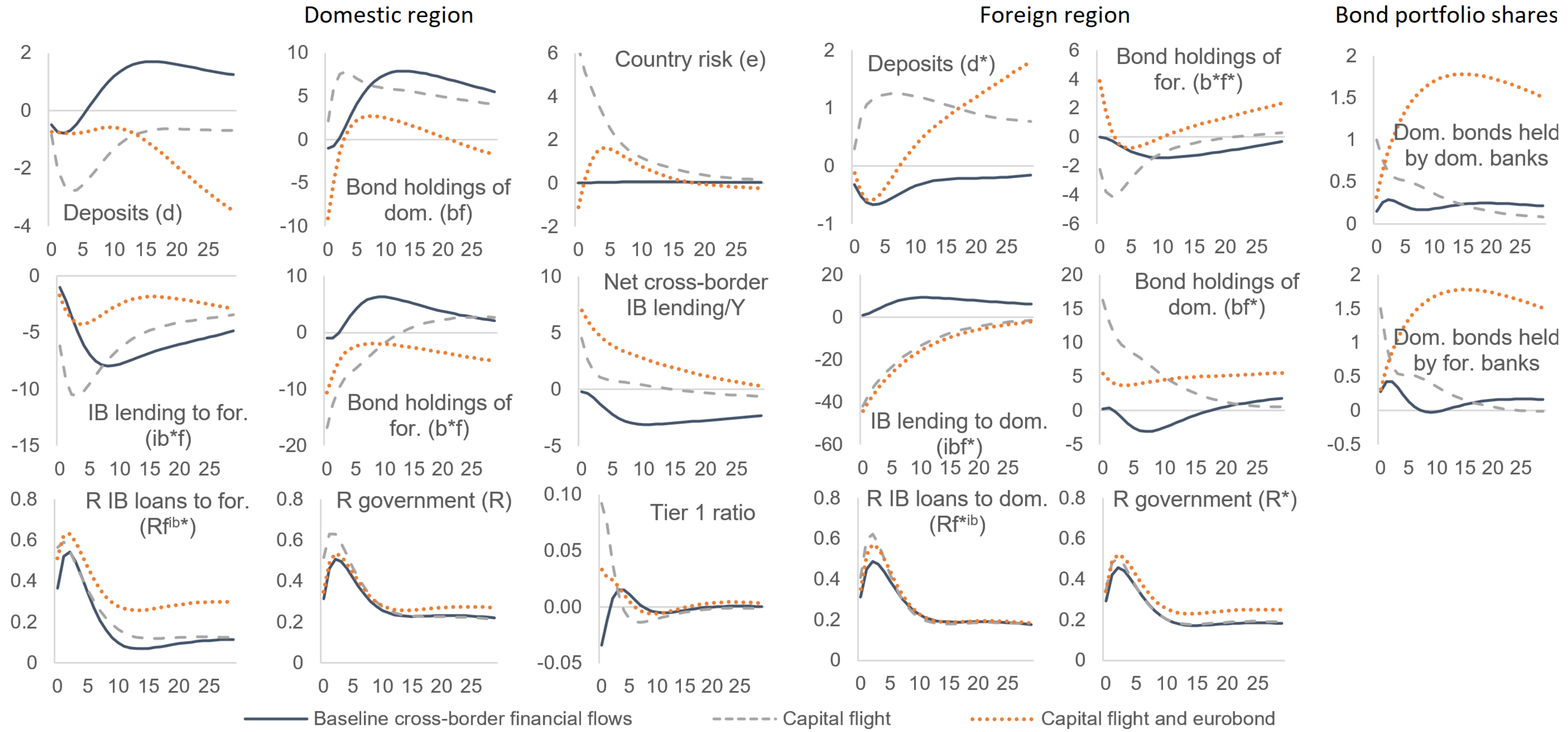
Note: interest rates and inflation expressed in percentage point change from initial steady state. All other variables expressed in percentage change from initial steady state.

Figure 9: Impulse response functions for a joint shock to domestic productivity (5% decrease) and government expenditure (25% increase), with and without international capital flights



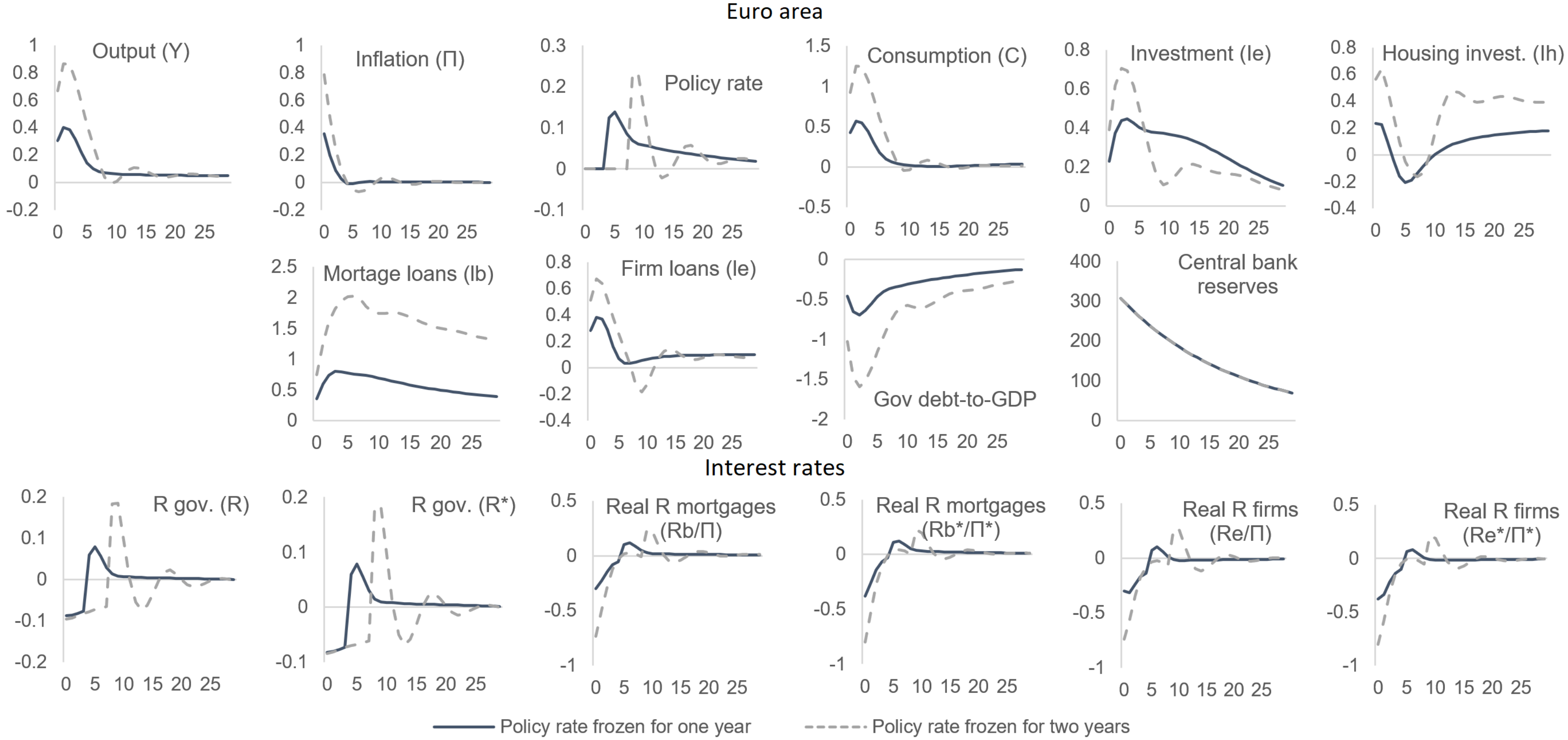
Note: interest rates, inflation and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Exports and imports in nominal terms. Capital flight is modeled as a 10 pp increase in ω^{IB^*}, together with a 99% decrease in σ^{IB} in both regions. Shocks are assumed to have autoregressive parameter 0.9, including the capital flight shocks.

Figure 10: Impulse response functions for a joint shock to domestic productivity (5% decrease) and government expenditure (25% increase), with and without international capital flights



Note: interest rates, country risk and ratios expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Capital flight is modeled as a 10 pp increase in ω^{IB^*}, together with a 99% decrease in σ^{IB} in both regions. Shocks are assumed to have autoregressive parameter 0.9, including the capital flight shocks.

Figure 11: Impulse response functions for an unconventional monetary policy shock (central bank purchase of 10% of outstanding government debt of both regions together with commitment to keep policy rate unchanged)



Note: interest rates and inflation expressed in percentage point change from steady state. All other variables expressed in percentage change from steady state. Bond purchases are assumed to have autoregressive parameter 0.95.

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