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ORIGINAL RESEARCH

Repayment of EU Bailout Loans in a Member-country of the ES: The Case of Greece

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Abstract

This paper quantifies the future implications of repayment of bailout loans received by Greece from the EU in the previous decade. These debt obligations amount today to around 240 billion euros or 70% of the country's total public debt and have to be repaid by 2070. This is investigated in a dynamic general equilibrium model calibrated to the Greek economy, in which fiscal policy is conducted under the rules of the new fiscal governance framework and quantitative monetary policy is subject to the rules of the Eurosystem. Our simulations show that, other things equal, repayment will have recessionary implications in the years to come, although the magnitude of these unpleasant implications will depend on how much privately-held public debt rises as the EU-held public debt falls. We then search for ways to mitigate these recessionary effects. While NGEU/RRF funds as they take place at the moment, as well as a new hypothetical support from the ES in the form of more quantitative easing are found to have small and/or temporary beneficial effects only, our simulations show that what can really help is an improvement in total factor productivity.

Keywords International loans · Fiscal policy · Monetary regimes

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1 Introduction

The global financial crisis, and the subsequent downturn of real economic activity, led to a substantial increase in the average public debt to output ratios in the Euro Area (EA). To make things worse, in a typical sovereign debt crisis, a number of countries in the periphery of the EA had to resort to official financial assistance from EU public institutions (EFSF, ESM, GLF, etc) and the IMF to meet their budget financing needs and probably remain in the EA. These countries (Cyprus, Greece, Ireland, Portugal and Spain) have to repay their bailout loans within country-specific time periods. Table 1 provides details of these loans as well as the remaining amounts owed at the end of 2023.

Repayment of these loans can be done through the creation of fiscal surpluses and/or through the replacement of this official part of public debt by new public debt negotiated in free markets. The latter is typically issued in less favorable terms relative to the non-market terms of the loans received by the EU and the IMF. At the same time, EA member-countries have to operate under the rules of the Eurosystem (ES), especially those that refer to quantitative monetary policies, as well as under the new fiscal framework of the European Union (EU), which gives emphasis to the growth rate of primary fiscal expenditures.

The purpose of this paper is to quantify the macroeconomic path from now on of a EA member-country that faces the aforementioned challenges.[1] As a case study, we focus on Greece. As Table 1 reveals, this is for two reasons. First, it is the country with the highest public debt over output in the EA (162% of GDP at the end of 2023). Second, and more importantly, Greece has received the biggest financial assistance by far. It received around 290 billion euros in the previous decade as result of three official fiscal bailout programs and, today, the remaining amount it owes to the EU is around 240 billion euros. This amount translates to 70% of its total public debt at the end of 2023 and has to be repayed in annual installments by 2070 (see Appendix C.1 for details on the time profile of repayments). Macroeconomic outcomes in the coming decades will therefore depend crucially on the evolution of the privately-held public debt (which will be equal to total public debt after 2070) and the associated market sovereign interest rates, the fiscal policies that the country will use to make its public debt sustainable in the longer term, as well as the monetary policy framework that will be adopted by the European Central Bank (ECB).

To study the above, we construct a New Keynesian dynamic general equilibrium (DGE) model of a small open economy augmented with rather detailed fiscal and monetary blocs; the latter is necessary to take into account the monetary and fiscal rules mentioned above. To this relatively general model, which we believe can also describe any EA member country in the current circumstances, we add EU-held debt as well as its repayment within a specific time period as they are in the case of Greece.

The model is calibrated using data from the Greek economy during the euro period and is solved when policy instruments and other exogenous variables are set at their

[1] We believe that the main issue addressed here is also relevant to other, non-EU, countries that owe money to international organizations like the IMF. That is, what happens when these countries repay their official loans obtained in policy terms by fiscal surpluses and/or new loans negotiated in markets?

Table 1 Official financial assistance to EA countries (billion of euros)

	Bailout loans	Repayment deadline	Remaining amount due (at end of 2023)	Debt-to-GDP, (at end of 2023)
Greece	289	2070	240	162%
Portugal	76	2040	48	99%
Ireland	68	2042	18	44%
Spain	41	2027	16	108%
Cyprus	7	2031	6	77%

Sources: European Stability Mechanism and Eurostat

recent values. Then, departing from this solution, with our simulations starting in 2024, we first investigate what happens when the country gradually repays by 2070 its 240 billion euros loan to the EU, when nothing else changes (i.e., at the first stage, we assume away funds from NGEU/RRF or any other policy changes and shocks, which are studied next).

Generally speaking, repayment of EU bailout loans, other things equal, will be recessionary in the decades to come, although the magnitude, duration and time profile of the resulting economic contraction will depend on how privately-held public debt evolves over time as EU-held debt declines. To understand this, it is useful to distinguish three channels through which EU debt repayment affect the economy over time. First, in an economy where public debt is non-neutral, as the privately-held public debt replaces the EU-held public debt, there is crowding out of private capital. This occurs both directly and indirectly. Directly, because, with small changes in saving, private investors need to allocate a larger share of their wealth to government bonds rather than to private capital. Indirectly, because the market sovereign interest rate on new privately-held debt is higher than the non-policy rate on EU loans and this drives up all rates in the economy. Second, except if the growth rate-interest rate differential is very favorable, debt repayments require primary fiscal surpluses in the form of spending cuts and/or tax hikes. Obviously such a fiscal austerity cannot but hurt the economy at least in the early periods. Third, with forward looking agents, in case the end-of-horizon public debt (which will be held by private agents only after 2070) will be relatively high, the anticipation of higher taxes needed to finance the associated debt obligations in the long run will hurt the economy all the time even in the short term.

It is the combined effect of the above three channels that will shape outcomes over time, although, which channel is more important, and hence what is the final effect on the economy, depends on the end-of-horizon privately-held public debt. We simulate the model under three different end-of-horizon public debt scenaria, where by end-of-horizon we mean long-run or trend public debt after the 2070 repayment has been completed: 60% which is the reference value of the Maastricht Treaty; 100% which is what the European Commission seems to recommend in most of reports on Greece; and 162% which is simply the public debt to GDP ratio in the data as this paper is being written. Our simulations show that EU debt repayment will have severe and long-lasting recessionary implications in the case of 162%, namely, in the case in which private lenders simply replace official lenders over time. This happens because, in this case, the damaging effects from the first and third channel discussed above are particularly strong. On the other hand, spending cuts can be milder and the need for big primary fiscal surpluses can be postponed. The case of 60% is symmetrically opposite. In this case, in which there is a relatively small rise in privately-held public debt and interest rates over time, the economic contraction will be short-lived only and the medium- and long-term primary fiscal surpluses will be relatively small and within the range recommended by the European Commission (EC) for Greece. However, this, too good to be true, scenario, can come at the cost of severe cuts in public spending and big primary fiscal surpluses in the short term in order to support low interest rates and public debt in the future. That is, now it is the second channel discussed above that is important. Finally, the case of 100% is a case in between with all three channels being in action. Now, although there is a long-lasting contraction, this is milder than in the case of 162%, and, although there is need for spending cuts in the short term, these cuts are smaller than in the case of 60%. Therefore, in general, EU debt repayment will be challenging if nothing else changes and there are trade-offs both intra-temporally and inter-temporally as usually happens during reforms.

Given these unpleasant news, we then investigate how such recessionary implications can be mitigated or even be reversed. We choose to experiment with three changes on top of debt repayment, one actual and two hypothetical. The actual one is the current financial assistance from NGEU/RRF. The two hypothetical ones are, first, more quantitative monetary policies by the ES in the form of sovereign bond purchases until they hit the official 33% threshold of the ES,[2] and, second, an improvement in the level of total factor productivity (TFP). Our new, enriched simulations show that the NGEU/RRF funds can have temporary growth effects only because, when they terminate around 2026, the recessionary effects of debt repayment will kick off and dominate. Similarly, a more generous QE policy can help but cannot alter the overall recessionary picture. By contrast, what can help, in the sense that it can offset the recessionary effects of debt repayment, is a long-lasting improvement in TFP. For instance, if the end-of-horizon public debt is 100%, an improvement of around 5% in TFP vis-a-vis its initial value will be enough to offset the recessionary effects most of the time, although primary fiscal surpluses will still be necessary. Therefore, searching for engines of long-term growth will be crucial.

We close with a remark on fiscal rules: All the above presuppose, of course, that we manage to get a dynamically stable solution with bounded public debt when we depart from the initial, current situation and travel towards a new long-run equilibrium in which EU loans will have been repaid. We report that this is not possible when primary public spending is set as recommended by the EC in its new fiscal governance framework (see European Commission (2023, 2024b) and European Parliament (2024a, b); this happens mainly because the EC's new spending rule does not react directly to public debt imbalances. To get dynamic stability and debt boundedness, we need to work as we typically do in the academic literature, which means that

[2] The ES holds only around 11% of Greek sovereign bonds at the moment because Greek bonds have been part of the Pandemic Emergency Purchase Programme (PEPP) only that started in 2020. See subsection 3.2 for details.

spending and/or tax instruments are contingent (among other things) on a public debt gap. This is what we have done to ensure a non-explosive public debt.

The present work is related to several branches of the literature. It is mainly related to the literature on debt stabilization and fiscal consolidation (see e.g. Alesina et al. (2019) and International Monetary Fund (2023), as well as the review included in Philippopoulos et al. 2017). It is also related to the literature on the interaction between fiscal and quantitative monetary policies (see e.g. International Monetary Fund (2024) and the review included in the paper by Dimakopoulou et al. (2024) on the EA). It also contributes to the debate on the EU's new fiscal rules (see e.g. Darvas et al. 2024 and European Parliament 2024b). Finally, it belongs to the group of dynamic general equilibrium models for the Greek economy (see e.g. Arellano and Bai 2017; Gourinchas et al. 2017; Economides et al. 2021; Dimakopoulou et al. 2022; Chodorov-Reich et al. 2023 and Dellas et al. 2024) which studied the Greek sovereign debt crisis of the previous decade; by contrast, here we investigate the future implications of repayment of the official bailout loans received during this crisis.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 calibrates the model to Greek data and solves it by using policy data for 2023; this solution serves as departure for our simulations. The implications of debt repayment to the EU, when nothing else changes, are in Section 4. Possible ways of coping with these implications are in Section 5. Section 6 closes the paper with policy lessons. Detailed solutions and data are in the appendix.

2 Model

This section presents a medium-scale New Keynesian model augmented with rather detailed public and monetary policy blocs. Inclusion of these blocs, as well as the scale of the model in general, are necessary for a relatively credible quantitative study of any country that is a member of the EA in the current circumstances. More specifically, the need for a relatively rich public sector and a detailed fiscal policy mix is obvious since we want to address public debt issues. For the same reason, since it is widely recognized that quantitative monetary policy can have an important impact of public debt financing (see the papers cited above), attention is paid to the balance sheet of the central bank and the latter's interaction with private agents regarding sovereign bold repurchases. On top of all this, we will allow for some Greek specific features, the most distinct one being the repayment of EU bailout loans.

We start with an informal description of the model. We will first present the model as if we study a typical EA country, and then explain and model where Greece differs.

2.1 Informal Description of the Model

Households Households consume a domestic and a foreign good, work in the private and the public sector, and can save by keeping deposits at domestic and foreign private banks. They also hold currency subject to a cash-in-advance constraint. As owners of private firms and banks, they receive their profits as dividends. Households are modeled in Section 2.2.

Private Firms A domestic final good is produced by identical final good firms that act competitively using differentiated intermediate goods à la Dixit-Stiglitz. Intermediate goods firms choose labor, capital and imported goods by acting monopolistically in their own product market and by facing price rigidities à la Rotemberg as well as financial constraints when they borrow from private banks. Firms are modeled in Section 2.3.

Private Banks On the asset side, private banks make loans to private firms, hold interest-bearing reserves at the NCB and buy domestic and foreign government bonds. On the side of liabilities, they receive deposits from households and loans from the NCB. On top of this, as happens in practice, private banks can sell a fraction of their outstanding government bonds to the NCB in the secondary market. To solve the profit-maximizing behavior of private banks, we work as in Cúrdia and Woodford (2011), which means that differences between different interest rates (the so-called asset pricing wedges) emerge as a result of costly financial intermediation. Private banks are modeled in Section 2.4.

State Firms State firms use labour supplied by households, goods purchased from the private sector and public capital (the latter is augmented by public investment) to produce a public good that provides utility-enhancing services to households and productivity-enhancing services to firms, where the associated spending inputs as shares of GDP are set as in the data. State firms are presented in Section 2.5.

Government On the revenue side, the government or the Treasury taxes households' income and consumption as well as firms' profits, receives a transfer from its NCB and issues bonds purchased by domestic and foreign private investors/banks. On the expenditure side, the Treasury spends on wages of public employees, government investment, government purchases of goods from the private sector, as well as transfer payments to households. In addition, it has to operate under the expenditure rule of the new fiscal framework of the EU. The Treasury and its policy instruments are modeled in Section 2.6.

National Central Bank (NCB) in the Eurosystem (ES) On the side of assets, the NCB makes loans to private banks and purchases government bonds in the secondary market where these bonds have been purchased in the past by domestic and foreign private banks in the primary market. On the liabilities side, the monetary base consists of banknotes, reserves and cross-border *Target2* liabilities to the ES. These are the largest asset and liability items observed in the financial statements of NCBs in most periphery EA countries including Greece's. In addition, the NCB has to operate under the rules of the ES. The NCB and its policy instruments are modeled in Section 2.7.

A Distinct Greek Feature In addition to private investors/banks, there is a third holder of national government bonds. Specifically, a big part of Greek public debt, around

70% of total public debt, is held by EU public institutions and this debt has to paid back by 2070. This is modeled in Section 2.8.

2.2 Households

There is a single family with $h = 1, 2, ..., N$ members, where $N^p < N$ members work in the private sector and the rest, $N^g = N - N^p$, work in the public sector (the corresponding population fractions are $n^p = \frac{N^p}{N}$ and $n^g = \frac{N^g}{N} = 1 - n^p$). Population sizes and fractions are exogenous and kept constant. There is full consumption and asset insurance within the family.[3]

The objective is to maximize each h's lifetime utility which is given by:

$$\sum_{t=0}^{\infty} \beta^t u \left(c_{h,t}, u_{h,t}; \overline{y}^g_{h,t} \right) \tag{1a}$$

where $c_{h,t}$ denotes h's consumption, $u_{h,t}$ denotes h's work hours, $\overline{y}^g_{h,t} = \frac{N^g y^g_{g,t}}{N}$ is per capita public goods/services provided and produced by the government, and $0 < \beta < 1$ is a time discount factor.

For our numerical solutions, we use a simple log-linear utility function (we report that by taking into account the calibration, our results do not depend on the functional form used):

$$u \left(c_{h,t}, , l_{h,t}; \overline{y}^g_t \right) = \mu_1 \log c_{h,t} + \mu_2 \log \left(1 - u_{h,t} \right) + (1 - \mu_1 - \mu_2) \log \overline{y}^g_{h,t} \tag{1b}$$

where $0 < \mu_1, \mu_2 < 1$ are preference parameters.

Since the household works in both sectors, we define $u_{h,t}$ as the weighted average of work hours in the two sectors:

$$u_{h,t} = n^p u^p_{h,t} + n^g u^g_{h,t} \tag{2}$$

where $u^p_{h,t}$ and $u^g_{h,t}$ are respectively work hours in the private and the public sector.

Also, since there are two final goods, home and foreign, we define the consumption index:

$$c_{h,t} = \frac{(c^H_{h,t})^{\nu} (c^F_{h,t})^{1-\nu}}{\nu^{\nu} (1 - \nu)^{1-\nu}} \tag{3}$$

where $c^H_{h,t}$ and $c^F_{h,t}$ denote h's domestic and foreign consumption respectively and $0 < \nu < 1$ is the weight given to the domestic relative to the foreign good.

[3] This modeling of the household sector permits maintaining the tractability of the representative agent approach, while, at the same time, there are different types of household members. See also e.g. Gertler and Kiyotaki (2010).

The period budget constraint of each h written in real terms is:

$$(1+\tau_t^c)\left(\frac{p_t^H}{p_t}c_{h,t}^H+\frac{p_t^F}{p_t}c_{h,t}^F\right)+j_{h,t}^H+\frac{e_t p_t^*}{p_t}j_{h,t}^F+\frac{p_t^f}{p_t}\frac{\upsilon}{2}\left(\frac{e_t p_t^*}{p_t}j_{h,t}^F\right)^2+m_{h,t}=$$

$$=(1-\tau_t^y)(n_t^p w_t^p u_{h,t}^p+n_t^g w_t^g u_{h,t}^g+\pi_{h,t})+$$

$$+(1+i_t^d)\frac{p_{t-1}}{p_t}j_{h,t-1}^H+(1+i_t^{d*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}j_{h,t-1}^F+\frac{p_{t-1}}{p_t}m_{h,t-1}+g_t^{tr} \tag{4}$$

where p_t^H is the price of the domestic good, p_t^F is the price of the foreign imported good expressed in domestic currency, p_t is the country's CPI specified below, p_t^* is the CPI abroad, e_t is the nominal exchange rate where an increase is a depreciation (in a currency union, $e_t=1$), $j_{h,t}^H$ is the real value of household's end-of-period deposits held at domestic banks earning a nominal interest rate i_{t+1}^d in the next period, $j_{h,t}^F$ is the real value of household's end-of-period deposits held at foreign private banks expressed in foreign prices and earning a nominal interest rate i_{t+1}^{d*} in the next period, $\frac{\upsilon}{2}\left(\frac{e_t p_t^*}{p_t}j_t^F\right)^2$ is a resource cost associated with banking abroad, $m_{h,t}$ is the real value of end-of-period currency carried over by the household from t to $t+1$, w_t^p and w_t^g are the real wage rates in the private and the public sector, $\pi_{h,t}$ is the dividend paid to the household by private firms and banks, $0\leq\tau_t^c,\ \tau_t^y<1$ are the tax rates on consumption and income, and g_t^{tr} is a per capita lump-sum income transfer from the government.

To give money a role, we use a cash-in-advance constraint like:

$$m_{h,t}\geq\kappa^m(1+\tau_t^c)\left(\frac{p_t^H}{p_t}c_{h,t}^H+\frac{p_t^F}{p_t}c_{h,t}^F\right) \tag{5}$$

where $0<\kappa^m\leq 1$ is a parameter.

The household chooses $\{c_{h,t}^H, c_{h,t}^F, c_{h,t}, u_{h,t}^p, j_{h,t}^H, j_{h,t}^F, m_{h,t}\}_{t=0}^\infty$ subject to the above (notice that, for simplicity, we assume that $u_{h,t}^g$ is not a choice variable meaning that work in the public sector is inelastically supplied at w_t^g). The first-order conditions are in Appendix A.1.

2.3 Private Firms and Production of Private Goods

A single domestic final good is produced by N^f identical final good firms indexed by subscript $f=1,2,...,N^f$. There are also N^i differentiated intermediate goods used as inputs for the production of the final good à la Dixit-Stiglitz. Each intermediate good is produced by an intermediate good firm indexed by $i=1,2,...,N^i$. In equilibrium, we will set $N^f=N^i=N^p$.

2.3.1 Final Good Firms

Each final good firm f produces $y_{f,t}$ by using intermediate goods according to a Dixit-Stiglitz technology:

$$y_{f,t} = \left[\sum_{i=1}^{N^i} \frac{1}{(N^i)^{1-\theta}} (y_{f,i,t})^{\theta} \right]^{\frac{1}{\theta}} \tag{6}$$

where $y_{f,i,t}$ is the quantity of intermediate good i used by each final good firm f and the parameter $1/(1-\theta)$ measures the substitutability among intermediate inputs.[4] Note that we use $\frac{1}{(N^i)^{1-\theta}}$ to avoid scale effects in equilibrium (for similar modelling, see e.g. Blanchard and Giavazzi 2003 and Dimakopoulou et al. 2024).[5]

The profit of each f written in real terms is:

$$\pi_{f,t} = y_{f,t} - \sum_{i=1}^{N} \frac{p_{i,t}^H}{p_t^H} y_{f,i,t} \tag{7}$$

where $p_{i,t}^H$ is the price of each domestically-produced intermediate good i.

The firm acts competitively. Its familiar first-order condition for $y_{f,i,t}$ is in Appendix A.2.

2.3.2 Intermediate Goods Firms

Each intermediate good firm i owns the capital stock and makes investment and other factor decisions acting as a monopolist in its own product market and facing capital adjustment costs, Rotemberg-type nominal fixities and financial constraints. Its new investment is financed by retained earnings and loans from private banks.

The net profit, $\pi_{i,t}$, of each i written in real terms is (for details see Appendix A.3):

$$\pi_{i,t} = (1-\tau_t^{\pi}) \left[\frac{p_{i,t}^H}{p_t} y_{i,t} - w_t^p u_{i,t} - \frac{p_t^F}{p_t} im_{i,t} \right] -$$
$$- \frac{p_t^H}{p_t} x_{i,t} - \frac{p_t^H}{p_t} \frac{\xi^k}{2} \left(\frac{k_{i,t}}{k_{i,t-1}} - 1 \right)^2 k_{i,t-1} - \frac{p_t^H}{p_t} \frac{\xi^p}{2} \left(\frac{p_{i,t}^H}{p_{i,t-1}^H} - 1 \right)^2 \overline{y}_{i,t} +$$
$$+ \left(l_{i,t} - (1+i_t^l) \frac{p_{t-1}}{p_t} l_{i,t-1} \right) \tag{8}$$

where $u_{i,t}$ is labor services used by each i, $im_{i,t}$ is imported goods used by each i, $x_{i,t}$ is i's investment in capital goods and $k_{i,t}$ is its stock of capital goods used in

[4] For simplicity, we assume that final good firms use domestically produced intermediate goods only. This is not important because intermediate goods firms will use imported goods (see next).

[5] That is, since $y_{f,i,t} = \frac{y_{i,t}}{N}$, where $y_{i,t}$ is the output of each intermediate good firm i, in a symmetric equilibrium we will simply have $y_{f,t} = y_{i,t}$.

production in the next period, $l_{i,t}$ is the real value of end-of-period loans received from domestic private banks on which the firm pays a nominal interest rate,[6] i^l_{t+1}, in the next period, $0 \leq \tau^{\pi}_t < 1$ the corporate tax rate, ξ^k is a parameter measuring capital adjustment costs and ξ^p is a parameter measuring Rotemberg-type convex price adjustment costs.[7]

The law of motion of the firm's capital stock is:

$$k_{i,t} = x_{i,t} + (1-\delta)\, k_{i,t-1} \tag{9}$$

where the parameter $0 \leq \delta \leq 1$ is the capital depreciation rate.

For the firm's production function, we adopt the CES form (for similar functional forms, see e.g. Acemoglu (2009, chapter 15) and Jones 2011):

$$y_{i,t} = A^p_t \left[\chi^p_k (k_{i,t-1})^{op} + \chi^p_l (u_{i,t-1})^{op} + \chi^p_{im} (im_{i,t})^{op} + \chi^p_g \left(\overline{y}^g_{i,t} \right)^{op} \right]^{1/op} \tag{10}$$

where $0 < \chi^p_k, \chi^p_l, \chi^p_{im}, \chi^p_g < 1$ with $\chi^p_k + \chi^p_l + \chi^p_{im} + \chi^p_g = 1$ measure the importance of different inputs in production, $op < 1$ is a technology parameter so that $1/(1-op)$ is the degree of complementarity or substitutability between inputs, $A^p_t > 0$ is TFP in the private sector, and $\overline{y}^g_{i,t} = \frac{N^g y^g_{g,t}}{N^i}$ is per firm public goods/services.

Firms are also subject to a working capital constraint.[8] Following e.g. Uribe and Schmitt-Grohé (2017, chapter 6), we assume that firms finance a fraction of payments to labor with loans from domestic private banks:

$$l_{i,t} \geq \eta w^p_t u_{i,t} \tag{11}$$

where the parameter $\eta \geq 0$ measures the tightness of borrowing conditions.

Each i maximizes the discounted sum of its profits distributed as dividends to households:

$$\sum_{t=0}^{\infty} \beta_{i,t} \pi_{i,t} \tag{12}$$

where, since firms are owned by households, we will ex post postulate that the firm's discount factor, $\beta_{i,t}$, equals the households' marginal rate of substitution between consumption at t and $t+1$ (see also e.g. Miao (2014, chapter 14)).

Each i chooses $\{u_{i,t}, im_{i,t}, k_{i,t}, l_{i,t}\}^{\infty}_{t=0}$ to maximize its stream of dividends, as defined in Eq. 12 subject to Eqs. 8-11 and the inverse demand function for its product

[6] We could also assume that firms receive loans from foreign private banks. This is not important to our results.

[7] Rotemberg-type costs associated with price changes are assumed to be proportional to average output, $\overline{y}^h_{i,t}$, which is taken as given by each i. This is not important but helps the smooth dynamics of the model.

[8] This financial constraint breaks the Modigliani-Miller irrelevance result and thereby allows bank loans and other financial variables to affect firms' production decisions and, in turn, the real economy. We could assume different types of financial constraints as in e.g. Gertler and Karadi (2011) and Sims and Wu (2020, 2021). This is not important to our results.

coming from the final good firm's problem above. Details and first-order conditions are in Appendix A.3.

2.4 Private Banks

There are N^b private banks indexed by the subscript $b = 1, 2, ..., N^b$, where we will again set $N^b = N^p$ in equilibrium. In addition to their standard role, which is the provision of intermediation between lenders and borrowers by converting households' deposits into loans to firms, we also allow private banks to hold interest-bearing reserves at the NCB, to get loans from the NCB and to purchase domestic and foreign government bonds. In other words, on the asset side of banks, we have loans to private firms, reserves held at the NCB, and domestic and foreign government bonds, while, on the liability side, we have deposits from households and loans from the NCB. Any profits made by banks are distributed to households.

In addition, as happens in reality and working as in Dimakopoulou et al. (2024), we assume that there is a secondary market for government bonds. In particular, we assume that, in the beginning of period t, each private bank b can keep a fraction, $0 \leq \Lambda_{b,t} \leq 1$, of the government bonds it has purchased in the past, $b_{b,t-1}$, and can sell the rest, $0 \leq 1 - \Lambda_{b,t} \leq 1$, to its NCB at a price Φ_t. When the latter happens, the private bank receives the amount $\Phi_t(1 - \Lambda_{b,t})\frac{p_{t-1}}{p_t}b_{b,t-1}$ from the NCB and this is credited in its reserves account held at the NCB.[9]

Each b's net real dividend, $\pi_{b,t}$, is (for details see Appendix A.4):

$$\pi_{b,t} = \left(1 - \tau_t^{\pi}\right)[(1 + i_t^l)\frac{p_{t-1}}{p_t}l_{b,t-1} + (1 + i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}f_{b,t-1} + (1 + i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1}+$$
$$+(1 + i_t^b)\frac{p_{t-1}}{p_t}\Lambda_{b,t}b_{b,t-1} + \Phi_t\frac{p_{t-1}}{p_t}(1 - \Lambda_{b,t})b_{b,t-1}-$$
$$-(1 + i_t^d)\frac{p_{t-1}}{p_t}j_{b,t-1} - (1 + i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1} - \frac{p_t^H}{p_t}\Xi_{b,t}]-$$
$$- l_{b,t} - b_{b,t} - \frac{e_t p_t^*}{p_t}f_{b,t} - m_{b,t} + j_{b,t} + z_{b,t} \tag{13}$$

where $l_{b,t}$ are loans given to domestic firms on which the bank receives a nominal interest rate i_{t+1}^l one period later, $f_{b,t}$ is the real value of one-period foreign government bonds denominated in foreign prices and acquired by each b at t on which the bank receives a nominal interest rate i_{t+1}^{b*} at $t+1$,[10] $m_{b,t}$ is the real value of interest-bearing reserves held at the NCB on which the bank earns a nominal interest rate i_{t+1}^r at $t+1$, $b_{b,t}$ is the real value of one-period domestic government bonds purchased by the bank at t and earning a nominal interest rate i_{t+1}^b at $t+1$ if the bank keeps them or Φ_{t+1} if

[9] The general idea behind such transactions is that they provide extra liquidity to private banks and reduce possible risks and costs associated with holding bonds of a highly-indebted sovereign (see also below).

[10] This is denominated in foreign currency. That is, if $F_{p,t}$ is the nominal value for each agent k, the real value is $f_{p,t} \equiv \frac{F_{p,t}}{p_t^*}$.

the bank sells them to its NCB in the secondary market, $j_{b,t}$ is deposits obtained by domestic households on which the bank pays a nominal interest rate i^d_{t+1} one period later, $z_{b,t}$ is loans from the NCB to the private bank on which the latter pays a nominal policy interest rate i^z_{t+1} one period later and $\Xi_{b,t}$ captures real operational costs faced by banks.[11] Also, τ^π_t is the profit tax rate as already defined above.

Real operational costs, $\Xi_{b,t}$, are assumed to be increasing in the volumes of government bonds, loans given to firms and loans taken from the NCB, while they are decreasing in the volume of reserves held at the NCB.[12] That is, $\Xi_{b,t} = \Xi(l_{b,t-1}, b_{b,t-1}, \frac{e_t p^*_t}{p_t} f_{b,t-1}, m_{b,t-1}, z_{b,t-1}, \Lambda_{b,t})$. In our numerical solutions, we will use the functional form:

$$\Xi_{b,t} \equiv \frac{\xi^l}{2}(l_{b,t-1})^2 + \frac{\xi^b}{2}(\Lambda_{b,t} b_{b,t-1})^2 + \frac{\xi^f}{2}\left(\frac{e_t p^*_t}{p_t} f_{b,t-1}\right)^2 + \\ + \frac{\xi^m}{2}[m_{b,t-1} + \Phi_t(1-\Lambda_{b,t})b_{b,t-1}]^{-2} + \frac{\xi^z}{2}(z_{b,t-1})^2 \tag{14}$$

where $\xi^l, \xi^b, \xi^f, \xi^m, \xi^z \geq 0$ are parameters which will be calibrated so as to mimic the data on interest rates and financial quantities. Notice that this specification produces well-defined demand and supply functions for different assets and liabilities. Notice also that the bank's costs are affected by credit operations in the secondary market, in the sense that, when the NCB purchases bonds in the secondary market, private banks' bonds are reduced and, at the same time, their reserves increase by the same amount. Finally, note that these transaction costs produce asset pricing wedges which in turn allow balance sheet monetary policies to have real effects.[13]

Each b maximizes the discounted sum of dividends:

$$\sum_{t=0}^{\infty} \beta_{b,t} \pi_{b,t} \tag{15}$$

where, since banks are owned by households, we will ex post postulate that the firm's discount factor, $\beta_{b,t}$, equals the households' marginal rate of substitution between consumption at t and $t+1$.

Each b chooses $\{l_{b,t}, b_{b,t}, f_{b,t}, m_{b,t}, z_{b,t}, \Lambda_{b,t}\}_{t=0}^{\infty}$ to maximize (15) subject to Eqs. 13 and 14. The bank's optimization problem is solved as in Cúrdia and Woodford (2011) and details and first-order conditions are provided in Appendix A.4.

11 That is, here we adopt the modelling of Cúrdia and Woodford (2011). The model of Gertler and Kiyotaki (2010) and Gertler and Karadi (2011, 2013) is the other popular model in this literature. We report that, given the appropriate calibration, the particular model of the banking sector used is not important to our results. Here we use the Cúrdia-Woodford model for its relative simplicity. Walsh (2017, chapter 11) reviews this literature. In Dimakopoulou et al. (2024), we have used the Gertler-Karadi-Kiyotaki framework in a DSGE model for the study of the EA.

12 This is similar to e.g. Cúrdia and Woodford (2011), where banks intermediate between borrowers and lenders and the associated intermediation cost falls with bank reserves held at the central bank.

13 Asset pricing wedges (produced here by costly financial intermediation a la Curdia and Woodford) breaks Wallace's (1981) irrelevance result and thereby allows balance sheet monetary policies to affect the real economy. See Walsh (2017, chapter 11.5) for a review of this literature and other ways of producing asset pricing wedges.

2.5 State Firms and Production of Public Goods/services

We now model the way in which state enterprises produce the publicly provided good/service. There are N^g state firms indexed by the subscript $g = 1, 2, ..., N^g$ producing a single public good/service (where N^g was defined at the start of Section 2.2). The cost of each g written in real terms is:

$$w_t^g u_{g,t} + \frac{p_t^H}{p_t}(g_{g,t}^g + g_{g,t}^i) \tag{16}$$

where $u_{g,t}$ is labor services used by each g, $g_{g,t}^g$ is goods purchased from the private sector by each g, and $g_{g,t}^i$ is investment made by each g.

The production function of each state firm g is similar to that in the private sector, namely:

$$y_{g,t}^g = A_t^g[\chi_k^g(k_{g,t-1}^g)^{og} + \chi_l^g(u_{g,t})^{og} + \chi_g^g\left(g_{g,t}^g\right)^{og}]^{1/og} \tag{17}$$

where $0 < \chi_k^g, \chi_l^g, \chi_g^g < 1$ are measures of factor intensity, $1/(1 - og)$ is the degree of substitutability or complementarity between productive factors and $A_t^g > 0$ is TFP in the public sector.

The stock of each state firm's capital evolves over time as:

$$k_{g,t}^g = (1 - \delta^g)k_{g,t-1}^g + g_{g,t}^i \tag{18}$$

where $0 < \delta^g < 1$ is the depreciation rate of public capital.

To specify the level of output produced by each state firm, $y_{g,t}^g$, and hence the amount of public goods/services provided to the society, we obviously have to specify the amounts of inputs, $u_{g,t}$, $g_{g,t}^g$ and $k_{g,t}^g$ or equivalently $g_{g,t}^i$ for the latter. We also need to specify w_t^g. The value of $u_{g,t}$ will be tied down by the supply side (see the household's problem), while the values of $g_{g,t}^g$, $g_{g,t}^i$ and w_t^g will be be determined respectively by data on government expenditure on goods purchased from the private sector, public investment and public wages (for details, see Appendix A.5).

2.6 Government

The government, or the Treasury, uses revenues from taxes, the issuance of new bonds and a transfer from the NCB to finance its various spending activities. On top of this, it has to operate under the new fiscal rules of the Stability and Growth Pact (SGP). In what follows, we first present the government budget constraint and then model the fiscal instruments under these rules.

2.6.1 Government Budget Constraint

In a typical open economy, public debt or sovereign bonds can be held by domestic private agents/banks and foreign private agents/banks (recall that central banks can purchase government bonds in the secondary market only and this is why such holdings are not included here; see below on this). Thus, if $0 \leq \lambda_t^d, \lambda_t^g \leq 1$, where $\lambda_t^g + \lambda_t^d = 1$, denote respectively the fractions of public debt held by domestic and foreign private agents/banks at t, the period government budget constraint written in real and per capita terms is:[14]

$$g_t^t + n^g \left[w_t^g u_{g,t}^g + \frac{p_t^H}{p_t} \left(g_{g,t}^g + g_{g,t}^i \right) \right] +$$
$$+ (1 + i_t^b) \frac{p_{t-1}}{p_t} \lambda_{t-1}^d b_{t-1} + (1 + i_t^b) \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} \frac{p_{t-1}}{e_{t-1} p_{t-1}^*} \lambda_{t-1}^g b_{t-1} =$$
$$= b_t + t_t^{tax} + t_t^{gov} \tag{19}$$

where recall that g_t^t is a lump-sum income transfer to households, $n^g[w_t^g u_{g,t} + \frac{p_t^H}{p_t}(g_{g,t}^g + g_{g,t}^i)]$ is the cost of inputs used by state firms, b_t is the end-of period public debt on which the government will pay the (endogenously determined) nominal interest rate i_{t+1}^b in the next period, t_t^{tax} denotes tax revenues (see below) and t_t^{gov} is a transfer from the NCB to the Treasury (see below). The terms in the second line of this budget identity are interest payments to domestic and foreign private lenders.

Tax revenues written in real and per capita terms, t_t^{tax}, are:

$$t_t^{tax} \equiv \tau_t^c \left(\frac{p_t^H}{p_t} c_{h,t}^H + \frac{p_t^F}{p_t} c_{h,t}^F\right) + \tau_t^y \left(n^p w_t^p u_{h,t}^p + n^g w_t^g u_{h,t}^g + \pi_{h,t}\right) +$$
$$+ \tau_t^\pi n^p \left(\frac{p_t^H}{p_t} y_{i,t} - w_t^p u_{i,t} - \frac{p_t^F}{p_t} im_{i,t} \right) +$$
$$+ \tau_t^\pi n^p [(1 + i_t^l) \frac{p_{t-1}}{p_t} l_{b,t-1} + (1 + i_t^{b*}) \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} f_{b,t-1} + (1 + i_t^r) \frac{p_{t-1}}{p_t} m_{b,t-1} +$$
$$+ (1 + i_t^b) \frac{p_{t-1}}{p_t} \Lambda_{b,t} b_{b,t-1} + \Phi_t \frac{p_{t-1}}{p_t} (1 - \Lambda_{b,t}) b_{b,t-1} -$$
$$- (1 + i_t^d) \frac{p_{t-1}}{p_t} j_{b,t-1} - (1 + i_t^z) \frac{p_{t-1}}{p_t} z_{b,t-1} - \frac{p_t^H}{p_t} \Xi_{b,t}] \tag{20}$$

One of the fiscal policy variables must follow residually to close the budget identity in Eq. 19. We typically assume that over time this role is played by the end-of-period total public debt, b_t. See next for how we model the rest of fiscal policy instruments that can be set independently.

[14] That is, if B_t^g denotes the total nominal value of public debt held by foreign banks and expressed in foreign prices, then its real value in domestic prices is $\frac{e_t B_t^g}{p_t}$, which in per capita terms is $\frac{e_t B_t^g}{p_t N} = \frac{e_t p_t^* B_t^g}{p_t p_t^* N} = \frac{e_t p_t^*}{p_t} b_t^g$, where $b_t^g = \frac{B_t^g}{p_t^* N}$ denotes the per capita real value of public debt held by foreign banks in terms of foreign prices. Then, we define $b_t^d \equiv \lambda_t^d b_t$ for the end-of-period real per capita public debt held by domestic private agents and $\frac{e_t p_t^*}{p_t} b_t^g \equiv \lambda_t^g b_t = (1 - \lambda_t^d) b_t$ for the end-of-period real per capita public debt held by foreign private agents.

2.6.2 Modeling of Fiscal Policy Instruments

Before we start, to maintain a closer link to the data, instead of working with the levels of primary public spending, $g_t^w, g_t^i, g_t^t, g_t^g$, we will work with their GDP shares, $0 < s_t^w, s_t^i, s_t^t, s_t^g < 1$, which are respectively the public wage bill, public investment, transfer payments and spending on goods and services purchased from the private sector, all four expressed as shares of GDP, and where $s_t \equiv s_t^w + s_t^i + s_t^t + s_t^g$ is public primary spending (i.e. net of interest payments) as share of GDP.[15] Thus, the independently set fiscal policy instruments are the paths of the four spending shares and the three tax rates, $s_t^w, s_t^i, s_t^t, s_t^g, \tau_t^c, \tau_t^y, \tau_t^\pi$.

We now specify rules for the independently set fiscal policy instruments. Regarding spending instruments in particular, there are two rather different approaches. There is the approach followed by policy makers and institutions, and the approach typically followed by the academic literature.

Starting with the former, and specifically, with the fiscal rules of the EU, these are usually in the form of numerical targets. In the new EU fiscal governance framework, although references to the 3% deficit target and the 60% debt target remain, the SGP relies on a single operational indicator in the form of the growth rate of net primary public expenditure (see e.g. European Commission (2023, 2024b) and European Parliament (2024a, 2024b)). In particular, the growth rate of nominal net primary public expenditure should not exceed the growth rate of nominal GDP and, for member countries with a government debt exceeding 60% of GDP or with more pronounced debt sustainability risks, this should be further adjusted to ensure a gradual debt reduction. This fiscal adjustment is shaped by the difference between the country's structural primary balance and a country-specific policy target value for this balance, where the latter is supposed to be consistent with "debt ratios on a plausibly downward path for member countries with a debt-to-GDP ratio above 60%" (we will label this country-specific policy target for the structural primary balance as POL_t).[16] To convert all these institutional rules into a maximum or reference path for the growth rate of net primary public expenditure, we use the formula in e.g. European Commission (2023,

[15] In particular, as shown in Appendices A.5 and A.6, real and per capita primary public spending is $g_t \equiv g_t^t + n^g \left[w_t^g u_{g,t}^g + \frac{p_t^H}{p_t} \left(g_{g,t}^g + g_{g,t}^i \right) \right] = (s_t^t + s_t^w + s_t^g + s_t^i) \frac{p_t^H}{p_t} n^p y_{i,t} \equiv s_t \frac{p_t^H}{p_t} n^p y_{i,t}$ and, hence, real and per capital primary public spending as share of real and per capita GDP, is simply $\frac{g_t}{\frac{p_t^H}{p_t} n^p y_{i,t}} = (s_t^t + s_t^w + s_t^g + s_t^i) \equiv s_t$. Appendix A.5 also expresses the various spending items in terms of shares. Specifically, we use $s_t^w \equiv \lambda^w s_t$, $s_t^i \equiv \lambda^i s_t$, $s_t^t \equiv \lambda^t s_t$ and $s_t^g \equiv (1 - \lambda^w - \lambda^i - \lambda^t) s_t$, where $s_t, \lambda^w, \lambda^i, \lambda^t$ are set as in the data (see section 3 below).

[16] According to the EU's new fiscal framework, this country-specific policy target for the structural primary balance is calculated by means of a Debt Sustainability Analysis (DSA) in a separate step. The DSA makes use of a single equation, the government's budget constraint, and calculates the path (or the distribution of paths) of public debt under different assumptions about the structural primary balance, future interest rates, growth rates, inflation, etc, as well as their stochastic properties (see e.g. European Commission 2025 for the DSA approach to fiscal sustainability). Then, the structural primary balance that is expected to lead to a declining debt ratio, as well to satisfy other fiscal safeguards, is what is labeled here as POL_t. For an evaluation of the DSA approach to public debt sustainability in particular, and more generally of the use of the government budget constraint only to study public debt sustainability, given exogenous assumptions about growth rates, interest rates, etc, see e.g. European Parliament (2024b) and Economides et al. (2024).

p. 5) and European Parliament (2024b, Box 4), which, in the context of our model, implies that s_t, as defined above, should obey:[17] [18]

$$s_t^{EC} \leq s_{t-1} \left[1 - \frac{\left(POL_t + \frac{(g_{t-1} - t_{t-1}^{tax})}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}} \right)}{\frac{g_{t-1}}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}}} \right] \tag{21a}$$

where the superscript EC indicates that this is the EC's spending rule, $\frac{(g_{t-1} - t_{t-1}^{tax})}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}}$ is the primary fiscal deficit (resp. surplus) if positive (resp. negative) as share of GDP in the previous period and $\frac{g_{t-1}}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}}$ is primary public spending as share of GDP again in the previous period. Notice that the required change in the primary balance, $\left(POL_t + \frac{(g_{t-1} - t_{t-1}^{tax})}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}} \right)$, can be small or even negative, and this can happen although public debt and hence POL_t are high, if a country happens to have a sizeable primary surplus, namely if $(g_{t-1} - t_{t-1}^{tax})$ is negative.[19] Also notice that the starting value of s_t will be its value in the initial steady state, while the value of POL_t for Greece, as well as numerical examples for Eq. 21a, will be provided in Section 3.2 below.

By contrast, the typical approach of the academic literature has been to assume that at least one of the independently set fiscal spending-tax policy instruments follows a debt-contingent policy rule according to which, in addition to an exogenous process (usually an $AR(1)$ process), fiscal policy instruments react to the outstanding public debt to GDP ratio as deviation from a policy target value; this is necessary to ensure a stable and determinate solution with bounded public debt (see e.g. Leeper et al.

[17] It should be said however that the EC's rule is more complicated than that in Eq. 21a; for example, it refers to structural balances (since our model is deterministic, structural and non-structural primary balances coincide), includes future projections, allows for deviations in case of crises, etc. Here, we do not incorporate all these details. However, (Eq. 21a captures the key properties of the new fiscal rule.

[18] Here are the details behind (21a). In nominal and total terms, if the growth rate of primary public spending should not exceed the growth rate of the country's GDP, then $\frac{G_t - G_{t-1}}{G_{t-1}} \leq \frac{Y_t - Y_{t-1}}{Y_{t-1}}$. Since $Y_t = p_t^H N^p y_{i,t}$, this becomes in real and per capita terms $\frac{g_t}{g_{t-1}} \leq \frac{\frac{p_t^H}{p_t} n^p y_{i,t}}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}}$. But, since $g_t = s_t \frac{p_t^H}{p_t} n^p y_{i,t}$, this simplifies to $s_t \leq s_{t-1}$ in terms of GDP shares. This explains the terms outside the bracket in Eq. 21a. In our computations, we will assume that the rule of the EC is switched on when the public debt ratio exceeds the threshold of 0.9 as recommended by the EU.

[19] Darvas et al. (2024, Table 1) list the values of the policy target, POL_t, and the term, $POL_t + \frac{(g_{t-1} - t_{t-1}^{tax})}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}}$, for each EU and EA country based on EC's forecasts. In the same paper, they also compare the new fiscal framework with the "old" one, where the main target for the primary structural balance was the so-called Medium-term budgetary objective (MTO).

(2010a, b), Sims and Wolff (2018), Malley and Philippopoulos (2023) and many others). If, for instance, we assume that it is the GDP share of primary public spending, s_t, that plays this role, we have the rule:

$$s_t^{AC} \equiv \rho^s s_{t-1} + \left(1 - \rho^s\right) s - \gamma^{s,b} \left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) \tag{21b}$$

where the superscript AC indicates that this is the rule typically used by the academic literature, $\gamma^{s,b} \geq 0$ is the feedback policy coefficient associated with the use of s_t^{AC}, $0 \leq \rho^s \leq 1$ is a persistence parameter, and variables without time subscripts denote policy target values (defined in Section 3 below).

Regarding the tax rates, τ_t^c, τ_t^y, τ_t^π, they will be kept constant at their data values (except otherwise explicitly stated).

2.7 The National Central Bank (NCB) in the Eurosystem

The NCB operates under the rules of the ES.[20] In what follows, we first present its budget constraint and then model the conduct of monetary policy under these rules.

2.7.1 Assets, Liabilities and the NCB's Budget Constraint

On the side of assets of the NCB, we include loans to private banks and government bonds. In particular, we allow the NCB to purchase domestic and foreign governments bonds in the secondary market where these bonds have been in the hands of domestic and foreign private investors/banks. On the side of liabilities, we include banknotes, reserves and *Target2* liabilities to the ES.[21] [22] These have been the largest (asset and liability) items in the financial statements of NCBs in the periphery countries of the EA since 2008.[23]

The change in assets and liabilities is captured by the NCB's budget constraint which is in real and per capita terms:

$$\Phi_t(1 - \Lambda_{b,t})\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + \Phi_t(1 - \Lambda_{b,t})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} +$$

$$+\Phi_t^*(1 - \Lambda_{b,t}^*)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{d*} b_{t-1}^* +$$

$$+n^p z_{b,t} + n^p(1 + i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1} + t_t^{gov} + t_t^{es} \equiv$$

[20] For reviews of monetary policy in the ES, see e.g. Coenen et al. (2020) and Bonam et al. (2024). For a clear presentation of the various rules of the ES, see e.g. the 2023 Annual Reports of Deutsche Bundesbank. For a review of macroeconomic structural models used by central banks, see e.g. Linde et al. (2016).

[21] See also e.g. Bassetto and Caracciolo (2021) for a similar menu of assets and liabilities and hence for the NCB's budget constraint that follows next.

[22] Appendix B provides details on *Target2* balances.

[23] Appendix C.2 presents related Greek data.

$$\equiv (1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1}+(1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1}+$$
$$+(1-\Lambda_{b,t}^*)(1+i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{d*}b_{t-1}^*$$
$$+n^p(1+i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1}+n^p m_{b,t}+\left(m_{h,t}-\frac{p_{t-1}}{p_t}m_{h,t-1}\right)+$$
$$+\left(TARG_t-\left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t}TARG_{t-1}\right)+s_t^{es} \quad (22)$$

where $n^p z_{b,t}$ is the end-of period loans to private banks on which the NCB receives a nominal interest rate i_{t+1}^z in the next period, $n^p m_{b,t}$ is the end-of period interest-bearing reserves held by private banks at the NCB for which the NCB pays a nominal interest rate i_{t+1}^r in the next period, $(1-\Lambda_{b,t})\lambda_{t-1}^d b_{t-1}$ and $(1-\Lambda_{b,t})\lambda_{t-1}^g b_{t-1}$ are domestic sovereign bonds having been purchased by domestic and foreign private banks respectively in the primary market in the past and repurchased now in the current period by the NCB in the secondary market at price Φ_t on which the NCB earns the market interest rate i_t^b,[24] $(1-\Lambda_{b,t}^*)\lambda_{t-1}^{d*}b_{t-1}^*$ are foreign sovereign bonds having been purchased by foreign private agents in the primary market in the past and repurchased now in the current period by the NCB in the secondary market at a price Φ_t^* on which the NCB earns the market interest rate i_t^{b*}, and t_t^{gov} is the transfer from the NCB to its government (see below on this). Regarding transactions with the ES, t_t^{es} denotes the transfer from the NCB to the ES and s_t^{es} is the other way around, namely, it is the transfer from the ES to the NCB, so that $(s_t^{es}-t_t^{es})$ is the net transfer from the ES to the NCB (see below on this). Finally, $TARG_t$ denotes is the end-of-period stock of real and per capita *Target2* liabilities to the ES on which the NCB pays the main refinancing operations' interest rate, i_{t+1}^{MRO}, in the next period (see also e.g. Bassetto and Caracciolo 2021). Thus, $m_{h,t}+n^p m_{b,t}+TARG_t$ is the monetary base of the NCB within the ES.

Thus, the budget identity in Eq. 22 reads that purchases of sovereign bonds in the secondary market plus loans to private banks plus transfers to the government are financed by the issuance of non-interest bearing banknotes, interest-bearing reserves and *Target2* liabilities to the ES, as well as income from the NCB's net assets plus a net transfer from the ES.

One of the monetary policy variables must follow residually to close the budget identity in Eq. 22. We assume that this role is played by *Target2* liabilities, $TARG_t$. See next for how we model the rest of monetary policy instruments that can be set independently.

2.7.2 Modeling of Monetary Policy Instruments

In Appendix A.7, we show in detail that, according to the rules of the ES, the resulting transfer from the NCB to its government is:

$$t_t^{gov}\equiv(1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1}+$$

[24] For simplicity but also for the lack of data, we assume the same fraction, $1-\Lambda_{b,t}$, of domestic government bonds purchased by the NCB from domestic and foreign private banks.

$$+(1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1}+$$

$$+n^p(1+i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1}-\frac{p_{t-1}}{p_t}m_{h,t-1}-n^p(1+i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1}-$$

$$-\left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t}TARG_{t-1}+$$

$$+(1-\Lambda_{b,t}^*)(1+i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{g*}b_{t-1}^* \tag{23a}$$

where again according to the rules of the ES this cannot be negative (a negative value would imply fiscal support of the ES) so that we impose:

$$t_t^{gov}\geq 0 \tag{23b}$$

Regarding the rest of monetary policy instruments, i_t^r, i_t^z, i_t^{MRO} and $(s_t^{es}-t_t^{es})$, as well as $(1-\Lambda_{b,t})$ and $(1-\Lambda_{b,t}^*)\lambda_{t-1}^{d*}b_{t-1}^*$, we will keep them constant at their recent values in the data at least in our baseline solutions (see Section 3 below). Notice that, since the policy interest rates, i_t^r, i_t^z, i_t^{MRO}, are determined at the ES level, they do not react to the state of a small member country (i.e. loss of interest rate policy independence), while, the net transfer from the ES to the NCB, $(s_t^{es}-t_t^{es})$, is the so-called "Net result of the pooling of monetary income" in the financial statements of a NCBs in the ES (again see Section 3 below). It should be added here that this net transfer represents the difference between the monetary income paid by the NCB to the common pool of the ES and the NCB's claim of that common pool (for modelling details, see Appendix A.7.2). Finally, in a currency union, $e_t\equiv 1$ at all t for the nominal exchange rate.

2.8 A Distinct Feature of the Greek Economy

In the case of Greece, as said in the Introduction, because of the three official fiscal bailouts in the last decade, a large part of the Greek public debt is currently in the hands of EU institutions and has to be paid back by 2070. In what follows, we explain how we model this extra feature.

2.8.1 Holders of Greek Public Debt and the Government Budget Constraint

We now assume that public debt or sovereign bonds are held by three different types of creditors: domestic private agents/banks, foreign private agents/banks, and EU public institutions (recall that central banks in the ES can purchase government bonds in the secondary market only). Thus, if $0\leq\lambda_t^d,\lambda_t^g,\lambda_t^{eu}\leq 1$, where $\lambda_t^d+\lambda_t^g+\lambda_t^{eu}=1$, denote respectively the fractions of public debt held by domestic private agents/banks, foreign private agents/banks and EU public institutions at t, then the period government budget constraint written in real and per capita terms changes from Eq. 19 to:[25]

$$g_t^t + n^g \left[w_t^g u_{g,t}^g + \frac{p_t^H}{p_t} \left(g_{g,t}^g + g_{g,t}^i \right) \right] +$$

$$+(1+i_t^b)\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + (1+i_t^b)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} +$$

$$+ (1+i^{eu})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{eu} b_{t-1} = b_t + t_t^{tax} + t_t^{gov} \tag{24}$$

where notice that now the sovereign interest rates can vary depending on the identity of the creditor; in particular, when the government borrows from the (domestic and foreign) market, it pays the market interest rate, i_t^b, while, when it borrows from EU public institutions, it pays a constant policy rate denoted as i^{eu}.

2.8.2 Repayment of Public Debt to EU Institutions

To model debt repayment to EU institutions, we assume that, from now on, the share of public debt owed to the EU follows the process:

$$\lambda_t^{eu} b_t \equiv 0.85 * \lambda_{t-1}^{eu} b_{t-1} \tag{25}$$

so that this part of public debt will vanish in around 40 years from now ($0.85^{40} \rightarrow 0$) as it has been agreed with the EU.[26]

2.9 Macroeconomic System and Solutions Steps

Market-clearing conditions (including the balance-of-payments) are presented in Appendix A.8, while the equations of the final macroeconomic equilibrium system are listed in Appendix A.9. This system consists of 47 equations in 47 endogenous variables. This is given the paths of the exogenously set policy variables whose processes have been defined above. In the next section (section 3), we will first parameterize the model and then solve it for the year 2023. In turn, sections 4 and 5 will quantify various policy scenaria departing from the 2023 solution. In other words, we will assume that the economy is at its initial steady state in 2023 at the time of a shock (specified below).

[25] That is, now we define $b_t^d \equiv \lambda_t^d b_t$ for the end-of-period real per capita public debt held by domestic private agents, $\frac{e_t p_t^*}{p_t} b_t^g \equiv \lambda_t^g b_t$ for the end-of-period real per capita public debt held by foreign private agents and $\frac{e_t p_t^*}{p_t} b_t^{eu} \equiv \lambda_t^{eu} b_t$ for the end-of-period public debt held by EU institutions.

[26] This is a simplified way of modelling repayment of the EU debt. As reported in Appendix C.1, in reality, actual repayment will take place by annual instalments that can vary over time. However, Eq. 25 does capture the declining official debt between now and 2070.

3 Parameterization, Policy Variables and Solution for the Year 2023

This section first parameterizes the model using annual data of the Greek economy over the period 2002-2023 (except otherwise said), then presents data for the model's exogenous policy and non-policy variables and, finally, solves for the model's "initial steady state" defined as a situation in which variables do not change and policy variables are set as in recent data. As we shall see, this solution can match reasonably well the recent key features of the Greek economy and can therefore serve as a natural departure point for our simulations in the next sections.

3.1 Parameter Values

Starting with households, the time discount factor, β, is calibrated from the steady state version of the Euler equation for domestic deposits (A.1c) in Appendix A.1 by setting the value of the deposit rate of Greek private banks slightly higher than the ECB's main refinancing operations rate at the end of 2022 ($i^{d} = 2.54\%$ and $i^{MRO} = 2.5\%$), so as to have well-defined demand and supply functions for financial assets (see the first-order conditions of private banks). The resulting value is $\beta = 0.9752$. The weights given to private consumption and leisure, μ_1 and μ_2, in the household's utility function are calibrated, for given $1-\mu_1-\mu_2$, from the steady state versions of Eqs. A.1a and A.1b in Appendix A.1, using data for the share of private consumption to GDP (0.6747), the labour income share (0.583), the percentage of time devoted to leisure (0.59236) and the effective income and consumption tax rates (0.30194 and 0.18537).[27] The resulting values of μ_1 and μ_2, by having assumed $1 - \mu_1 - \mu_2 = 0.05$, are 0.5436 and 0.4064 respectively. We report that our main results are robust to changes in $1 - \mu_1 - \mu_2$, namely, the weight given to utility-enhancing public services, whose value is agnostic and is usually set between 0 and 0.1 (see e.g. Baxter and King 1993 and Baier and Glomm 2001). The degree of preference for home over foreign goods in consumption, ν, also known as home bias, is calibrated from the equilibrium expression $\frac{e_t p_t^*}{p_t} = (\frac{p_t^f}{p_t^h})^{2\nu-1}$ (see Appendix A.10), where $\frac{e_t p_t^*}{p_t}$ is the real exchange rate and $\frac{p_t^f}{p_t^h}$ is the ratio of the price level of the foreign imported good to the price level of the domestically produced good. Using annual data for the average real effective exchange rate (1.07450) and the average ratio of foreign to domestic prices (1.14243), the resulting value is $\nu = 0.77$.[28] We set the interest rate earned from deposits held at foreign private banks slightly higher than the ECB's main refinancing operations rate at the end of 2022, i.e. $i^{d*} = 2.6\%$, while we set the transaction cost parameter

[27] These are average values. The data regarding the share of total labor compensation in GDP, the percentage of time devoted to leisure and the share of private consumption in GDP are from "The Conference Board Total Economy Database" of Eurostat and our own calculations. Also, following usual practice, we have defined total hours available on a yearly basis as $52 \times 14 \times 7 = 5096$. Finally, the series of the effective tax rates are based on data from Eurostat and our own calculations.

[28] The data on the real effective exhange rate have been obtained from the Federal Reserve Bank of St. Louis, while, for the ratio of foreign to domestic prices, as a proxy, we use the ratio of foreign to domestic GDP deflator. Regarding the foreign GDP deflator, we have chosen to use the German one, whereas the data for both deflators, i.e. the Greek and the German one, are obtained from Eurostat.

in Eq. 4, υ, at 0.028, so as to get deposits at foreign private banks equal to 0.25 of their respective deposits at domestic private banks (i.e. $j^f = 0.25 * j^h$). The coefficient in the households' cash-in-advance constraint, κ^m, is calibrated by setting the consumption and money to GDP ratios, as well as the effective consumption tax rate, at their 2023 values (the data are from Eurostat and the Bank of Greece); this gives $\kappa^m = 0.06$.

We continue with final good firms. To set the Dixit-Stiglitz parameter, θ, in the production function of the final good in Eq. 6, we use information from Eggertsson et al. (2014) who report that the gross markup in traded goods (recall that we have traded goods only in our model) is around 1.17 in the periphery countries of the EZ (and 1.14 in the core countries). Thus, as in Eggertsson et al. (2014, section 3.7), we pin down θ by targeting a steady state gross markup of 1.17 and this gives $\theta = 0.85$ (note that this corresponds to 6.88 in the Eggertsson et al functional specification).

Consider next intermediate goods firms. In their production function in Eq. 10, by setting the intensity of public output, x_g^p, at 0.05 (as in Baxter and King (1993), Ramey (2020) and many others), we calibrate x_k^p and x_{im}^p from the steady versions of Eqs. A.3b-A.3c in Appendix A.3. The resulting values for x_k^p and x_{im}^p are respectively 0.244 and 0.223.[29] In turn, the intensity of labour, x_l^p, follows residually and is 0.483. Regarding the substitutability parameter, op, in Eq. 10, it is set at 0.5, which implies an elasticity of substitution of 2 (the same value of 0.5 will be used in the state firm's production function below). We set the parameter in the Rotemberg-type price adjustment costs, ξ^p, at 100, which is a value within commonly used parameter ranges (see e.g. Sims and Wolff 2017 and Malley and Philippopoulos 2023). We calibrate the transaction cost parameter associated with capital changes so as the investment loss in terms of output to be around 1% which implies $\xi^k = 0.45$ (we report that our main results are robust to changes in the value of ξ^k). We set the coefficient, η, in their financial constraint (11) at 0.8, which is a value within commonly used ranges (see e.g. Schmitt-Grohé and Uribe 2007).

In the state firms' production function in Eq. 17, the intensity parameters, x_k^g and x_l^g, are set respectively at 0.200 and 0.537, which correspond to average payments for public investment and public wages expressed as shares of total public payments to all inputs used in the production of public goods (the data are from Eurostat). In turn, the intensity parameter on goods purchased from the private sector, x_g^g, follows residually and is 0.263. We set $u_{h,t}^g = u_{g,t} = 0.3$ for the given work hours in the public sector. The fraction of household members who work in the public sector, n^g, is set at 0.2 as in the data, so that the fraction working in the private sector, n^p, follows at 0.8.

The capital depreciation rate, δ, is set at 0.1 so as to match the fixed capital formation data. The same value will be used for the depreciation rate of public capital. Both the TFP parameters (in the private and the public sector production functions) are normalized at 1, at least in the baseline parameterization.

Continuing with private banks, we set the parameters in their operational cost function (14) so as to match related data in the year 2023. In particular, we set the parameters associated with reserves, ξ^m, foreign bond holdings, ξ^f, and loans provided by the

[29] The data regarding the capital stock to output ratio are obtained from AMECO, whereas, the data for imported capital goods are from OECD.

NCB to private banks, ξ^z, at 0.0000063, 0.25 and 0.02 respectively, so as to match the GDP shares of Greek private banks' reserves held at the NCB, Greek private banks' holdings of foreign bonds, and loans provided by the NCB to private banks (the data are from the website of the Bank of Greece). In addition, we set the parameters associated with bank loans to firms, ξ^l, and with domestic bond holdings, ξ^b, at 0.28 and 0.17 respectively, so as to match the average value of private banks' lending rate to firms and the nominal interest rate on the 10-year Greek government bond in 2023.

Table 2 Baseline parameter values

Parameter	Description	Value	
ν	home goods bias in consumption	0.77	calibr
μ_1	weight of consumption in utility	0.5436	calibr
μ_2	weight of leisure in utility	0.4064	calibr
μ_3	weight of public goods in utility	0.05	calibr
β	time discount factor	0.9752	calibr
δ and δ^g	depreciation of private and public capital	0.1	calibr
υ	transaction cost in foreign deposit market	0.03	calibr
A^p	TFP in private interm. production	1	set
A^g	TFP in public production	1	set
χ_k^p	importance of capital in private interm. production	0.244	calibr
χ_l^p	importance of labor in private interm. production	0.483	calibr
χ_{im}^p	importance of imports in private interm. production	0.223	calibr
χ_g^p	importance of pub goods in private interm. production	0.05	set
χ_k^g	importance of capital in public production	0.200	calibr
χ_l^g	importance of labor in public production	0.537	calibr
χ_g^g	importance of private goods in public production	0.263	calibr
op	substitutability parameter in private interm. production	0.5	set
og	substitutability parameter in public production	0.5	set
ξ^p	Rotemberg cost parameter	100	set
ξ^k	capital adjustment cost parameter	0.45	calibr
κ^m	coeff. in cash-in-advance constraint	0.06	calibr
η	working capital constraint parameter	0.8	set
ϑ	exponent in exports function	3.040	set
θ	substitutability parameter in private final production	0.85	calibr
n^p	share of priv workers in labor force	0.8	set
ξ^l	transaction cost parameter, banks' loans to firms	0.28	calibr
ξ^z	transaction cost parameter, NCB loans to banks	0.02	calibr
ξ^b	transaction cost parameter, banks' holdings of domestic bonds	0.17	calibr
ξ^m	transaction benefit parameter, banks' reserves held at the NCB	0.0000063	calibr
ξ^f	transaction cost parameter, banks' holdings of foreign bonds	0.25	calibr

Finally, following the econometric study of Dinopoulos et al. (2020) for the Greek economy, we set the exports elasticity, as captured by the parameter ϑ in Eq. A.8h in Appendix A.8, at 3.040; we report however that our main results are robust to changes in the value of ϑ.

These parameter values are listed in Table 2.

3.2 Policy Variables

Regarding fiscal policy instruments, using data from Eurostat as of 2022 (these are the latest available data for effective tax rates when writing the paper), we set s_t^i, s_t^g, s_t^t, s_t^w, τ_t^c and τ_t^π, which are respectively the GDP shares of government spending on investment, goods purchased from the private sector, transfers, public wages, as well as the effective tax rates on consumption and corporate profits, at 0.04, 0.06, 0.23, 0.12, 0.18 and 0.27 respectively, where, for τ_t^π, we use the effective tax rate on capital income. Given these values, in the initial steady state solution, for the public debt to GDP ratio to be as in the data in 2023 (162%), we have to set the income tax rate, τ_t^y, at 0.32. The fractions of Greek public debt in the hands of foreign private agents/banks and EU public institutions, λ_t^g and λ_t^{eu}, are set at 0.04 and 0.70 respectively as indicated in the data (the data are from the website of the Greek Public Debt Management Agency and our own calculations). The values of the feedback policy coefficients on the public debt gap in the feedback policy rule in Eq. 21b will be defined later, but our general principle will be that they are set at the minimum value required for dynamic stability in each case studied. In the EC spending rule in Eq. 21a, the policy target value for the primary fiscal balance as share of GDP, POL_t, is set at 0.019 (i.e. 1.9% of GDP) as in Table 1 in Darvas et al. (2024).[30] [31]

Regarding monetary policy instruments, for the policy interest rates, to be consistent with most of the fiscal data above, we use data as of at the end of 2022 (the rates during 2023 are much higher but this is believed to be temporary being triggered by Russia's invasion in Ukraine and the jump in inflation). We thus set the interest rates on reserves

[30] This value is also within the range recommended for Greece in European Commission (2022). We report that if we set $POL_t = 0.005$ (meaning 0.5% of GDP), which is the required annual surplus in Table 1 of Darvas et al. (2024), all our results remain unchanged. We prefer to use the more demanding value of 1.9% because our solutions below will imply that the EC rule cannot restore stability even with a more ambitious annual primary surplus like 1.9% of GDP. The reason is discussed below in Section 4.2.1.

[31] Here is a numerical example that confirms the variable units and so the formula is Eq. 21a make sense. Say that $POL_t = 0.02$. Also, say that, as it was in Greece in 2023, that there was a primary surplus, $\frac{(g_{t-1}-t_{t-1}^{tax})}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}} = -0.016$, and say, for example, that public spending to GDP, $\frac{g_{t-1}}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}}$, was 0.4. Then, the term in brackets in Eq. 21a is 0.01, which means that primary public spending to GDP today can be 99% of that yesterday. To see the importance of the primary surplus, imagine now that there was instead a primary deficit, $\frac{(g_{t-1}-t_{t-1}^{tax})}{\frac{p_{t-1}^H}{p_{t-1}} n^p y_{i,t-1}} = 0.016$, other things equal. Then, the term in brackets in Eq. 21a is 0.09, which means that primary public spending to GDP should be cut significantly, being 91% only of that yesterday.

and main refinancing operations, i_t^r and i_t^{MRO}, at 2% and 2.5% respectively, while we set the interest rate on loans from the NCB to private banks equal to the main refinancing operations rate, i.e. $i_t^z = i_t^{MRO}$.

Moving on to quantitative monetary policy instruments, we set the fraction of Greek sovereign bonds in the hands of the NCB equal to around 11% as is the case in the current data.[32] Note that the latter translates to $(1 - \Lambda_{b,t}) = 0.37$; this is because the NCB repurchases bonds from private banks/agents and not from official lenders, where the former hold 30% of total public debt only, namely, $\lambda^d + \lambda^g = 0.3$ since $\lambda^{eu} = 0.7$, so that $0.3x0.37 = 0.11$. Also note that since, in the baseline solutions in Section 4, we keep this fraction at 11% all the time, there is no need to impose the ES's 33% upper boundary for sovereign bond holdings (however, we will impose it when we allow the NCB to start increasing its holdings in Section 5). In addition, the NCB's holdings of foreign (euro area and non-euro area economies) bonds equals 40% of GDP ($(1 - \Lambda_{b,t}^*)\lambda_{t-1}^{g*}\frac{b_{t-1}^*}{y_t} = 0.4$), as in the data (the data are from the website of the Bank of Greece). Regarding κ^{qe*}, which is the coefficient in the pricing equation of foreign bonds in the secondary market, $\Phi_t^* = \kappa^{qe*}(1 + i_{t-1}^{b*})$, we set $\kappa^{qe*} = 0.987$, which implies that the spread between $(1 + i^{b*})$ and Φ^* is equal to 1%. Finally, we set $(s_t^{es} - t_t^{es})$ as share of GDP at 0.0042 as in the data; as said above, this is recorded as "Net result of the pooling of monetary income" in the financial statements of NCBs (the data are from the website of the Bank of Greece).

Finally, the non-market interest rate on loans from the EU, i^*, is set at 1%, the rate on deposits earned by households at foreign private banks, i^{d*}, is set at 2.6% which is approximately equal to the domestic deposit rate, while the interest rate on foreign government bonds, i^{b*}, is set at 3% which is approximately the average yield of the 10-year government bonds in the EA at the end of 2023 (the data are from the website of the ES).

The values of policy variables and parameters are listed in Table 3.

3.3 Solution for the Year 2023 (Departure Solution)

Table 4 reports the values of the main endogenous variables produced by the model's solution when we use the parameter and policy values in Tables 2-3 and when variables do not change (this is the system defined in Section 2.9 above). This is what we call the "initial steady state". As can be seen, this solution can match reasonably well the recent key features of the Greek economy and can thus serve as a reasonable departure point for our policy simulations presented in the next two sections. These simulations will start in 2024.

32 This applies to the period after 2019 and in particular to the PEPP, because Greek government bonds have not been part of the PSPP which started officially in 2015. Nevertheless, they were included in PEPP in 2020 although they were not eligible for other ECB purchase programs at the time due to their sub-investment grade status.

Table 3 Policy variables and parameters

Parameter	Description	Value	
s^i	public investment to output (%)	0.04	data
s^g	gov purchases from the priv sector to output (%)	0.06	data
s^w	public wage bill to output (%)	0.12	data
s^{tr}	gov transfers to output (%)	0.23	data
POL	primary fiscal balance, policy target	1.9%	set
τ^c	consumption tax rate	0.18	data
τ^y	personal income tax rate	0.31	calibr
τ^π	corporate tax rate	0.27	data
λ^{eu}	share of public debt held by EU institutions	0.70	data
λ^g	share of public debt held by foreign private banks	0.05	data
i^r	interest rate on reserves at the NCB	2.0%	data
i^z	interest rate on NCB's loans to banks	2.5%	data
i^{MRO}	interest rate on main refinancing operations	2.5%	data
$(1-\Lambda_b)$	fraction of NCB's holdings of domestic gov bonds, repurchased from private banks	0.37	calib
$(1-\Lambda_b^*)\lambda^{d*}\frac{b^*}{y}$	NCB's holdings of foreign bonds to output (%)	0.4	data
κ^{qe*}	parameter in pricing function of foreign bonds	0.987	set
$s^{es}-t^{es}$	net transfer from the ES to the NCB to output (%)	0.0042	data
i^{d*}	interest rate on foreign deposits	2.6%	set
i^*	interest rate on EU bailout loans	1.0%	set
i^{b*}	interest rate on foreign bonds	3.0%	data

Table 4 Model's solution for key endogenous variables, 2023

Variable	Description	Model	Data
b/y	public debt to GDP	162%	162%
c/y	private consumption to GDP	65%	67%
inv/y	private investment to GDP	14%	14%
m/y	money balances to GDP	5%	5%
f/y	foreign debt to GDP	116%	
l/y	private banks' loans to firms to GDP	38%	53%
j/y	households' bank deposits to GDP	91%	90%
m_p/y	private banks' reserves at NCB to GDP	12%	12%
z/y	NCB's loans to private banks to GDP	6%	6%
$TARG/y$	NCB's *Target2* liabilities to GDP	47%	52%
i^l	interest rate on bank loans	6.1%	6.1%
i^d	interest rate on bank deposits	2.5%	0.5%
i^b	interest rate on government bonds	4.0%	4.0%

4 Repayment of EU Loans and their Macroeconomic Implications

The only change in this section, relative to the initial steady state solution in the previous section, is the repayment of the official debt to EU institutions by 2070 as modelled in Eq. 25. All else is kept constant as in the initial steady state. We will first present results for the new terminal steady state, in which public debt held by EU institutions will be zero (it will have been fully repaid by 2070) and hence all public debt will be in the hands of private banks/agents only; this is in Section 4.1. In turn, in Section 4.2, we will study the economy's transitional path as we depart from the initial steady and travel to the new one.[33]

Throughout the paper, we focus on three cases regarding the end-of-horizon public debt in the new terminal steady state (which, as just said, it will be privately held only). First, the case in which the end-of-horizon public debt is 60% of GDP which is the reference value of the Maastricht Treaty; second, the case in which the end-of-horizon public debt is 100% of GDP which is the value for high-debt countries like Greece implicitly recommended in most policy reports of the EC; third, the case in which the end-of-horizon public debt is 162% of GDP which is simply the same value of the public debt ratio as it was at the end of 2023, so that, in this case, we return to the same public debt ratio as the initial one (but not necessarily to the initial steady state solution since the mix of public debt will be different).

In all the above cases: (a) as the EU-held public debt falls and finally becomes zero around 2070 ($\lambda^{eu} = 0$ around 2070), the privately held public debt can rise;[34] (b) in the new terminal steady state, since the public debt to GDP ratio is exogenously set as said above, the income tax rate, τ^y, will need to adjust residually so as to close the government budget constraint (c) debt repayments to the EU start after 2026 since in 2024 and 2025 the installments are relatively small (see Appendix C for the data).

4.1 Steady State Results

Table 5 presents solutions for the key macro variables in the three new terminal steady states corresponding to the three end-of-horizon public debt ratios, 60%, 100% and 162%. For comparison, we also include the solution of the same variables in the initial steady state presented in Table 4 above. As can be seen, in all cases, replacement of EU-held public debt with privately-held public debt leads to a rise in the sovereign interest rate (i^b) relative to the initial steady state. This rise is naturally much bigger in the case where the end-of-horizon public debt is 100% or 162%. Actually, in these two cases of 100% and 162%, there are substantial real costs and this happens for two interrelated

[33] By new terminal steady state, we typically mean the situation where variables stop changing and the model has converged to its new steady state after a permanent shock. In this section, the only shock imposed is the repayment of EU loans by 2070 and this drives the Greek economy to a new steady state (given convergence).

[34] As λ_t^{eu} decreases gradually over time so as $\lambda_t^{eu} b_t$ becomes zero around 2070, $\lambda_t^d = (1 - \lambda_t^g - \lambda_t^{eu})$ rises by definition (with λ_t^g remaining at 4%, its 2023 value). On the other hand, what happens to privately held public debt, $\left(\lambda_t^d + \lambda_t^g\right) b_t$, and hence to total public debt, b_t, will depend on the endogenously determined time-path of b_t.

Table 5 Steady state solutions (initial and terminal)

Variable	Initial steady state	Terminal steady states		
b/y	162%	60%	100%	162%
τ^y	32%	32%	37%	49%
y	0.293	0.293	0.285	0.268
i^b	4%	5%	7%	10%
$i^b b$	0.019	0.010	0.021	0.042
k	0.416	0.415	0.403	0.376
u	0.398	0.395	0.383	0.358
c	0.190	0.193	0.182	0.158
$\frac{t^{tax}-g}{\frac{p^H}{p}n^p y_i}$	2%	2%	6%	14%

reasons. First, there is crowding out of private capital (see the values of k). This happens both directly (as private agents need to allocate a larger share of their wealth to government bonds rather than to private capital) and indirectly (as all market interest rates rise following the increase in the sovereign interest rate).[35] Second, a relatively high public debt (b), in combination with high market sovereign interest rates (i^b), translates to high interest payments ($i^b b$) whose funding necessitates a high income tax rate (τ^y) needed to close the end-of-horizon government budget constraint. These two detrimental effects are worse, the higher the end-of-horizon public debt ratio; see the drops in capital (k), work hours (u), output (y) and consumption (c) when we end up with 100% or 162% public debt ratios. Notice also the big primary fiscal surpluses required for long-term fiscal sustainability in the cases of 100% and 162%. It is also interesting to point out that the 2% trend primary fiscal surplus usually recommended by the EC in its policy reports for Greece (see e.g. European Commission 2022), seems to presuppose that the end-of horizon public debt is 60% only.

4.2 Transition Results

4.2.1 The Issue of Dynamic Stability and Debt Boundedness

Transition results presuppose that one can get a stable solution with bounded debt. We report however that, to the extent that the country pays back its official debt to EU institutions by 2070 as in Eq. 25, this is not possible if primary public spending obeys the EC's new fiscal rule in Eq. 21a and the rest of fiscal policy instruments remain as in the current data meaning at their values in the initial steady state. And this happens independently of what the end-of-horizon public debt ratio is. This problem

[35] Public debt is non-neutral in our model. Besides distortionary taxation, there are financial frictions through which public debt affects the bahavior of private agents - private banks and in turn households and firms. For instance, in the private banks' problem above, holding sovereign bonds is costly but, on the other hand, these bonds can be sold to the NCB in the secondary and can be deposited as reserves at the NCB which reduces the banks' operational costs. That is, there is a tradeoff. See Angeletos et al. (2023) for a recent paper with tradeoffs in public debt and a review of the related literature.

arises for, at least, two reasons. First, the EC's fiscal rule is pro-cyclical by nature and hence destabilizing. In particular, this rule implies that when the economy does well and there are primary fiscal surpluses, the government can increase its spending; and vice versa: when the economy does poorly and there are primary fiscal deficits, the government should cut spending. Second, and more importantly, according to this rule, fiscal instruments (public primary public spending, in particular) do not react directly to outstanding public debt. To the extent that the policy target, POL_t, included in Eq. 21a has been calculated through a separate DSA exercise, which is for given assumptions about growth rates, interest rates, inflation rates, beginning-of-period and end-of-period debt, etc (see the discussion around Eq. 21a), the resulting POL_t is essentially a number, or a time path of numbers, and not an explicit reaction function of outstanding public debt (see Section 3.2 above and the values in Darvas et al. (2024, Table 1)). Hence, if it happens that the path of public debt is unstable in the difference equation for debt (19), plugging (21a) into Eq. 19 cannot guarantee that stability is restored. In other words, a direct response to debt is needed (see also European Parliament (2024b, p. 1)).

Therefore, stability and determinacy with bounded public debt are restored when we use, instead of Eq. 21a, the debt-contingent rule in Eq. 21b. That is, as has been a long practice in the academic literature (see the references in Section 2.6 above), a direct reaction to the gap between the outstanding public debt ratio and its long run value is needed when something happens that moves the economy off its initial situation.[36]

Actually, in our simulations, we will allow for a more flexible rule that nests (21a) and (21b) like:

$$s_t \equiv \min\left[s_t^{AC}, s_t^{EC}\right] \tag{26}$$

so as to investigate when, and for long, each policy rule binds.

Also, in the high end-of-horizon case of 162%, stability with bounded public debt require, not only public spending, but also at least one of the tax rates to react concurrently with public spending to the debt gap.[37] Since there is empirical evidence that in such cases almost all tax rates are used for debt stabilization (for policy practice, see e.g. Alesina et al. 2019), we will allow all three tax rates to do so do, Thus, for τ_t^j, where $j \equiv c, \pi, y$, we also have in the case in which the end-of-horizon public debt is 162%:

$$\tau_t^j \equiv \rho^{\cdot j}\tau_{t-1}^j + \left(1-\rho^j\right)\tau^j + \gamma^{j,b}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) \tag{27}$$

[36] When the end-of-horizon public debt ratio is 60% and 100%, we set $\rho^s = 0.5$ and $\gamma^{s,b} = 0.1$ in Eq. 21b, where the latter is approximately the minimum value that guarantees stability. For the case in which the end-of-horizon public debt ratio is 162%, see next.

[37] We report that in some experiments with 162% end-of-horizon public debt, we do manage to get stability even without tax reaction. But this would require a strong reaction of spending to the debt gap, like $\gamma^{s,b} \geq 0.5$, in Eq. 21b. In addition, in this case, the impulse response functions exhibit erratic fluctuations which are not seen in practice. Hence, we also allow for tax policy reaction in this regime.

where $\gamma^{j,b} \geq 0$ is the feedback policy coefficient associated with the use of tax rate j, $0 \leq \rho^{j} \leq 1$ is a persistence parameter, and variables without time subscripts denote terminal steady state values.[38]

4.2.2 Macroeconomic Outcomes and Fiscal Policy in the Transition

Now we are able to solve for the transition to the new terminal steady state(s). Figure 1 plots the paths of output under the three different scenaria regarding the end-of-horizon public debt to GDP ratio. As can be seen, in all three scenaria, repayment of EU debt, all else being kept at their initial 2023 values, will be recessionary at least for some time. However, while the economy rebounds relatively quickly when the end-of-horizon public debt is 60% and actually the GDP gets slightly higher than initially in the mid 2030s, there is a long-lasting downturn when the end-of-horizon public debt ratio is relatively high, 100% or 162%, and especially in the case of 162%.

To quantify these effects, we have also calculated the cumulative output gap (as difference from its departure value in 2023) under the three scenaria for the end-of-horizon public debt ratio. At any time t, this is defined as:

$$\varphi_t \equiv \sum_{s=0}^{t} (y_s - y) \tag{28}$$

Using our simulation numbers, the cumulative output gaps for the three end-of-horizon cases are reported in Table 6 (indicatively for the years 2034 and 2124). They confirm the long-lasting recessionary effects in case of high public debt in the long run, especially in the case of 162%.

The channels through which EU debt repayment hurts the economy along the transition (although at different degrees depending on what the end-of-horizon public debt will be) are the same as those discussed in the steady state analysis above. Namely, as discussed in the previous subsection, the replacement of EU-held public debt with privately-held public debt crowds out private capital both directly and indirectly and also, with forward-looking agents, the anticipation of high tax rates needed to service the high debt burden in the case of 100% and 162%, hurts the economy all the time. In addition, along the transition, there is an extra channel: debt stabilization requires cuts in public spending and perhaps rises in tax rates as implied by the feedback policy rules above, and fiscal austerity makes the recession deeper (but again, as we shall see next, the size and duration of this fiscal austerity varies depending on the end-of-horizon public debt). These three channels are illustrated by the graphs presented below.

Figure 2 presents the associated paths of private capital and the real (gross) sovereign interest rate. As can be seen, as the privately-held public debt rises, the real sovereign interest rate rises and, the higher the end-of-horizon public debt, the higher this increase is. Regarding the stock of private capital, there is crowding out in general, although its

[38] When the end-of-horizon debt ratio is 162%, in which case both spending and tax instruments react to debt imbalances, in addition to $\rho^{s} = 0.5$ and $\gamma^{s,b} = 0.1$ in Eq. 21b as said above, we also set $\rho^{j} = 0.5$ and $\gamma^{j,b} = 0.1$ in Eq. 27.

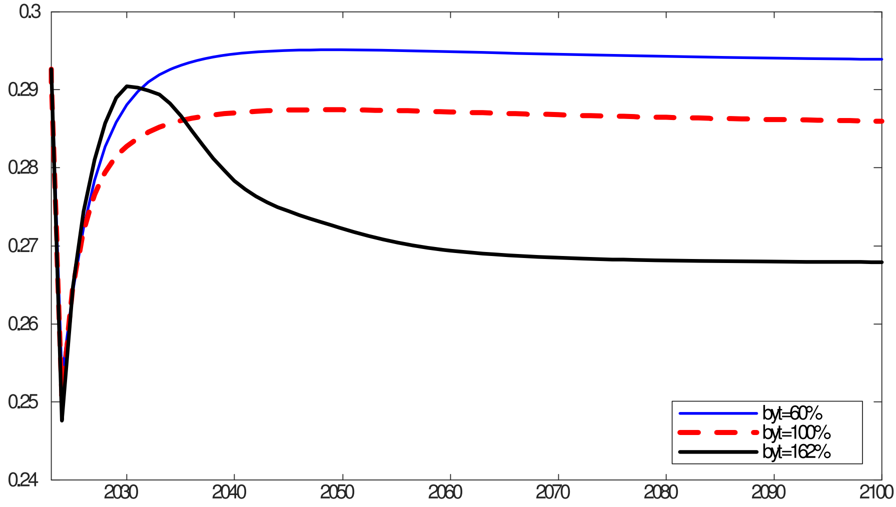

Fig. 1 Path of output under the three end-of-horizon public debt scenaria (levels)

Table 6 Cumulative output gap under the three end-of-horizon public debt scenaria

Year	Cumulative output gap		
	60%	100%	162%
2034	−0.13	−0.17	−0.13
2124	0.02	−0.72	−2.18

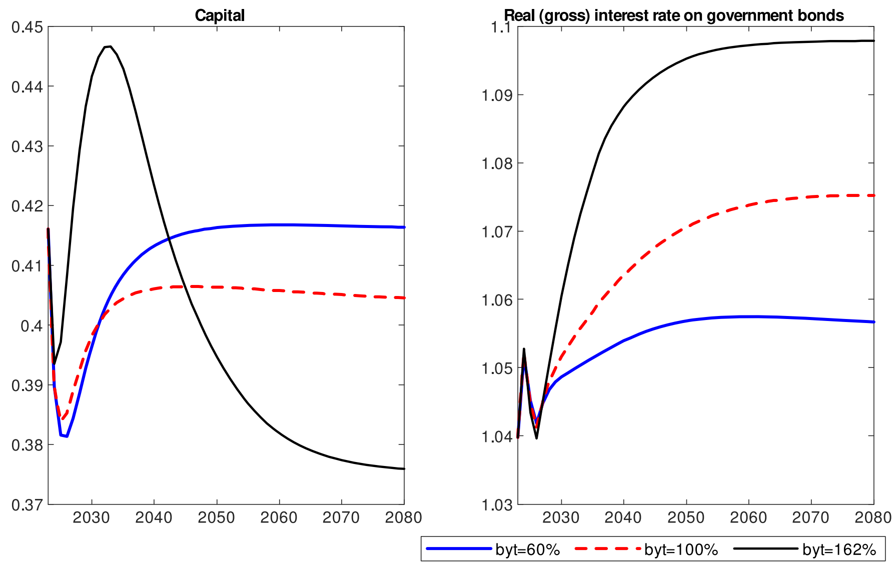

Fig. 2 Paths of key macro variables under the three end-of-horizon public debt scenaria (levels)

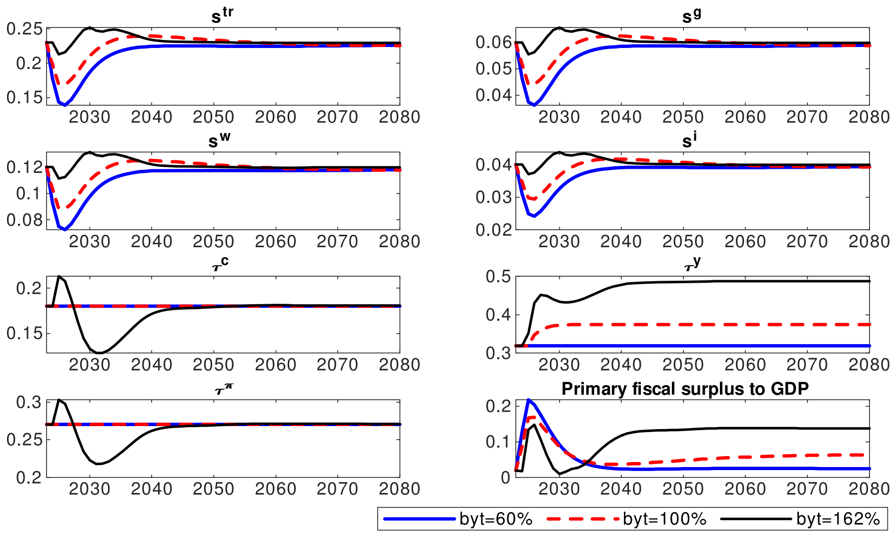

Fig. 3 Paths of policy variables under the three end-of-horizon public debt scenaria (as share of GDP)

exact path depends on the end-of-horizon public debt ratio like in Fig. 1 above. If the latter is relatively low (60% and 100%) there is a strong crowding out in the short term but then the capital stock rebounds especially in the case of 60%, while, if the end-of-horizon public debt ratio is relatively high (162%), the crowing-out is postponed but there is then a long-lasting detrimental effect in the medium- and long-term. Thus, there is an intertemporal trade-off here.

Finally, Fig. 3 illustrates the associated paths of fiscal policy instruments and public finance variables. As can be seen, given EU debt repayment, fiscal sustainability requires spending cuts and tax rises in general, although again the mix, timing as well as the size of these fiscal corrections vary depending on the end-of-horizon public debt ratio. If the latter is 60% only, there is need for big spending cuts and big primary fiscal surpluses in the short term,[39] but the fiscal corrections needed after 2040 are small. By contrast, when the end-of-horizon debt ratio is 100% and in particular when it is 162%, the country can afford smaller spending cuts and primary fiscal surpluses in the short term, but this comes at the cost of tax hikes, especially in the form of high income tax rates, and big primary fiscal surpluses in the medium- and long-term. Thus, there is again an intertemporal trade-off between front-loading and back-loading fiscal austerity.

Therefore, summing up the results from Graphs 1-3, in terms of GDP over time, it would be better to go for an ambitious public debt target (e.g. 60% of GDP), but this would require severe cuts in public spending and big primary fiscal surpluses in the short term. At the other end, allowing the end-of-horizon public debt to be high (e.g. 162% of GDP) would avoid big spending cuts in the short term, but it would generate a long-lasting economic contraction and will also require big primary fiscal surpluses

[39] Formally, this is because the debt gap in the feedback rule (21b) is much bigger when the end-of-horizon public debt ratio is 60%.

over time. A public debt target in between (e.g. 100% of GDP) is a relatively mild mix of all the above, meaning a mix of mild economic downturn, spending cuts, tax rises and primary fiscal surpluses. Therefore, as usually in the case of reforms, there are trade-offs so social/political judgements have to be made.

Recall that all this happens when the only thing that changes is the repayment of 240 billion euros until 2070.

5 How can the Country Offset the Recessionary Effects of Debt Repayment?

As seen above, in all cases, repayment of EU debt is projected to be recessionary over time when everything else is kept constant. In this section, we investigate how this pessimistic result can become milder or even reversed. Actually, if we look at the current data, the Greek economy is growing, partly due to NGEU/RRF funds. We will therefore start with the role of the still ongoing NGEU/RRF funds (Section 5.1). Then, we will study the implications of more quantitative easing (Section 5.2), and we will finally close with the potential effects of improvements in total factor productivity (Section 5.3). To save on space, we will report results for the public debt case in between, namely, when the end-of-horizon public debt ratio is 100% (other debt scenaria are available upon request). All changes studied here will be on top of the debt repayment change analysed in the previous section. Also, for comparability with the above results, we keep the values of the feedback policy coefficients as in the previous section (except otherwise explicitly stated).

5.1 NGEU/RRF and Temporary Growth

To capture the positive growth rates enjoyed by the Greek economy in the current situation, we allow for NGEU/RRF funds. In particular, we assume that both private and state firms receive transfers, denoted as $RRF_{i,t}$ and $RRF_{g,t}$ respectively, and these transfers are earmarked for investment in the two sectors. That is, the motions of private and state firms' capital stock change to:

$$k_{i,t} = (1-\delta)\, k_{i,t-1} + x_{i,t} + RRF_{i,t} \tag{29a}$$

$$k^{g}_{g,t} = (1-\delta^{g})k^{g}_{g,t-1} + g^{i}_{g,t} + RRF_{g,t} \tag{29b}$$

and we further assume that these transfers are used for the improvement of the outstanding capital stock in the two sectors:

$$RRF_{i,t} = \xi_t k_{i,t-1} \tag{30a}$$

$$RRF_{g,t} = \xi_t k^{g}_{g,t-1} \tag{30b}$$

where ξ_t will be calibrated to match actual and projected data.[40] Further modelling details for this extension are provided in Appendix D. Notice that this way of modeling the role of NGEU/RRF funds resembles the capital "quality" shock used by the financial literature (see e.g. Gertler and Kiyotaki 2010 and Gertler and Karadi 2013), or investment shocks used by the macroeconomic literature (see e.g. Ramey 2016).

The new path of output is shown in Fig. 4, which also includes for comparison the path of output in the baseline case of section 4 (recall that in this section we focus on the case in which the end-of-horizon public debt is 100%). As can be seen, thanks to this productive transfer shock from the EU, there is growth in the early periods and also the economic contraction becomes slightly milder in the medium term relative to the benchmark case in the previous section. Nevertheless, once the NGEU/RRF funds stop, macro outcomes will be shaped by the recessionary effects of EU-debt repayment as in the previous section.[41]

5.2 More Quantitative Easing (QE)

So far we have assumed that Greek sovereign bonds held by the NCB, and the ES in general, are kept at 11% of total ones all the time (as we saw in Section 3 this is the value in the current data). Now, to study the possible complementarity between fiscal and quantitative monetary policies, we allow these sovereign bond holdings by the NCB to gradually increase over time until they reach the threshold of 33% of total public debt, where the latter is the upper limit according to EA restrictions (see Dimakopoulou et al. (2024) for a detailed analysis of the role of QE in the EA).

Formally, we allow the fraction $(1 - \Lambda_{b,t})$ to follow the exogenous $AR(2)$ process:[42]

$$(1 - \Lambda_{b,t}) = \left(1 - \rho_1^{\Lambda} - \rho_2^{\Lambda}\right)(1 - \Lambda_b) + \rho_1^{\Lambda}(1 - \Lambda_{b,t-1}) + \rho_2^{\Lambda}(1 - \Lambda_{b,t-2}) \quad (31)$$

where ρ_1^{Λ} and ρ_2^{Λ} are persistence parameters and $(1 - \Lambda_b)$ is the value in the new terminal steady state. In our simulations, we set the initial value of the policy instrument $(1 - \Lambda_b)$ so as the NCB to hold 11% of total bonds (as we have done so far), while the terminal value of $(1 - \Lambda_b)$ is set so as the NCB to hold 33%, which is the ES's upper limit. Given the law-of-motion in Eq. 31 this increase happens gradually over time.[43]

The path of output under this scenario is shown in Fig. 4. Note that this policy change is on top of debt repayment as modeled in Section 4 and NGEU/RRF funds as modeled in Section 5.1. As can be seen, more QE can help the real economy like

[40] To calibrate ξ_t, we work as follows. We set the cumulative total RRF_t funds received by Greece during 2024-2027 at around 19% as share of GDP in 2023 (which is close to the data), and split it among the years 2024-2027 so as to get an average growth rate of around 2.5% in the years 2024-2026 which is close to the projections of the EC for Greece (see European Commission 2024a).

[41] For the effects of NGEU/RRF, see also e.g. Malliaropulos et al. (2021) and Bańkowski et al. (2022).

[42] Papers by ECB researchers also use an $AR(2)$ process for the exogenous part of asset purchases (e.g. Coenen et al. 2020, 2021 and Mazelis et al. 2023).

[43] Regarding the autoregressive parameters in the $AR(2)$ process for $(1 - \Lambda_t)$, their values are set as in studies by ECB researchers (see e.g. Coenen et al. 2020), namely $\rho_1^{\Lambda} = 1.5$ and $\rho_2^{\Lambda} = -0.54$.

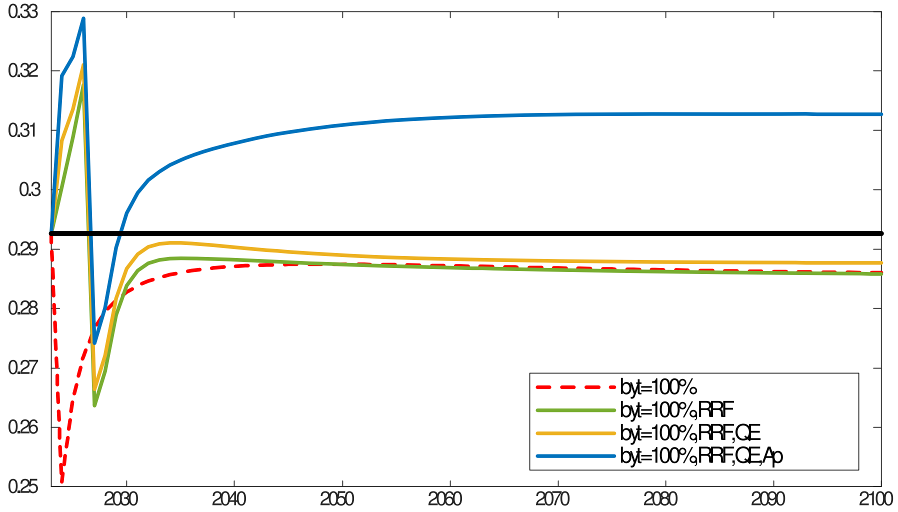

Fig. 4 Path of output under various scenaria when the end-of-horizon public debt is 100% (levels)

NGEU/RRF did above. In other words, it can contribute to growth in the short term and can also make the medium- and long-term contraction even milder relative to the case with debt repayment and NGEU/RRF transfers only. Nevertheless, again like NGEU/RRF, its beneficial effect is rather small so that, after a point in time, the recessionary effects of EU-debt repayment will dominate.

5.3 Productivity and Durable Growth

We finally assume that, instead of being equal to 1 all the time, the TFP in the private firms' production function follows an $AR(1)$ process of the form:

$$A_t^p = \left(A_{t-1}^p\right)^{\rho^{A,p}} \left(A^p\right)^{1-\rho^{A,p}} \tag{32}$$

where $0 < \rho^A < 1$ is a persistence parameter, the initial value is as in this baseline calibration (namely, 1) and A^p is the value in the new terminal steady state. We assume that TFP rises gradually over time until it reaches a new higher value, say, $A^p = 1.05$. That is, we assume an ad hoc increase by 5% in total factor productivity in the private sector.[44]

The implications of this long-lasting improvement in the level of TFP are illustrated in Fig. 4. This exogenous productivity improvement is on top of debt repayment as modeled in Section 4, NGEU/RRF funds as modeled in Section 5.1 and more QE as modeled in Section 5.2. As can be seen, now, and differently from all previous cases, the assumed improvement in productivity can help the economy to more than offset the recessionary effects of debt repayment almost all the time. Actually, it can generate growth although, of course, this depends on the assumed magnitude of the rise in A^p.

44 Regarding the autoregressive parameter in the $AR(1)$ process, we set $\rho^{A,p} = 0.9$.

Before we close this section, it is necessary to add the following clarification regarding TFP. The beneficial effects that can arise from an improvement in TFP are not surprising. For instance, the literature on growth accounting has already established that the observed levels and growth rates of output per worker over time in each country, as well as cross-country differences in these levels and growth rates, cannot be understood solely on the basis of conventional inputs, like physical and human capital; differences in the residual TFP play a key role (see e.g. Prescott 1998, Hall and Jones 1999, Acemoglu (2009, pp. 105-6) and Azzimonti et al. (2024, chapter 12)).

But if TFP matters, what is TFP? Although clear conclusions cannot be drawn, we believe it is safe to say the following. For advanced economies meaning economies close to the frontier of labor productivity, the most likely source of an increase in TFP is technological progress and technology adoption (see e.g. Azzimonti et al. (2024, p. 345)).[45] For LDCs or for DCs which are not close to the frontier, two "variables" stand out as determinants of TFP and hence as growth drivers: human capital and so the quality of education and training (see e.g. Lucas 1988, 2015, Barro and Lee 2015 and Hanushek and Woessmann 2015) and the so-called "allocation efficiency" meaning how efficiently scare resources and inputs are being used (see e.g. Prescott 1998, 2002 and Restuccia and Rogerson 2013, 2017). But, as many authors have pointed out (see e.g. Acemoglu (2009, pp. 105-6 and 109-112)), there must be other, deeper reasons that prevent some countries from investing enough in technology, physical, human or intangible capital, and also from using their resources efficiently or solving problems of collective action. And such a deeper reason is the underlying "institutions", meaning rules, regulations, laws and policies that affect economic incentives (for empirical evidence, see e.g. Knack and Keefer 1997, Hall and Jones 1999, Acemoglu et al. 2005, Easterly 2005, Easterly et al. 2006, Acemoglu (2009, chapter 4), Jones and Vollrath (2013, chapter 7) and Azzimonti et al. (2024, p. 346)). The quality of institutions is measured by various indexes and a common finding is that Greece lags behind most of its European partners (the role of institutional quality for the Greek macroeconomy during the sovereign debt crisis of the previous decade has been quantified by e.g. Economides et al. 2021).

6 Conclusions, Policy Lessons and Limitations

In this paper, we studied the implications of repayment of the three official fiscal bailout loans received by Greece from the EU during the country's sovereign debt crisis in the previous decade. Since the main results have already been listed in the Introduction, here we prefer to close with some general conclusions, policy lessons and limitations of our work.

Debt repayments, on their own, will be recessionary. This is a rather general and robust result in our paper and should not be surprising. It happens because, other things

[45] Research leads to the creation of new ideas and new technology which in turn produce new and/or better varieties of goods and services (see the seminal models by Romer 1990, Aghion and Howitt 1992 and Jones 1995). But there is another way to upgrade technology which is by adopting technologies that already exist but have not been used yet for various reasons (for models of technology adoption and diffusion, see e.g. Acemoglu (2009, chapter 18) and Comin and Mestieri 2014).

equal, the replacement of officially-held public debt by privately-held public debt cannot but crowd out the accumulation of private capital and, in addition, spending cuts and/or tax rises are needed to create the fiscal surpluses required for debt repayment over time. Our prediction is supported by empirical evidence that in most cases fiscal austerity is contractionary (as pointed out by CESifo 2014, chapter 3, in its review for fiscal austerity, the view that the latter is expansionary "has proved to be rather elusive"). On the other hand, it is important to emphasize that the size and duration of these recessionary implications will depend crucially on how the privately-held public debt will evolve over time as the EU-held public debt decreases and eventually becomes zero around 2070. And, perhaps more importantly in terms of policy planning, the implications of EU-debt repayment in the years to come will depend on developments in productivity and hence economic growth. Here, we showed that a relatively small improvement in the level of TFP (5%) can counter the recessionary effects to the extent that it is rather permanent.

A final question and some possible answers: If we accept the above, why don't we observe a rise in market sovereign interest rates from early on? An answer could be that agents believe that the economy will manage to grow out its debt obligations thanks to a rise in productivity like the one studied in Section 5.3. Other possible answers, less encouraging than optimistic productivity and growth forecasts, can include that agents extra discount the future which means a degree of myopia and/or that there are deviations from rational expectations (see e.g. Angeletos and Huo (2021) although in a different context).

Closing with limitations and caveats, here we treated several important variables as exogenous. As already said in the previous section, an example is our experiment with the TFP shock. Although we believe we took a step in the right direction by showing how important productivity and hence economic growth will be for a country like Greece with severe debt obligations, we treated it as given. This might be a relatively common approach in the literature (see e.g. the discussion in the review paper by Jones and Manuelli (2005, pp. 18-19)), but, as also said above, it would be more interesting to go deeper and incorporate the determinants of TFP and the channels through which policy shapes TFP. It would also be interesting to do the same for TFP in the public sector. We leave these extensions for future work.

Appendix A: Model Solution

A.1: Households' Problem

The household maximizes:

$$\sum_{t=0}^{\infty}\beta^t u\left(c_{h,t}, u_{h,t}; \overline{y}^g_{h,t}\right)$$

subject to:

$$u\left(c_{h,t}; \overline{y}^g_t\right) = \mu_1 \log c_{h,t} + \mu_2 \log\left(1 - u_{h,t}\right) + \mu_3 \log \overline{y}^g_{h,t}$$

$$u_{h,t} = n^p u_{h,t}^p + n^g u_{h,t}^g$$

$$c_{h,t} = \frac{(c_{h,t}^H)^\nu (c_{h,t}^F)^{1-\nu}}{\nu^\nu (1-\nu)^{1-\nu}}$$

$$(1+\tau_t^c)\left(\frac{p_t^H}{p_t}c_{h,t}^H + \frac{p_t^F}{p_t}c_{h,t}^F\right) + j_{h,t}^H + \frac{e_t p_t^*}{p_t} j_{h,t}^F + \frac{p_t^f}{p_t}\frac{\upsilon}{2}\left(\frac{e_t p_t^*}{p_t} j_{h,t}^F\right)^2 + m_{h,t} =$$

$$= (1-\tau_t^y)(n_t^p w_t^p u_{h,t}^p + n_t^g w_t^g u_{h,t}^g + \pi_{h,t}) +$$

$$+(1+i_t^d)\frac{p_{t-1}}{p_t} j_{h,t-1}^H + (1+i_t^{d*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t} j_{h,t-1}^F + \frac{p_{t-1}}{p_t} m_{h,t-1} + \overline{g}_t^{tr}$$

$$m_{h,t} \geq \kappa^m (1+\tau_t^c)\left(\frac{p_t^H}{p_t}c_{h,t}^H + \frac{p_t^F}{p_t}c_{h,t}^F\right)$$

The first-order conditions are:

$$\frac{\mu_1}{c_{h,t}} = \left(\lambda_{h,t} + \kappa^m \psi_{h,t}\right)(1+\tau_t^c) \tag{A.1a}$$

$$\frac{\mu_2}{\left(1-u_{h,t}\right)} = \lambda_{h,t}(1-\tau_t^y) w_t^p \tag{A.1b}$$

$$\lambda_{h,t} = \beta \lambda_{h,t+1}(1+i_{t+1}^d)\frac{p_t}{p_{t+1}} \tag{A.1c}$$

$$\lambda_{h,t}\frac{e_t p_t^*}{p_t}\left(1 + \frac{p_t^F}{p_t}\upsilon\left(\frac{e_t p_t^*}{p_t} j_{h,t}^f\right)\right) = \beta\lambda_{h,t+1}\frac{e_{t+1} p_{t+1}^*}{p_{t+1}}(1+i_{t+1}^{d*})\frac{p_t^*}{p_{t+1}^*} \tag{A.1d}$$

$$\frac{c_{h,t}^H}{c_{h,t}^F} = \frac{\nu}{(1-\nu)}\frac{p_t^F}{p_t^H} \tag{A.1e}$$

$$\lambda_{h,t} - \psi_{h,t} = \beta\lambda_{h,t+1}\frac{p_t}{p_{t+1}} \tag{A.1f}$$

$$\psi_{h,t}\left(\kappa^m(1+\tau_t^c)\left(\frac{p_t^H}{p_t}c_{h,t}^H + \frac{p_t^F}{p_t}c_{h,t}^F\right) - m_{h,t}\right) = 0 \tag{A.1g}$$

where $\lambda_{h,t}$ and $\psi_{h,t}$ are the Lagrange multipliers associated with the budget constraint and the cash-in-advance constraint respectively.

The first-order conditions also include the consumption index, total hours worked and the budget constraint:

$$c_{h,t} = \frac{(c_{h,t}^H)^\nu (c_{h,t}^F)^{1-\nu}}{\nu^\nu (1-\nu)^{1-\nu}} \tag{A.1h}$$

$$u_{h,t} = n^p u_{h,t}^p + n^g u_{h,t}^g \tag{A.1i}$$

$$(1+\tau_t^c)\left(\frac{p_t^H}{p_t}c_{h,t}^H + \frac{p_t^F}{p_t}c_{h,t}^F\right) + j_{h,t}^H + \frac{e_t p_t^*}{p_t} j_{h,t}^F + \frac{p_t^F}{p_t}\frac{\upsilon}{2}\left(\frac{e_t p_t^*}{p_t} j_{h,t}^F - \overline{j^f}\right)^2 + m_{h,t} =$$

$$= (1-\tau_t^y)(n_t^p w_t^p u_{h,t}^p + n_t^g w_t^g u_{h,t}^g + \pi_{h,t}) +$$

$$+ (1+i_t^d)\frac{p_{t-1}}{p_t}j_{h,t-1}^H + (1+i_t^{d*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}j_{h,t-1}^F + \frac{p_{t-1}}{p_t}m_{h,t-1} + g_t^t \quad \text{(A.1j)}$$

Thus, in this block, we have 10 equations associated with the paths of $\{c_{h,t}^H, c_{h,t}^F, c_{h,t}, u_{h,t}^p, u_{h,t}, j_{h,t}^H, j_{h,t}^F, m_{h,t}, \lambda_{h,t}, \psi_{h,t}\}_{t=0}^{\infty}$. Notice that only $u_{h,t}^p$ is endogenous (by contrast, $u_{h,t}^g$ is work hours at the public sector and is set parametrically).

Also note that the above imply that the CPI is:

$$p_t = (p_t^H)^{\nu}(p_t^F)^{1-\nu} \quad \text{(A.1k)}$$

where:

$$p_t^F = e_t p_t^{h*} \quad \text{(A.1l)}$$

where we will set $e_t = 1$ and assume that $\Pi_t^{H*} = p_t^{H*}/p_{t-1}^{H*}$ follows an exogenous process.

Thus, in this block, we have 2 extra equations associated with the paths of $\{p_t, p_t^F\}_{t=0}^{\infty}$.

A.2: Final Good Firms' Problem

Each final good firm $f = 1, 2, ..., N^p$ acts competitively. The first-order condition for $y_{f,i,t}$ gives the familiar demand function:

$$p_{i,t}^H = p_t^H \left(\frac{y_{i,t}}{y_{f,t}}\right)^{\theta-1}$$

which, from the zero-profit condition, $\pi_{f,t} = 0$, implies:

$$p_t^H = \left[\sum_{i=1}^{N^i} \frac{1}{N^i}(p_{i,t}^H)^{\frac{\theta}{\theta-1}}\right]^{\frac{\theta-1}{\theta}}$$

Thus, in a symmetric equilibrium where intermediate goods firms are alike ex post, we will have $y_{f,t} = y_{i,t}$ and $p_t^H = p_{i,t}^H$.

A.3: Intermediate Goods Firms' Problem

The gross profit of each intermediate goods firm $i = 1, 2, .., N^p$, denoted as $\pi_{i,t}^{gross}$, is defined as sales minus the wage bill minus the cost of imported goods minus adjustment costs:

$$\pi_{i,t}^{gross} \equiv \frac{p_{i,t}^H}{p_t}y_{i,t} - w_t^p u_{i,t} - \frac{p_t^F}{p_t}im_{i,t} -$$

$$-\frac{p_t^H}{p_t}\frac{\xi^k}{2}\left(\frac{k_{i,t}}{k_{i,t-1}} - 1\right)^2 k_{i,t-1} - \frac{p_t^H}{p_t}\frac{\xi^p}{2}\left(\frac{p_{i,t}^H}{p_{i,t-1}^H} - 1\right)^2 \overline{y}_{i,t}$$

This gross profit is used for retained earnings, the payment of corporate taxes to the government, dividends to shareholders and interest payments to loans received from private banks. Thus,

$$\pi_{i,t}^{gross} \equiv RE_{i,t} + \tau_t^{\pi} \left(\frac{p_{i,t}^H}{p_t} y_{i,t} - w_t^p u_{i,t} - \frac{p_t^F}{p_t} im_{i,t} \right) + \pi_{i,t} + i_t^l \frac{p_{t-1}}{p_t} l_{i,t-1}$$

The motion of capital stock is:

$$k_{i,t} = (1-\delta)\, k_{i,t-1} + x_{i,t}$$

New investment is financed by retained earnings and loans from private banks:

$$\frac{p_t^H}{p_t} x_{i,t} \equiv RE_{i,t} + (l_{i,t} - \frac{p_{t-1}}{p_t} l_{i,t-1})$$

Combining the above, we have for the dividend as in the main text:

$$\pi_{i,t} \equiv (1-\tau_t^{\pi}) \left[\frac{p_{i,t}^H}{p_t} y_{i,t} - w_t^p u_{i,t} - \frac{p_t^F}{p_t} im_{i,t} \right] -$$

$$-\frac{p_t^H}{p_t} \left[k_{i,t} - (1-\delta) k_{i,t-1} \right] - \frac{p_t^H}{p_t} \frac{\xi^k}{2} \left(\frac{k_{i,t}}{k_{i,t-1}} - 1 \right)^2 k_{i,t-1} - \frac{p_t^H}{p_t} \frac{\xi^p}{2} \left(\frac{p_{i,t}^H}{p_{i,t-1}^H} - 1 \right) 2\overline{y}_{i,t} +$$

$$+ \left(l_{i,t} - (1+i_t^l) \frac{p_{t-1}}{p_t} l_{i,t-1} \right)$$

Therefore, each firm i maximizes the discounted sum of dividends distributed to its owners:

$$\sum_{t=0}^{\infty} \beta_{i,t} \pi_{i,t}$$

where, since firms are owned by households, we will ex post postulate that the firm's discount factor, $\beta_{i,t}$, equals the household's marginal rate of substitution between consumption at t and $t+1$, namely, $\beta_{i,0} \equiv 1$ at $t = 0$ and $\beta_{i,t} \equiv \beta^t \frac{\lambda_{k,t}}{\lambda_{k,0}}$ at $t = 1, 2, ...$

The optimality conditions written in a symmetric equilibrium (note that in symmetric equilibrium we have $p_t^H = p_{i,t}^H$) are:

$$(1-\tau_t^{\pi}) w_t^p + N_{i,t} \eta w_t^p = [(1-\tau_t^{\pi}) \theta \frac{p_t^H}{p_t} - \frac{p_t^H}{p_t} \xi^p \left(\frac{p_{i,t}^H}{p_{i,t-1}^H} - 1 \right) \frac{p_t^H}{p_{i,t-1}^H} \frac{(\theta-1)\overline{y}_{i,t}}{y_{i,t}} +$$

$$+ \beta \frac{\lambda_{h,t+1}}{\lambda_{h,t}} \frac{p_{t+1}^H}{p_{t+1}} \xi^p \left(\frac{p_{i,t+1}^H}{p_{i,t}^H} - 1 \right) \frac{p_{i,t+1}^H}{p_{i,t}^H} \frac{(\theta-1)\overline{y}_{i,t+1}}{y_{i,t}}] \frac{\partial y_{i,t}}{\partial u_{i,t}} \quad \text{(A.3a)}$$

$$(1-\tau_t^{\pi})\frac{p_t^f}{p_t}=[(1-\tau_t^{\pi})\theta_t\frac{p_t^H}{p_t}-\frac{p_t^H}{p_t}\xi^p\left(\frac{p_{i,t}^H}{p_{i,t-1}^H}-1\right)\frac{p_t^H}{p_{i,t-1}^H}\frac{(\theta-1)\overline{y}_{i,t}}{y_{i,t}}+$$

$$+\beta\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\frac{p_{t+1}^H}{p_{t+1}}\xi^p\left(\frac{p_{i,t+1}^H}{p_{i,t}^H}-1\right)\frac{p_{i,t+1}^H}{p_{i,t}^H}\frac{(\theta-1)\overline{y}_{i,t+1}}{y_{i,t}}]\frac{\partial y_{i,t}}{\partial im_{i,t}} \tag{A.3b}$$

$$\frac{p_t^H}{p_t}\left[1+\xi^k\left(\frac{k_{i,t}}{k_{i,t-1}}-1\right)\right]=\beta\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\frac{p_{t+1}^H}{p_{t+1}}[1-\delta+(1-\tau_{t+1}^{\pi})\theta\frac{\partial y_{i,t+1}}{\partial k_{i,t}}-$$

$$-\frac{\xi^k}{2}\left(\frac{k_{i,t+1}}{k_{i,t}}-1\right)^2+\xi^k\left(\frac{k_{i,t+1}}{k_{i,t}}-1\right)\frac{k_{i,t+1}}{k_{i,t}}]-$$

$$-\beta\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\frac{p_{t+1}^H}{p_{t+1}}\xi^p\left(\frac{p_{i,t+1}^H}{p_{i,t}^H}-1\right)\frac{p_{i,t+1}^H}{p_{i,t}^H}(\theta-1)\frac{\overline{y}_{i,t+1}}{y_{i,t+1}}\frac{\partial y_{i,t+1}}{\partial k_{i,t}}+$$

$$+\beta^2\frac{\lambda_{h,t+2}}{\lambda_{h,t}}\frac{p_{t+2}^H}{p_{t+2}}\xi^p\left(\frac{p_{i,t+2}^H}{p_{i,t+1}^H}-1\right)\frac{p_{i,t+2}^H}{p_{t+1}^H}(\theta-1)\frac{\overline{y}_{i,t+2}}{y_{i,t+1}}\frac{\partial y_{i,t+1}}{\partial k_{i,t}} \tag{A.3c}$$

$$1+N_{i,t}=\beta\frac{\lambda_{h,t+1}}{\lambda_{h,t}}(1+i_{t+1}^l)\frac{p_t}{p_{t+1}} \tag{A.3d}$$

$$N_{i,t}\left(L_{i,t}-\eta w_t^p u_{i,t}\right)=0 \tag{A.3e}$$

where $N_{i,t}$ is i's multiplier associated with the borrowing constraint.

The first-order conditions also include the constraints:

$$\pi_{i,t}\equiv(1-\tau_t^{\pi})\left[\frac{p_{i,t}^H}{p_t}y_{i,t}-w_t^p u_{i,t}-\frac{p_t^F}{p_t}im_{i,t}\right]-$$

$$-\frac{p_t^H}{p_t}\left[k_{i,t}-(1-\delta)k_{i,t-1}\right]-\frac{p_t^H}{p_t}\frac{\xi^k}{2}\left(\frac{k_{i,t}}{k_{i,t-1}}-1\right)^2k_{i,t-1}--\frac{p_t^H}{p_t}\frac{\xi^p}{2}\left(\frac{p_{i,t}^H}{p_{i,t-1}^H}-1\right)^2\overline{y}_{i,t}+$$

$$+\left(l_{i,t}-(1+i_t^l)\frac{p_{t-1}}{p_t}l_{i,t-1}\right) \tag{A.3f}$$

$$k_{i,t}=(1-\delta)\,k_{i,t-1}+x_{i,t} \tag{A.3g}$$

$$y_{i,t}=A^p\left[\chi_k^p(k_{i,t-1})^{op}+\chi_l^p(u_{i,t-1})^{op}+\chi_{im}^p(im_{i,t})^{op}+\chi_g^p\left(\overline{y}_{i,t}^g\right)^{op}\right]^{1/op} \tag{A.3h}$$

where in the above we use:

$$\overline{y}_{i,t}^g=\frac{N^g y_{g,t}^g}{N^i}=\frac{n^g y_{g,t}^g}{n^p}$$

$$\frac{\partial y_{i,t}}{\partial u_{i,t}}=(y_{i,t})^{1-op}(A^p)^{op}\chi_l^p(u_{i,t-1})^{op-1}$$

$$\frac{\partial y_{i,t}}{\partial im_{i,t}} = (y_{i,t})^{1-op}(A^p)^{op}\chi^p_{im}(im_{i,t-1})^{op-1}$$

$$\frac{\partial y_{i,t+1}}{\partial k_{i,t}} = (y_{i,t+1})^{1-op}(A^p)^{op}\chi^p_k(k_{i,t})^{op-1}$$

Thus, in this block, we have 8 equations associated with the paths of $\{u_{i,t}, im_{i,t}, k_{i,t}, x_{i,t}, y_{i,t}, l_{i,t}, N_{i,t}, \pi_{i,t}\}_{t=0}^{\infty}$.

A.4: Private Banks' Problem

The gross profit of each private bank b, denoted as $\pi^{gross}_{b,t}$, is defined as net interest income (income from assets minus payments to liabilities) minus operational costs:

$$\pi^{gross}_{b,t} \equiv (1+i^l_t)\frac{p_{t-1}}{p_t}l_{b,t-1} + (1+i^{b*}_t)\frac{p^*_{t-1}}{p^*_t}\frac{e_t p^*_t}{p_t}f_{b,t-1} + (1+i^r_t)\frac{p_{t-1}}{p_t}m_{b,t-1}+$$

$$+(1+i^b_t)\frac{p_{t-1}}{p_t}\Lambda_{b,t}b_{b,t-1} + \Phi_t\frac{p_{t-1}}{p_t}(1-\Lambda_{b,t})b_{b,t-1}-$$

$$-(1+i^d_t)\frac{p_{t-1}}{p_t}j_{b,t-1} - (1+i^z_t)\frac{p_{t-1}}{p_t}z_{b,t-1} - \frac{p^H_t}{p_t}\Xi_{b,t}$$

This gross profit is used to pay taxes, $\tau^\pi_t\pi^{gross}_{b,t}$, dividends to shareholders, $\pi_{b,t}$, and what is left is net worth, $n_{b,t}$:

$$\pi^{gross}_{b,t} \equiv \tau^\pi_t\pi^{gross}_{b,t} + \pi_{b,t} + n_{b,t}$$

where net worth is defined as assets minus liabilities:

$$n_{b,t} \equiv l_{b,t} + b_{b,t} + \frac{e_t p^*_t}{p_t}f_{b,t} + m_{b,t} - j_{b,t} - z_{b,t}$$

Combining the above, we have as in the main text:

$$\pi_{b,t} = \left(1-\tau^\pi_t\right)[(1+i^l_t)\frac{p_{t-1}}{p_t}l_{b,t-1} + (1+i^{b*}_t)\frac{p^*_{t-1}}{p^*_t}\frac{e_t p^*_t}{p_t}f_{b,t-1} + (1+i^r_t)\frac{p_{t-1}}{p_t}m_{b,t-1}+$$

$$+(1+i^b_t)\frac{p_{t-1}}{p_t}\Lambda_{b,t}b_{b,t-1} + \Phi_t\frac{p_{t-1}}{p_t}(1-\Lambda_{b,t})b_{b,t-1}-$$

$$-(1+i^d_t)\frac{p_{t-1}}{p_t}j_{b,t-1} - (1+i^z_t)\frac{p_{t-1}}{p_t}z_{b,t-1} - \frac{p^H_t}{p_t}\Xi_{b,t}]-$$

$$-l_{b,t} - b_{b,t} - \frac{e_t p^*_t}{p_t}f_{b,t} - m_{b,t} + j_{b,t} + z_{b,t}$$

To solve this problem, we work as in e.g. Cúrdia and Woodford (2011). Thus, we set in each time period:

$$(1+i_t^d)\frac{p_{t-1}}{p_t}j_{b,t-1}+(1+i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1}=(1+i_t^l)\frac{p_{t-1}}{p_t}l_{b,t-1}+$$

$$+(1+i_t^b)\Lambda_{b,t}\frac{p_{t-1}}{p_t}b_{b,t-1}+\Phi_t\frac{p_{t-1}}{p_t}(1-\Lambda_{b,t})b_{b,t-1}+$$

$$+(1+i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}f_{b,t-1}+(1+i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1}$$

so that by leading it one period forward and rearranging we have for deposits at t:

$$j_{b,t}\equiv\frac{(1+i_{t+1}^l)\frac{p_t}{p_{t+1}}l_{b,t}+(1+i_{t+1}^b)\frac{p_t}{p_{t+1}}\Lambda_{b,t+1}b_{b,t}+\Phi_{t+1}\frac{p_t}{p_{t+1}}(1-\Lambda_{b,t+1})b_{b,t}}{(1+i_{t+1}^d)\frac{p_t}{p_{t+1}}}+$$

$$+\frac{(1+i_{t+1}^{b*})\frac{p_t^*}{p_{t+1}^*}\frac{e_{t+1}p_{t+1}^*}{p_{t+1}}f_{b,t}+(1+i_{t+1}^r)\frac{p_t}{p_{t+1}}m_{b,t}-(1+i_{t+1}^z)\frac{p_t}{p_{t+1}}z_{b,t}}{(1+i_{t+1}^d)\frac{p_t}{p_{t+1}}}$$

Combining the above, we have:

$$\pi_{b,t}=j_{b,t}+z_{b,t}-l_{b,t}-b_{b,t}-\frac{e_t p_t^*}{p_t}f_{b,t}-m_{b,t}-\left(1-\tau_t^\pi\right)\frac{p_t^H}{p_t}\Xi_{b,t}$$

Therefore, the bank maximizes:

$$\sum_{t=0}^{\infty}\beta_{b,t}\pi_{b,t}$$

where, since private banks are owned by households, we again postulate ex post that $\beta_{b,0}=1$ at $t=0$ and $\beta_{b,t}\equiv\beta^t\frac{\lambda_{h,t}}{\lambda_{h,0}}$ at $t=1,2,\ldots$.

The optimality conditions for $L_{b,t}$, $b_{b,t}$, $f_{b,t}$, $m_{b,t}$, $z_{b,t}$ and $\Lambda_{b,t}$ are respectively:

$$\frac{p_{t+1}^H}{p_{t+1}}\beta\frac{\lambda_{h,t+1}}{\lambda_{h,t}}(1-\tau_{t+1}^\pi)\xi^l l_{b,t}=\frac{(1+i_{t+1}^l)}{(1+i_{t+1}^d)}-1 \quad \text{(A.4a)}$$

$$\frac{p_{t+1}^H}{p_{t+1}}\beta\frac{\lambda_{h,t+1}}{\lambda_{h,t}}(1-\tau_{t+1}^\pi)\xi^b(\Lambda_{b,t+1})^2 b_{b,t}=\frac{(1+i_{t+1}^b)\Lambda_{b,t+1}+\Phi_{t+1}(1-\Lambda_{b,t+1})}{(1+i_{t+1}^d)}-1+ \quad \text{(A.4b)}$$

$$+\frac{p_{t+1}^H}{p_{t+1}}\beta(1-\tau_{t+1}^\pi)\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\xi^m\left(m_{b,t}+\Phi_{t+1}(1-\Lambda_{b,t+1})b_{b,t}\right)^{-3}\Phi_{t+1}(1-\Lambda_{b,t+1})$$

$$\frac{p_{t+1}^H}{p_{t+1}}\beta(1-\tau_{t+1}^\pi)\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\xi^f\left(\frac{e_{t+1}p_{t+1}^*}{p_{t+1}}\right)^2 f_{b,t}=\frac{(1+i_{t+1}^{b*})\frac{p_t^*}{p_{t+1}^*}\frac{e_{t+1}p_{t+1}^*}{p_{t+1}}}{(1+i_{t+1}^d)\frac{p_t}{p_{t+1}}}-\frac{e_t p_t^*}{p_t} \quad \text{(A.4c)}$$

$$\frac{p^H_{t+1}}{p_{t+1}}\beta(1-\tau^{\pi}_{t+1})\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\xi^m\left(m_{b,t}+\Phi_{t+1}(1-\Lambda_{b,t+1})b_{b,t}\right)^{-3}=1-\frac{(1+i^r_{t+1})}{(1+i^d_{t+1})} \tag{A.4d}$$

$$\frac{p^H_{t+1}}{p_{t+1}}\beta(1-\tau^{\pi}_{t+1})\frac{\lambda_{h,t+1}}{\lambda_{h,t}}\xi^z z_{b,t}=1-\frac{(1+i^z_{t+1})}{(1+i^d_{t+1})} \tag{A.4e}$$

$$\frac{\beta\lambda_{h,t}}{\lambda_{h,t-1}}\frac{p^H_t}{p_t}(1-\tau^{\pi}_t)\xi^b\Lambda_{b,t}b_{b,t-1}+$$

$$+\frac{\beta\lambda_{h,t}}{\lambda_{h,t-1}}\frac{p^H_t}{p_t}(1-\tau^{\pi}_t)\xi^m[m_{b,t-1}+\Phi_t(1-\Lambda_{b,t})b_{b,t-1}]^{-3}\Phi_t=\frac{(1+i^b_t-\Phi_t)}{(1+i^d_t)} \tag{A.4f}$$

The first-order conditions also include the definitions and constraints:

$$\pi_{b,t}=j_{b,t}+z_{b,t}-l_{b,t}-b_{b,t}-\frac{e_t p^*_t}{p_t}f_{b,t}-m_{b,t}-\left(1-\tau^{\pi}_t\right)\frac{p^H_t}{p_t}\Xi_{b,t} \tag{A.4g}$$

$$j_{b,t}\equiv\frac{(1+i^l_{t+1})\frac{p_t}{p_{t+1}}l_{b,t}+(1+i^b_{t+1})\frac{p_t}{p_{t+1}}\Lambda_{b,t+1}b_{b,t}+\Phi_{t+1}\frac{p_t}{p_{t+1}}(1-\Lambda_{b,t+1})b_{b,t}}{(1+i^d_{t+1})\frac{p_t}{p_{t+1}}}+$$

$$+\frac{(1+i^{b*}_{t+1})\frac{p^*_t}{p^*_{t+1}}\frac{e_{t+1}p^*_{t+1}}{p_{t+1}}f_{b,t}+(1+i^r_{t+1})\frac{p_t}{p_{t+1}}m_{b,t}-(1+i^z_{t+1})\frac{p_t}{p_{t+1}}z_{b,t}}{(1+i^d_{t+1})\frac{p_t}{p_{t+1}}} \tag{A.4h}$$

$$\Xi_{b,t}\equiv\frac{\xi^l}{2}(l_{b,t-1})^2+\frac{\xi^b}{2}(\Lambda_{b,t}b_{b,t-1})^2+\frac{\xi^f}{2}\left(\frac{e_t p^*_t}{p_t}f_{b,t-1}\right)^2+$$

$$+\frac{\xi^m}{2}[m_{b,t-1}+\Phi_t(1-\Lambda_{b,t})b_{b,t-1}]^{-2}+\frac{\xi^z}{2}(z_{b,t-1})^2 \tag{A.4i}$$

Thus, in this block, we have 9 equations associated with the paths of $\{l_{b,t}, b_{b,t}, f_{b,t}, m_{b,t}, z_{b,t}, \Lambda_{b,t}, j_{b,t}, \pi_{b,t}, \Xi_{b,t}\}_{t=0}^{\infty}$.

A.5: State Firms and Public Spending Items used by them

$$y^g_{g,t}=A^g[\chi^g_k(k^g_{g,t-1})^{og}+\chi^g_l(u_{g,t})^{og}+\chi^g_g\left(g^g_{g,t}\right)^{og}]^{1/og} \tag{A.5a}$$

$$k^g_{g,t}=(1-\delta^g)k^g_{g,t-1}+g^i_{g,t} \tag{A.5b}$$

Thus, in this block, we have 2 equations associated with the paths of $\{y^g_{g,t}, k^g_{g,t}\}_{t=0}^{\infty}$.

In addition, if "demand" equals "supply", the policy variables, w^g_t, $g^g_{g,t}$ and g^g_t, should satisfy:

$$w^g_t\equiv\frac{s^w_t\frac{p^H_t}{p_t}n^p y_{i,t}}{n^g u_{g,t}} \tag{A.5c}$$

$$g_{g,t}^{g} \equiv \frac{s_t^g n^p y_{i,t}}{n^g} \tag{A.5d}$$

$$g_{g,t}^{i} \equiv \frac{s_t^i n^p y_{i,t}}{n^g} \tag{A.5e}$$

and we have similarly for transfers:

$$g_t^t \equiv s_t^t \frac{p_t^H}{p_t} n^p y_{i,t} \tag{A.5f}$$

where $0 < s_t^w, s_t^i, s_t^t, s_t^g < 1$ are respectively the public wage bill, public investment, transfer payments and spending on goods and services purchased from the private sector, all four expressed as shares of GDP, so they can be set as in the data. Notice that, to the extent that we work with total primary public spending as share of GDP, s_t, we can equivalently define $s_t^w \equiv \lambda^w s_t, s_t^i \equiv \lambda^i s_t, s_t^t \equiv \lambda^t s_t$ and $s_t^g \equiv (1-\lambda^w-\lambda^i-\lambda^t)s_t$, where now it is λ^w, λ^i, λ^t and s_t that can be set as in the data.

Thus, in this block, we have 4 extra equations associated with the paths of $\{w_t^g, g_{g,t}^g, g_{g,t}^i, g_{g,t}^t\}_{t=0}^{\infty}$.

A.6: Government Budget Constraint

The government budget identity is:

$$g_t^t + n^g \left[w_t^g u_{g,t}^g + \frac{p_t^H}{p_t} \left(g_{g,t}^g + g_{g,t}^i \right) \right] +$$

$$+(1+i_t^b)\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + (1+i_t^b)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1}+$$

$$+ (1+i^{eu})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{eu} b_{t-1} = b_t + t_t^{tax} + t_t^{gov} \tag{A.6a}$$

where notice that, using the definitions in Appendix A.5, we have for real and per capita primary public spending (see the terms in the first line of the budget constraint above) $g_t \equiv g_t^t + n^g \left[w_t^g u_{g,t}^g + \frac{p_t^H}{p_t} \left(g_{g,t}^g + g_{g,t}^i \right) \right] = (s_t^w + s_t^i + s_t^t + s_t^g)\frac{p_t^H}{p_t} n^p y_{i,t} \equiv s_t \frac{p_t^H}{p_t} n^p y_{i,t}$ and, hence, real and per capital primary public spending, expressed as share of real and per capita GDP, is $\frac{g_t}{\frac{p_t^H}{p_t} n^p y_{i,t}} = (s_t^w + s_t^i + s_t^t + s_t^g) \equiv s_t$.

Real and per capita tax revenues are:

$$t_t^{tax} \equiv \tau_t^c \left(\frac{p_t^H}{p_t} c_{h,t}^H + \frac{p_t^F}{p_t} c_{h,t}^F\right) + \tau_t^y \left(n^p w_t^p u_{h,t}^p + n^g w_t^g u_{h,t}^g + \pi_{h,t}\right) +$$

$$+\tau_t^\pi n^p \left[\frac{p_t^H}{p_t} y_{i,t} - w_t^p u_{i,t} - \frac{p_t^F}{p_t} m_{i,t}\right] +$$

$$+\tau_t^{\pi} n^p[(1+i_t^l)\frac{p_{t-1}}{p_t} l_{b,t-1} + (1+i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t} f_{b,t-1} + (1+i_t^r)\frac{p_{t-1}}{p_t} m_{b,t-1} +$$

$$+(1+i_t^b)\frac{p_{t-1}}{p_t}\Lambda_{b,t} b_{b,t-1} + \Phi_t \frac{p_{t-1}}{p_t}(1-\Lambda_{b,t}) b_{b,t-1} -$$

$$-(1+i_t^d)\frac{p_{t-1}}{p_t} j_{b,t-1} - (1+i_t^z)\frac{p_{t-1}}{p_t} z_{b,t-1} - \frac{p_t^H}{p_t}\Xi_{b,t}] \tag{A.6b}$$

Thus, in this block, we have 2 equations associated with the paths of $\{b_t, t_t^{tax}\}_{t=0}^{\infty}$.

A.7: National Central Bank (NCB)

A.7.1 Budget Constraint of the NCB

The budget identity of the NCB is:

$$\Phi_t(1-\Lambda_{b,t})\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + \Phi_t(1-\Lambda_{b,t})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} + n^p z_{b,t} +$$

$$+\Phi_t^*(1-\Lambda_{b,t}^*)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{d*} b_{t-1}^* +$$

$$+n^p(1+i_t^r)\frac{p_{t-1}}{p_t} m_{b,t-1} + t_t^{gov} + t_t^{es} \equiv$$

$$\equiv (1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + (1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} +$$

$$+n^p(1+i_t^z)\frac{p_{t-1}}{p_t} z_{b,t-1} + n^p m_{b,t} + \left(m_{h,t} - \frac{p_{t-1}}{p_t} m_{h,t-1}\right) +$$

$$+\left(TARG_t - \left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t} TARG_{t-1}\right) + s_t^{es} \tag{A.7a}$$

$$+(1-\Lambda_{b,t}^*)(1+i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{d*} b_{t-1}^*$$

Thus, in this block, we have 1 equation associated with the path of $\{TARG_t\}_{t=0}^{\infty}$.

A.7.2 Monetary Policy Instruments

If we add and subtract the term

$$(1-\Lambda_{b,t}) i_t^{MRO}\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + (1-\Lambda_{b,t}) i_t^{MRO}\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1}$$

and also add and subtract the term

$$(1-\Lambda_{b,t}^{*})i_t^{MRO}\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g*}b_{t-1}^{*}$$

on the RHS of the NCB's budget constraint above, we have:

$$\Phi_t(1-\Lambda_{b,t})\frac{p_{t-1}}{p_t}\lambda_{t-1}^{d}b_{t-1}+\Phi_t(1-\Lambda_{b,t})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g}b_{t-1}+n^p z_{b,t}+$$

$$+\Phi_t^{*}(1-\Lambda_{b,t}^{*})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g*}b_{t-1}^{*}+$$

$$+n^p(1+i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1}+t_t^{gov}+t_t^{es}\equiv$$

$$\equiv(1-\Lambda_{b,t})(1+i_t^{MRO})\frac{p_{t-1}}{p_t}\lambda_{t-1}^{d}b_{t-1}+(1-\Lambda_{b,t})(1+i_t^{MRO})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g}b_{t-1}+$$

$$+(1-\Lambda_{b,t})(i_t^{b}-i_t^{MRO})\frac{p_{t-1}}{p_t}\lambda_{t-1}^{d}b_{t-1}+(1-\Lambda_{b,t})(i_t^{b}-i_t^{MRO})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g}b_{t-1}+$$

$$+n^p(1+i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1}+n^p m_{b,t}+\left(m_{h,t}-\frac{p_{t-1}}{p_t}m_{h,t-1}\right)+$$

$$+\left(TARG_t-\left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t}TARG_{t-1}\right)+s_t^{es}+$$

$$+(1-\Lambda_{b,t}^{*})(1+i_t^{MRO})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g*}b_{t-1}^{*}+(1-\Lambda_{b,t}^{*})(i_t^{b*}-i_t^{MRO})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g*}b_{t-1}^{*}$$

Now by the rules of the ES (for a clear presentation of the various rules of the ES, see e.g The Annual Reports of Deutsche Bundesbank 2023), the transfer to the common pool of the ES and the transfer to the government are respectively:[46]

$$t_t^{es}\equiv(1-\Lambda_{b,t})(1+i_t^{MRO})\frac{p_{t-1}}{p_t}\lambda_{t-1}^{d}b_{t-1}+(1-\Lambda_{b,t})(1+i_t^{MRO})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g}b_{t-1}+$$

$$+n^p(1+i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1}-\frac{p_{t-1}}{p_t}m_{h,t-1}-n^p(1+i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1}-\left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t}TARG_{t-1}+$$

$$+(1-\Lambda_{b,t}^{*})(1+i_t^{MRO})\frac{p_{t-1}^{*}}{p_t^{*}}\frac{e_t p_t^{*}}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^{*}}\lambda_{t-1}^{g*}b_{t-1}^{*}$$

46 When a NCB contributes its monetary income from net assets to the common pool of the ES, the reference interest rate on bonds being part of PSPP and PEPP is the MRO (hence the NCB retains the difference between the actual return and the MRO), while, for the majority of other assets and liabilities, the reference rate is the actual one. The interest rate on TARGET2 balances is also the MRO.

and

$$t_t^{gov} \equiv (1-\Lambda_{b,t})(i_t^b - i_t^{MRO})\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + (1-\Lambda_{b,t})(i_t^b - i_t^{MRO})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} + s_i^{es} +$$

$$+(1-\Lambda_{b,t}^*)(i_t^{b*} - i_t^{MRO})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{g*} b_{t-1}^*$$

where, again by the rules of the ES, and since the capital key of the Greek NCB in the ES is around 2%, the transfer from the ES to the Greek NCB, s_t^{es}, is:

$$s_t^{es} \equiv (0.02)\left(t_t^{es} + \sum_{j=1}^{19} t_{j,t}^{es}\right)$$

But, since there are data on the net transfer, $(s_t^{es} - t_t^{es})$, which is recorded as "Net result of the pooling of monetary income" in the financial statements of the Greek NCB, we can write:

$$s_t^{es} \equiv (s_t^{es} - t_t^{es}) + t_t^{es}$$

where $(s_t^{es} - t_t^{es})$ is set as in the data and t_t^{es} has been defined above.

Therefore, all the above can be summarized by:

$$t_t^{gov} \equiv (1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + (1-\Lambda_{b,t})(1+i_t^b)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} +$$

$$+n^p(1+i_t^z)\frac{p_{t-1}}{p_t}z_{b,t-1} - \frac{p_{t-1}}{p_t}m_{h,t-1} - n^p(1+i_t^r)\frac{p_{t-1}}{p_t}m_{b,t-1} - \left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t}TARG_{t-1} +$$

$$+(1-\Lambda_{b,t}^*)(1+i_t^{b*})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{g*} b_{t-1}^* \qquad \text{(A.7b)}$$

where, as said in the main text, $(s_t^{es} - t_t^{es})$ is set as in the data.

Thus, in this block, we have 1 equation associated with the path of $\{t_t^{gov}\}_{t=0}^{\infty}$.

Notice that plugging the above into the budget constraint of the NCB, the latter is ex post reduced to:

$$\Phi_t^*(1-\Lambda_{b,t}^*)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{g*} b_{t-1}^* +$$

$$+\Phi_t(1-\Lambda_{b,t})\frac{p_{t-1}}{p_t}\lambda_{t-1}^d b_{t-1} + \Phi_t(1-\Lambda_{b,t})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1} + n^p z_{b,t} =$$

$$= m_{h,t} + n^p m_{b,t} + TARG_t$$

which reads that bonds plus loans to private banks are equal to the monetary base.

A.8: Market-clearing Conditions

Labor market (private sector):

$$u_{i,t} = u^{p}_{h,t} \tag{A.8a}$$

Labor market (public sector):

$$u_{g,t} = u^{g}_{h,t} \equiv 0.3 \tag{A.8b}$$

Dividend market:

$$\pi_{h,t} = n^{p}(\pi_{i,t} + \pi_{b,t}) \tag{A.8c}$$

Loan market (private):

$$l_{i,t} = l_{b,t} \tag{A.8d}$$

Deposit market:

$$j_{h,t} = n^{p} j_{b,t} \tag{A.8e}$$

Domestic sovereign bond market:

$$\lambda^{d}_{t} b_{t} = n^{p} b_{b,t} \tag{A.8f}$$

where we use $\lambda^{d}_{t} = 1 - \lambda^{g}_{t} - \lambda^{eu}_{t}$ (and so $b_{t} = \lambda^{d}_{t} b_{t} + \lambda^{g}_{t} b_{t} + \lambda^{eu}_{t} b_{t}$).

Gross Domestic Product (GDP) identity

$$n^{p} y_{i,t} = c^{H}_{h,t} + n^{b}(g^{g}_{g,t} + g^{i}_{g,t}) + c^{f*}_{t} + n^{p} x_{i,t} +$$

$$+ n^{p} \frac{\xi^{k}}{2} \left(\frac{k_{i,t}}{k_{i,t-1}} - 1 \right)^{2} k_{i,t-1} + n^{p} \frac{\xi^{p}}{2} \left(\frac{p^{H}_{t}}{p^{H}_{t-1}} - 1 \right)^{2} y_{i,t} + n^{p} \Xi_{b,t} \tag{A.8g}$$

where c^{f*}_{t} denotes exports to the rest of the world. Since in a small open economy this is an exogenous variable, we assume, following e.g. Lorenzoni (2014, p. 698), that:

$$c^{f*}_{t} = \left(\frac{p^{h}_{t}}{p^{f}_{t}} \right)^{-\vartheta} \tag{A.8h}$$

where $\vartheta > 0$ is a parameter.

Thus, in this block, we have 8 equations associated with the paths of $\{w_{t}, u_{g,t}, \pi_{h,t}, i^{l}_{t}, i^{d}_{t}, i^{b}_{t}, p^{H}_{t}, c^{f*}_{t}\}$.

Combining all the above constraints, we get the country's balance of payments (notice however that this is a linear combination of all budget constraints above and hence is not included in the system):

$$\frac{p^{F}_{t}}{p_{t}} \left(c^{F}_{h,t} + n^{p} im_{i,t} \right) - \frac{p^{H}_{t}}{p_{t}} c^{f*}_{t} +$$

$$+\frac{e_t p_t^*}{p_t} j_{h,t}^F + \frac{p_t^F}{p_t} \frac{\upsilon}{2} \left(\frac{e_t p_t^*}{p_t} j_{h,t}^F \right)^2 + n^p \frac{e_t p_t^*}{p_t} f_{b,t} +$$

$$+[(1+i_t^b)\Lambda_{b,t} + \Phi_t(1-\Lambda_{b,t})] \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} \frac{p_{t-1}}{e_{t-1} p_{t-1}^*} \lambda_{t-1}^g b_{t-1} +$$

$$+\left[\Phi_t^* - (1+i_t^{b*})\right](1-\Lambda_{b,t}^*) \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} \frac{p_{t-1}}{e_{t-1} p_{t-1}^*} \lambda_{t-1}^{g*} b_{t-1}^* +$$

$$+(1+i_t^{eu}) \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} \frac{p_{t-1}}{e_{t-1} p_{t-1}^*} \lambda_{t-1}^{eu} b_{t-1} =$$

$$= \left(1+i_t^{d*}\right) \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} j_{h,t-1}^F + n^p \left(1+i_t^{b*}\right) \frac{p_{t-1}^*}{p_t^*} \frac{e_t p_t^*}{p_t} f_{b,t-1} +$$

$$+\lambda_t^g b_t + \lambda_t^{eu} b_t + \left(TARG_t - \left(1+i_t^{MRO}\right) \frac{p_{t-1}}{p_t} TARG_{t-1} \right) + (s_t^{es} - t_t^{es})$$

where notice that $TARG_t$ remains in the balance of payments.

A.9: Macroeconomic System

Therefore, we have 47 equations (see the numbered equations only) in 47 endogenous variables which are $\{c_{h,t}^H, c_{h,t}^F, c_{h,t}, u_{h,t}^p, u_{h,t}, j_{h,t}^H, j_{h,t}^F, m_{h,t}, \lambda_{h,t}, \psi_{h,t}\}_{t=0}^{\infty}$, $\{u_{i,t}, im_{i,t}, k_{i,t}, l_{i,t}, x_{i,t}, y_{i,t}, N_{i,t}, \pi_{i,t}\}_{t=0}^{\infty}$, $\{l_{b,t}, b_{b,t}, f_{b,t}, m_{b,t}, z_{b,t}, \Phi_t, j_{b,t}, \pi_{b,t}, \Xi_{b,t}\}_{t=0}^{\infty}$, $\{p_t, p_t^F\}_{t=0}^{\infty}$, $\{y_{g,t}^g, k_{g,t}^g\}_{t=0}^{\infty}$, $\{b_t, t_t^{tax}\}_{t=0}^{\infty}$, $\{w_t^g, g_{g,t}^g, g_{g,t}^i, g_{g,t}^t\}$, $\{TARG_t, t_t^{gov}\}_{t=0}^{\infty}$, $\{w_t^p, u_{g,t}, \pi_{h,t}, i_t^l, i_t^d, i_t^b, p_t^H, c_t^{f*}\}_{t=0}^{\infty}$. This is given the exogenously set policy instruments.

A.10: Transformed Price Variables

We define $\frac{p_t^F}{p_t^H} \equiv TT_t$ to be the terms of trade (an increase means an improvement in competitiveness vis-à-vis the rest of the world). Then, we have $\frac{p_t^H}{p_t} = (TT_t)^{\nu-1}$, $\frac{p_t^F}{p_t} = (TT_t)^{\nu}$, $\frac{e_t p_t^*}{p_t} = (TT_t)^{2\nu-1}$, $\Pi_t \equiv \frac{p_t}{p_{t-1}} = \Pi_t^H \left(\frac{TT_t}{TT_{t-1}}\right)^{1-\nu}$ and $\frac{TT_t}{TT_{t-1}} = \frac{e_t}{e_{t-1}} \frac{\Pi_t^{H*}}{\Pi_t^H}$, where $\Pi_t^H \equiv \frac{p_t^H}{p_{t-1}^H}$. Also, $\frac{e_t}{e_{t-1}}$ is the gross exchange rate depreciation which is set at one all the time in a currency union. In other words, instead of $\{p_t, p_t^H, p_t^F\}_{t=0}^{\infty}$, the endogenous variables are $\left\{TT_t, \Pi_t^H, \Pi_t\right\}_{t=0}^{\infty}$ and, in all other equations, we use the above transformations Recall that, in a small open economy, $\Pi_t^{H*} \equiv \frac{p_t^{H*}}{p_{t-1}^{H*}}$ is exogenous, while, $\Pi_t^* \equiv \frac{p_t^*}{p_{t-1}^*}$ is also treated for simplicity as exogenous (namely, unaffected by home prices).

Appendix B: A Note on *Target2* Balances

Target2 balances are net bilateral positions vis-a-vis the ES, which means that the NCB of a member country transferring money abroad records a *Target2* liability to the rest of the ES, while the NCB of a member country receiving money from abroad records a *Target2* asset. Changes in *Target2* balances can arise, for instance, when a private bank in one member-country makes a cross-border payment to another bank in the ES (this was particularly relevant during the European debt crisis as result of flight to safety). Changes in *Target2* balances can also arise from cross-border transactions by the NCBs themselves such as purchases and sales of securities (this is particularly relevant in the more recent period as a result of asset purchase programmes). See e.g. Whelan (2014, 2017) for a detailed analysis.

Target2 balances appear in the balance sheets of individual NCBs and the ECB itself; they enter as an extra item of liabilities for a country with Intra-Eurosystem liabilities like Greece, or as an extra item of assets for a country with Intra-Eurosystem claims like Germany. On the other hand, these balances cancel each other out at the aggregate ES level and this is why they do not appear in the consolidated balance sheet of the ES as a whole (see the website of the ECB). Since they are cross-border flows, they are also recorded in the balance of payments of ES member countries (under "other investment of the NCB"). In other words, in terms of modelling, they do remain in the balance of payments of a member country like any other foreign assets or liabilities (see also our balance of payments identity in Appendix A.8).

The economic role of these balances has been a hotly debated issue in the ES. For details, examples and different views, see e.g. Sinn and Wollmershauser (2012), Sinn (2015), Lorenzoni (2014), Whelan (2014, 2017), etc. For a relatively recent paper by ECB researchers which openly discusses the role of these balances, see Eisenschmidt et al. (2022).

Finally, it is worth providing some data. *Target2* balances were close to zero before the global financial crisis of 2008. By contrast, in 2012, at the peak of the European debt crisis, *Target2* liabilities were 98, 255, 66 and 337 billion euros in Greece, Italy, Portugal and Spain respectively, while, *Target2* claims were 665 billion euros in Germany. At the end of 2021, at the peak of the pandemic crisis and the ES's PEPP program, these numbers rose to 104, 590, 79 and 513 for Greece, Italy, Portugal and Spain, while claims rose to 1261 for Germany (see the website of ECB). More detailed data for Greece, the country under study, are provided below.

Appendix C: Greek Policy Data

C.1: Greece's Repayment Obligations

As result of the three official bailout loans in 2010, 2012 and 2018, and more recently new loans from the NGEU/RRF, most of the Greek public debt is in the hands of EU public institutions (member states of the euro area, EFSF, ESM, etc). This Appendix presents the time profile of repayment of the remaining debt to the EU (the data

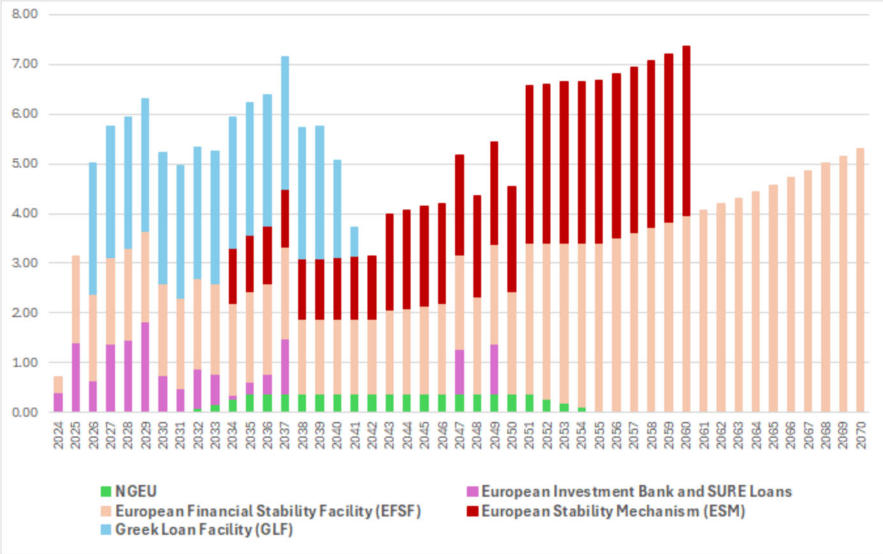

Fig. 5 Repayment profile of Greek public debt to EU public institutions (billion euros)

are from various publications of the Public Debt Management Agency Public Debt Management Agency (2023) of the Hellenic Republic):

C.2: Balance Sheet of the Greek NCB

In this Appendix, we display the biggest assets and liabilities of the Greek NCB over time (the data are from the website of the Bank of Greece).

Table 7 Bank of Greece's assets (billions of euros, end of year)

Year	Loans to banks	Securities	Total assets
2010	98	24	13
2011	128	21	168
2012	121	21	160
2013	73	21	109
2014	56	31	103
2015	107	40	163
2016	67	57	142
2017	34	74	125
2018	11	76	109
2019	8	75	109
2020	43	110	183
2021	53	148	238
2022	37	160	238
2023	14	160	226

Source: Bank of Greece

Table 8 Bank of Greece's liabilities (billions of euros, end of year)

Year	Banknotes	TARGET2	Reserves	Total liabilities
2010	29	87	10	138
2011	41	105	5	168
2012	38	98	2	160
2013	35	51	2	109
2014	32	49	3	103
2015	48	94	1	163
2016	43	72	1	142
2017	31	59	2	125
2018	29	29	7	109
2019	21	26	9	109
2020	22	80	27	183
2021	34	104	49	238
2022	16	112	43	238
2023	10	115	28	226

Source: Bank of Greece

Appendix D: Modelling of NGEU/RRF

We assume that new funds enter the country from abroad and are split between private firms and public enterprises according to their population weights. Thus,

$$RRF_t = n^p RRF_{i,t} + n^b RRF_{g,t}$$

where $RRF_{i,t}$ and $RRF_{g,t}$ are the funds received by each private and state firm respectively and RRF_t is per capita funds from abroad.

As stated in the main text, the law of motion of each type of capital is:

$$k_{i,t} = (1-\delta)\, k_{i,t-1} + x_{i,t} + RRF_{i,t}$$

$$k^g_{g,t} = (1-\delta^g)k^g_{g,t-1} + g^i_{g,t} + RRF_{g,t}$$

and we also assume that:

$$RRF_{i,t} = \xi_t k_{i,t-1}$$

$$RRF_{g,t} = \xi_t k^g_{g,t-1}$$

These new funds increase demand for GDP (i.e. we assume for simplicity that nothing of this transfer goes to imports) so the GDP identity changes from Eq. A.8g in Appendix A.8 to:

$$n^p y_{i,t} = c^H_{h,t} + n^b(g^g_{g,t} + g^i_{g,t}) + c^{f*}_t + n^p x_{i,t} + RRF_t +$$

$$+n^{p}\frac{\xi^{k}}{2}\left(\frac{k_{i,t}}{k_{i,t-1}}-1\right)^{2}k_{i,t-1}+n^{p}\frac{\xi^{p}}{2}\left(\frac{p_{t}^{H}}{p_{t-1}^{H}}-1\right)^{2}y_{i,t}+n^{p}\,\Xi_{b,t}$$

Also, total RRF funds appear as an extra terms in BoP:

$$\frac{p_t^F}{p_t}\left(c_{h,t}^F+n^p im_{i,t}\right)-\frac{p_t^H}{p_t}c_t^{f*}+$$

$$+\frac{e_t p_t^*}{p_t}j_{h,t}^F+\frac{p_t^F}{p_t}\frac{\upsilon}{2}\left(\frac{e_t p_t^*}{p_t}j_{h,t}^F\right)^2+n^p\frac{e_t p_t^*}{p_t}f_{b,t}+$$

$$+[(1+i_t^b)\Lambda_{b,t}+\Phi_t(1-\Lambda_{b,t})]\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^g b_{t-1}+$$

$$+\left[\Phi_t^*-(1+i_t^{b*})\right](1-\Lambda_{b,t}^*)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{g*}b_{t-1}^*+$$

$$+(1+i_t^{eu})\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}\frac{p_{t-1}}{e_{t-1}p_{t-1}^*}\lambda_{t-1}^{eu}b_{t-1}=$$

$$=\left(1+i_t^{d*}\right)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}j_{h,t-1}^F+n^p\left(1+i_t^{b*}\right)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t}f_{b,t-1}+$$

$$+\lambda_t^g b_t+\lambda_t^{eu}b_t+\left(TARG_t-\left(1+i_t^{MRO}\right)\frac{p_{t-1}}{p_t}TARG_{t-1}\right)+(s_t^{es}-t_t^{es})+\frac{p_t^H}{p_t}RRF_t$$

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Declarations

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