The Green Transition and Public Finances[*]

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Abstract

As the world faces rising temperatures, extreme weather events and environmental disruption, the imperative to mitigate climate change has never been more pressing. Yet the pursuit of effective mitigation could threaten the sustainability of public debt due to the potentially huge fiscal costs of the associated policies. This paper uses a dynamic general equilibrium approach that takes into account the macroeconomic implications of the green transition and its consequences for public finances. It shows that when the government relies too heavily on expenditure-based measures, it threatens the sustainability of public debt, by increasing the probability of sovereign default, leading to higher interest rates on government bonds. This higher public default risk has potentially significant repercussions on investment financing conditions for the private sector, and increases the cost of the transition to a net-zero economy. On the other hand, carbon pricing policies make the transition more viable for public finances, at the expenses of similarly high economic costs, while remaining effective in reducing greenhouse gas emissions. The welfare-maximizing optimal policy mix yields to a balanced approach, where the share of the mitigation effort undertaken by the public sector ranges from 25% to 40% between 2030 and 2050.

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1 Introduction

As the world faces rising temperatures, extreme weather events and environmental disruption, the need to mitigate climate change has never been more pressing. As global efforts to limit climate change intensify, more and more countries have set themselves net-zero emissions targets. However, questions remain as to whether these climate change pledges will be met, as current and announced policies are insufficient to achieve the temperature target (1.5°C) set in the Paris Agreement. Therefore, additional mitigation efforts are needed to meet this environmental constraint and political commitment. This paper analyzes the economic and fiscal costs of these necessary mitigation efforts, according to the alternative policy instruments available to implement them.

Climate change mitigation policies aim to encourage and support private agents to engage in the transition to low-carbon activities, which involves sending incentives to decarbonize the production process through abatement technologies. While the transition to a low-carbon economy brings invaluable benefits (limiting the harmful consequences of global warming), it may also generate costs in terms of welfare, in particular with lower consumption. One mitigation policy to encourage the transition is for the government to charge private agents for the quantity of greenhouse gases in proportion to their level of pollution. This policy is generally referred to as "carbon pricing". As this policy runs up against problems of acceptability or social justice – requiring lower consumers' expenditures –, the government can also support the transition by bearing part of the costs through public investment in abatement technologies, or by subsidizing the private sector in its own abatement effort. While carbon pricing policies generate revenues for the government, supporting the transition through public spending measures entails significant budgetary costs that can make public debt unsustainable. Rising public debt leads in turn to higher probability of default and a rise in sovereign risk premium. This may further increase the financing costs of the green transition, especially in case of spillovers to the private sector financing conditions.

This paper examines the complex interplay between mitigation policies and fiscal considerations, highlighting the critical need for a balanced approach to addressing these parallel challenges. While the impact of mitigation policies on public finances has been addressed in policy debates (Emambakhsh et al. (2023), IMF (2023)), the topic has so far received little attention from the academic literature.[1] Rare contributions include Agarwala et al. (2021) and Zenios (2022). The first paper provides a taxonomy of how the physical and transition impacts from climate change translate into fiscal risks and shows its usefulness to estimate both the fiscal costs of decarbonization and the pace at which it can be achieved in the case of the UK. Zenios (2022) combines two Integrated Assessment Models (IAMs) with a stochastic debt sustainability analysis (DSA) to assess the available fiscal space to finance climate policies and understand how sovereign debt dynamics can be affected by climate-

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[1] For a more extended literature review on the joint challenges of public debt sustainability and climate-related costs, refer to Seghini (2024).

related risks. Using Italy as a case study (as a high-debt country), he shows with a scenario analysis how mitigation and adaptation costs could further strain public finance for indebted countries, while climate change amplifies the unsustainability of public debt by suppressing growth.

A few papers also investigate empirically the link between transition risk and sovereign bond yields. Battiston and Monasterolo (2020) employ an asset pricing model with forward-looking features to estimate the effects of climate risk on 34 sovereign markets. They find that countries with high exposure to carbon-intensive sectors tend to achieve higher yields on their sovereign bonds. Similarly, Klusak et al. (2021) estimate with an AI-based approach the additional cost of sovereign debt resulting from climate-driven downgrades under various transition scenarios. They find that climate policies, aimed at limiting warming to below 2°C, could limit the effect of climate change on sovereign ratings. On the other hand, in higher emissions scenarios (i.e., with lower transition risks but higher physical risks), 63 out of 108 countries are expected to see their ratings downgraded due to climate by 2030, with an average reduction of more than one notch. By 2100, the number of countries facing downgrades is expected to rise to 80, with an average downgrade of 2.5 notches.

This scant literature remains mostly either conceptual, with a focus on case studies applied in the context of scenario analyses, or empirical, estimating climate effects to sovereign debt instruments. While all papers combine the effects of both transition and physical risks on sovereign debt sustainability, they remain silent on how the transition is conducted and through which channels those risks are transmitted to the macroeconomy and to public debt dynamics. We therefore aim to fill this gap by adopting a dynamic general equilibrium approach that takes into account the macroeconomic implications of alternative green transition policies and their consequences for public finances.

Our contribution lies at the intersection of two strands of literature. On the one hand, we rely on a macro-climate real model, which allows us to analyze the dynamics of the economy in the presence of the greenhouse gas-related externality, as in Heutel (2012) or Annicchiarico and Di Dio (2015). On the other hand, the integration of public debt sustainability issues into macroeconomic models has given rise to an abundant literature, including Corsetti et al. (2013). We use a stylized version of this literature to establish a link between choices in terms of mitigation policies to achieve climate goals and sovereign risks without having to model a detailed financial sector. In an extension, we also take into account the spillover effects of public debt sustainability issues on the private sector financing conditions, which prove to modify the macroeconomic effects and the performance of the various mitigation measures.

Our results show that government over-reliance on expenditure-based policies threatens public debt sustainability by increasing the probability of sovereign default, leading to higher interest rates on government bonds. On the other hand, carbon pricing policies make the transition more viable for public finances at the cost of higher economic costs and larger consumption losses. However, when including the spillover effects to the private sector financing conditions, we show that policies leading to higher sovereign interest rates increase the macroeconomic cost (lower GDP and consumption) of the transition to a low-carbon economy.In contrast, the negative effects of carbon policies on GDP and consumption are reduced because they lead to a general easing of financing costs, benefiting from fiscal consolidation. When analyzing a welfare-maximizing policy mix, we find indeed the optimality of a balanced approach, where the share of the mitigation effort undertaken by the public sector ranges from 25% to 40% between 2030 and 2050. This result is robust to the presence or not of spillover effects, but remains sensitive to public finance conditions (like the share of government expenditures) and relative mitigation costs.

The rest of the paper is organized as follows. The complete model is presented in Section 2. Section 3 presents the calibration of the model and justifies key choices. Section 4 shows various sets of results showing the implications of alternative mitigation policies on macroeconomic trends and public debt. Section 5 completes our analysis with a welfare maximization exercise in order to define the optimal share of public abatement. Section 6 concludes with some policy implications and ideas for possible extensions.

2 A macro-climate model with risky government debt

We introduce a streamlined yet comprehensive macro-climate model designed to evaluate the interplay between green transition policies, public debt, and macroeconomic variables. We integrate a macro-climate Neoclassical real model inspired by Annicchiarico and Di Dio (2015), with a framework for risky government debt based on insights from Corsetti et al. (2013) and Darracq Pariès, Jacquinot, and Papadopoulou (2016). The core aim is to scrutinize the impact of green policies on public finances and the consequent sustainability of public debt under alternative mitigation strategies. The model incorporates a carbon budget constraint, which aligns with the global commitments undertaken with the Paris Agreement. The economy is made of a competitive private sector, households and the government. Emissions are a by-product of the production of final goods. Firms engage in profit maximization, factoring in labor, capital, carbon taxation, abatement costs and green subsidies. They adapt over time to environmental policies, established by the government. Households make decisions regarding consumption, labor supply, and investment in private capital and in government bonds. Their investment in public debt is risky, since in case of default they would be only partially compensated by their loss through public transfers. Their behavior aims to maximize their own utility and it is shaped by taxation, and the overall economic conditions. The government's role is multifaceted, involving bond issuance, the management of taxes and public spending according to policy rules, and ensuring the respect of the political constraints on carbon emissions. It determines carbon taxes, green subsidies to firms and direct public mitigation efforts in line with the available carbon budget. The model also potentially includes climate damages on productivity as a consequence of cumulative carbon emissions, according to different functional forms proposed in the macro-climate literature.

The model captures the main channels through which reducing carbon emissions impacts the real economy and public finances. For different shares of the public direct effort over total mitigation and the level of green subsidies to the private sector, we determine, thus, the sustainability of public debt in alternative mitigation scenarios. Figure 1 shows the structured interaction of the model components, which is described in detail below.

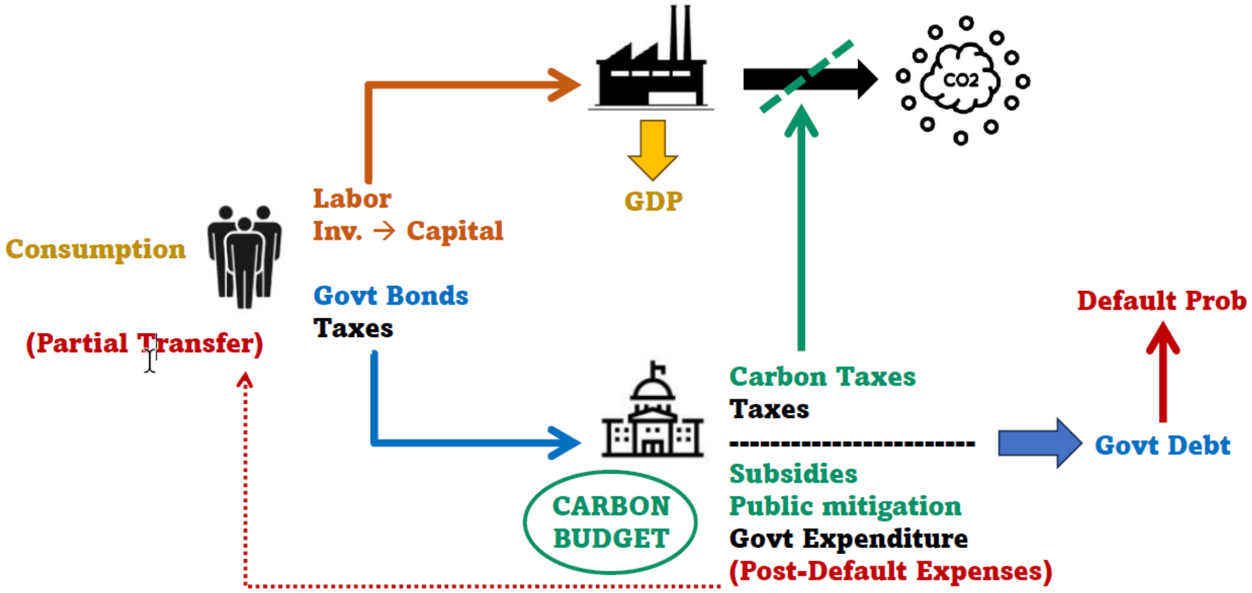

Figure 1: The model's structure. Variables between parentheses are not null only in case of default on government debt.

The carbon budget. The economy operates within a total carbon budget that the government must respect:

$$\sum_{t=0}^{+\infty} E_t \leq \bar{E}_0^n \tag{1}$$

where E_t represents national emissions in one period, and $\bar{E}_0^n$ the carbon budget available to the economy from period 0 onwards. The imposition of this constraint captures the political commitments signed under the Paris Agreement, in order to avoid adverse effects of climate change, generated by the use of carbon emissions.

Final Good Production In our economy a unique final good Y_t, which is used for consumption and investment, is produced by a continuum of competitive firms $i \in (0,1)$. We assume a standard Cobb-Douglas production function with capital $K_t(i)$ and labor $L_t(i)$ as inputs, with the potential addition of climate damages on productivity. Each firm produces:

$$Y_t(i) = D_f(H_t^G)K_t(i)^\kappa[Z_tL_t(i)]^{1-\kappa}, \ \ \kappa \in (0,1), \quad f \in \{\mathrm{NC}, \mathrm{AD}, \mathrm{DV}\} \tag{2}$$

where κ is the elasticity of output with respect to capital and $Z_t = Z_0e^{zt}$ is labor-intensive technological progress. We will normalize $Z_0 = 1$, for the sake of simplicity. D_f represents the total factor productivity (TFP), which is potentially decreasing in global cumulative GHG emissions, since 1850, H_t^G.

TFP, climate damages and cumulative emissions. We will perform a sensitivity analysis of the importance of climate damages for the fiscal sustainability of the transition, by making use of two different specifications, to be compared with the case where we rule out climate impact in the TFP:

$$D_{\mathrm{NC}}(H_t^G) = \bar{D}, \quad D_{\mathrm{AD}}(H_t^G) = \bar{D}(1-\gamma_0-\gamma_1H_t^G-\gamma_2H_t^{G^2}), \quad D_{\mathrm{DV}}(H_t^G) = \bar{D}\exp\left\{-\frac{\gamma_3}{2}(\gamma_4H_t^G)^2\right\}$$

NC stands for "No Climate" impact, AD for Annicchiarico and Di Dio (2015), DV for Dietz and Venmans (2019).[2] We assume that the examined country, when selecting its own transition path, will automatically set the path for the global economy.[3] Therefore, in order to define global emissions we multiply national emissions by a factor equal to the ratio between the global and the national carbon budget. Then, global cumulative emissions write as:

$$H_t^G = H_{-1}^G + \frac{\bar{E}_0^G}{\bar{E}_0^n}H_t = H_{t-1}^G + \frac{\bar{E}_0^G}{\bar{E}_0^n}E_t,$$

where $\bar{E}_0^G$ and $\bar{E}_0^n$ are respectively the global and the national carbon budget from 2024 onward, whose first quarter represents our period 0.[4] National cumulative emissions at time t H_t are defined as: $H_t = \sum_{j=0}^t E_j = H_{t-1} + E_t$.

Emissions. Emissions of firm i in one period are defined as a by-product of output, and this relationship is affected by the private abatement effort $m_t(i)$ and the public abatement intervention m_t^g, which we assume to be constant across firms :

$$E_t(i) = \xi_t[1 - m_t(i) - m_t^g]Y_t(i) \tag{3}$$

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[2] D_{AD} is fitted in Heutel (2012) to match the impact of cumulative emissions on output loss in Nordhaus (2008)'s DICE-2007 model.

[3] This can be done through, for example, political bargaining efforts, or carbon border adjustment mechanisms, which are not explicitly modeled here.

[4] For simplicity, we rule out any cumulative emissions' decay (which appears in Annicchiarico and Di Dio (2015), but as very small or approximately null) and any delay in the response of temperature to emissions (which appears in Dietz and Venmans (2019), but it is compensated here by a conservative choice in the damage function's calibration).

where $\xi_t = \xi_0 e^{-\omega t} = \xi_{t-1} e^{-\omega}$, $\xi_0 > 0$, is output's carbon intensity (emissions per unit of output in the absence of abatement effort), which is decreasing over time at rate $\omega > 0$.

Private abatement technology cost. Similarly to Annicchiarico and Di Dio (2015) and Jondeau et al. (2023), the private abatement technological cost is defined as:

$$A_t(i) = \theta_1 [m_t(i)]^{\theta_2} Y_t(i) \tag{4}$$

where $\theta_1 > 0, \theta_2 > 1$ are parameters of the abatement cost function.

Profit maximization Each firm i maximizes profits:

$$\Pi_t(i) = Y_t(i) - W_t L_t(i) - R_t^k K_t(i) - (1 - s_t^A) A_t(i) - \tau_t^E E_t(i), \tag{5}$$

subject to the production function (2). W_t, R_t^k, τ_t^E and s_t^A are respectively the real wage, the rental rate on capital, the carbon tax and the public subsidy to abatement costs. The latter two depend on the environmental policy regime, decided by the government. Cost minimization at the margin implies:[5]

$$(\delta L_t(i)) \quad \Theta_t(i) D_f(H_t^G) K_t(i)^\kappa (1-\kappa) Z_t^{1-\kappa} L_t(i)^{-\kappa} = W_t \tag{6}$$

$$(\delta K_t(i)) \quad \Theta_t(i) D_f(H_t^G) \kappa K_t(i)^{\kappa-1} (Z_t L_t(i))^{1-\kappa} = R_t^k \tag{7}$$

$$(\delta m_t(i)) \quad \tau_t^E \xi_t = (1 - s_t^A) \theta_1 \theta_2 [m_t(i)]^{\theta_2 - 1} \quad \Longrightarrow m_t(i) = \left[\frac{\tau_t^E \xi_t}{(1 - s_t^A) \theta_1 \theta_2} \right]^{1/(\theta_2 - 1)} \tag{8}$$

where $\Theta_t(i)$ is the Lagrange multiplier associated to (2), corresponding to the marginal cost's component attached to labor and capital.[6] In the following, we drop the i index, since in equilibrium all firms are identical and perfectly competitive, thus, will make the same choice. The marginal cost of output is:

$$MC_t = \quad \Theta_t + (1 - s_t^A) \theta_1 m_t^{\theta_2} + \tau_t^E \xi_t (1 - m_t - m_t^g) \tag{9}$$

$$\text{where} \quad \Theta_t = \frac{(W_t)^{1-\kappa} \left(R_t^k\right)^\kappa}{D_f(H_t^G) Z_t^{(1-\kappa)} \kappa^\kappa (1-\kappa)^{(1-\kappa)}} \tag{10}$$

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[5] Equivalently to profit maximization, firms minimize total costs under the production function (2).

[6] From the two First-Order Conditions (FOCs) (6) and (7) we get that the capital-to-labor ratio, for all firms i, satisfies:

$$\frac{K_t(i)}{L_t(i)} = \frac{\kappa}{1-\kappa} \frac{W_t}{R_t^k}.$$

We define the mitigation process according to the following rule, in order to be consistent with the carbon budget (1):

$$m_t + m_t^g = \left(\frac{H_{t-1}}{\bar{E}_0^n}\right)^p \tag{11}$$

$$\frac{m_t^g}{m_t + m_t^g} = \theta \tag{12}$$

where $p > 0$ represents the curvature of the mitigation policy rule, and we assume the fraction θ, representing the share of government direct investment in total abatement efforts, to be constant, for the sake of simplicity. In Section 5, we will optimally determine this share through a welfare maximization exercise.

Households. The economy is inhabited by a representative, infinitely-lived household, who maximizes her intertemporal utility:

$$\mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \left(\ln C_{t+i} - \mu_L \frac{L_{t+i}^{1+\sigma_l}}{1+\sigma_l}\right), \quad \sigma_l > 0, \mu_L > 0.$$

Here, $\beta \in (0,1)$ is the discount factor, which is constant over time. C_t and L_t denote respectively the consumption of the final goods and the work hours supplied by the household. The disutility of labor is weighted by μ_L, while σ_l serves as the inverse of the Frisch elasticity of labor supply. Similarly to Corsetti et al. (2013), the household's budget constraint for each period is given by:

$$C_t + I_t + B_t = (1-\vartheta_t) R_{t-1}^d B_{t-1} + W_t L_t + \Pi_t + R_t^k K_t - T_t + V_t. \tag{13}$$

$B_t \equiv \frac{d_t Y_t}{R_t^d}$, as defined below, corresponds to the investment in government bonds made by the household. This corresponds to the amount of bonds $D_{t+1} \equiv d_t Y_t$ she bought, divided by the gross interest rate R_t^d, the government must pay on each bond to compensate the investor. Government debt is risky: ϑ_t represents the haircut, which is zero when the government fully honors its debt commitments, and $\vartheta_t = \vartheta \in [0,1)$, when the government partially defaults on debt, event which happens with probability PD_t. The latter represents the probability of default on currently outstanding debt $D_t \equiv R_{t-1}^d B_{t-1}$, to be repaid at t. Investors evaluate the probability of default according to the following condition:

$$b_M e^{\varepsilon_t} < b_t \quad \text{where} \quad \varepsilon_t \sim N(0, \sigma_B) \tag{14}$$

where b_M is the fiscal limit of our economy, in terms of maximum sustainable government borrowing-to-GDP ($b_t \equiv \frac{B_t}{Y_t}$). This fiscal limit is subjected to uncertainty, represented by the random log-normal shock e^{ε_t} with zero-mean and volatility σ_B. The probability of default writes then as a standard normal c.d.f.:

$$\mathsf{PD}_{t+1} = \Phi\left(\frac{\ln(b_t) - \ln(b_M)}{\sigma_B}\right), \tag{15}$$

similarly to Darracq Pariès, Jacquinot, and Papadopoulou (2016), Collard, Habib, and Rochet (2015) and Seghini (2023), with parameter σ_B and b_M. $V_t \equiv (1-f)\vartheta_t R^d_{t-1} B_{t-1}$ is a lump-sum transfer that, should a government default on its debt, partially reimburses bondholders for a fraction $1-f$ of the financial losses they sustain due to the default. The standard lump-sum taxes or transfers from the government are given by T_t, and dividends from owning firms that produce the final goods are Π_t. Labor income and rental income from capital services are represented by $W_t L_t$ and $R^k_t K_t$, respectively. In each period t, each member inherits K_{t-1} units of physical capital from the prior period, devalued by a depreciation rate δ, and makes investment decisions I_t. The capital accumulation equation is expressed as:

$$\begin{aligned} &K_t = (1-\delta)K_{t-1} + I_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right], \quad \delta \in (0,1). \\ &\text{where} \quad S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\iota}{2}\left(\frac{I_t}{I_{t-1}} - e^z\right)^2 \end{aligned} \tag{16}$$

where $S(\cdot)$ represents the investment adaptation cost function and e^z the steady-state growth rate of investment. The first-order conditions obtained from the household's maximization problem, are:[7]

$$(\delta C_t) \quad \frac{1}{C_t} = \lambda_t \tag{19}$$

$$(\delta L_t) \quad \mu_l L_t^{\sigma_l} = \lambda_t W_t \tag{20}$$

$$(\delta B_t) \quad \frac{\lambda_t}{\beta \mathbb{E}_t\left[\lambda_{t+1}\right]} = \mathbb{E}_t\left[(1 - f\vartheta_{t+1})R^d_t\right] \tag{21}$$

$$\begin{aligned} (\delta I_t) \quad \lambda_t &= \lambda^k_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \beta\mathbb{E}_t\left[\lambda^k_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right] \\ &= \lambda^k_t\left[1 - \frac{\iota}{2}\left(\frac{I_t}{I_{t-1}} - e^z\right)^2 - \iota\left(\frac{I_t}{I_{t-1}} - e^z\right)\frac{I_t}{I_{t-1}}\right] + \beta\mathbb{E}_t\left[\lambda^k_{t+1}\iota\left(\frac{I_{t+1}}{I_t} - e^z\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right] \end{aligned} \tag{22}$$

$$(\delta K_{t+1}) \quad \lambda^k_t = \beta\mathbb{E}_t\left[\lambda_{t+1} R^k_{t+1}\right] + \beta(1-\delta)\mathbb{E}_t\left[\lambda^k_{t+1}\right] \tag{23}$$

where λ_t and λ^k_t are the Lagrange multipliers assigned to the budget constraint and the capital accumulation constraint. Tobin's Q corresponds to $q^k_t = \lambda^k_t / \lambda_t$, and is equal to 1 when there are no

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[7] The Lagrangian function writes as:

$$\mathscr{L}_t = \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \Big\{ \ln C_{t+i} - \mu_L \frac{L_{t+i}^{1+\sigma_l}}{1+\sigma_l} + \lambda_{t+i} \left[\begin{array}{c} (1 - f\vartheta_{t+i}) R^d_{t+i-1} B_{t+i-1} + W_{t+i} L_{t+i} + \Pi_{t+i} + \\ + R^k_{t+i} K_{t+i} - T_{t+i} - I_{t+i} - C_{t+i} - B_{t+i} \end{array} \right] \tag{17}$$

$$+ \lambda^k_{t+i}\left[(1-\delta)K_{t+i} + I_{t+i}\left[1 - S\left(\frac{I_{t+i}}{I_{t+i-1}}\right)\right] - K_{t+i+1}\right]\Big\}. \tag{18}$$

investment adjustment costs ($\frac{I_t}{I_{t-1}} = e^z$).[8] Therefore, from the FOCs, we can derive the following equality between the stochastic discount factor –representing the risk-free interest rate– and the rental rate on capital:[9]

$$R_t \equiv \frac{\lambda_t}{\beta \mathbb{E}_t\left[\lambda_{t+1}\right]} = \beta^{-1}\frac{\mathbb{E}_t\left[C_{t+1}\right]}{C_t} = \frac{1}{q_t^k \mathbb{E}_t\left[\lambda_{t+1}\right]}\left\{\mathbb{E}_t\left[\lambda_{t+1}R_{t+1}^k\right] + (1-\delta)\mathbb{E}_t\left[\lambda_{t+1}q_{t+1}^k\right]\right\}. \tag{24}$$

Therefore, we can rewrite the FOC with respect to investment in government debt (21) as:

$$R_t = (1 - f\mathbb{E}_t\left[\vartheta_{t+1}\right])R_t^d = (1 - f\vartheta \mathsf{PD}_{t+1})R_t^d, \tag{25}$$

where the term between parentheses represents the wedge between the risk-free rate of the economy and the return on risky government bonds.[10]

Government budget constraint and the fiscal limit. The government levies the lump-sum tax T_t (which can also take the form of transfers) and the carbon tax τ_t^E on emissions, to finance the purchases of goods and services in quantity G_t, provide subsidies s^A to private abatement costs, and finance direct public mitigation efforts m^g. It issues bonds D_{t+1}, which pay a rate of return R_t^d to households (bondholders), in order to borrow B_t, and has to repay old debt D_t. In case of default, it also pays lump-sum transfers V_t to households for compensation and is forced to unexpectedly face additional public expenditure $G_t^d \equiv f\vartheta_t B_{t-1}R_{t-1}^d$, which corresponds to a proportion f of financial losses. G_t^d represents unexpected debt restructuring or reputational costs, which arise in case of default (Borensztein and Panizza, 2009).[11] For the sake of tractability, and in similar spirit to Corsetti et al. (2013), we assume that the combination of transfers and post-default government spending is set such that a sovereign default does not change the actual debt level. Consequently, ex post, regardless of whether a sovereign default has occurred, the sovereign risk premium remains unaffected. This setup prevents the counterintuitive scenario of lower risk premia before a default due to anticipations

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[8] Notice that the Lagrange multiplier on the household's budget constraint, λ_t, is equivalent to the marginal utility of consumption. The Lagrange multiplier on the capital accumulation equation, λ_t^k, represents the marginal product of capital. The marginal rate of substitution between consumption and hours worked at time t is:

$$\mathrm{MRS}_t \equiv -\frac{U_{l,t}}{U_{c,t}} = C_t \mu_l L_t^{\sigma_l} = W_t.$$

[9] In steady state, where there are no adjustment costs, this becomes:

$$R_* = R_*^k + 1 - \delta$$

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[10] The Consumption Euler Equation takes the usual form:

$$C_t = \frac{\mathbb{E}_t\left[C_{t+1}\right]}{\beta R_t}. \tag{26}$$

[11] Notice that when the debt-to-GDP level is below its fiscal limit, V_t and G_t^d will be null.

of a reduced debt stock post-default.[12] Thus, the government budget constraint can be written as:

$$B_t = (1-\vartheta_t)B_{t-1}R^d_{t-1} - S_t + V_t + G^d_t, \tag{27}$$

where we use $D_t \equiv d_{t-1}Y_{t-1} \equiv B_{t-1}R^d_{t-1}$ for the face value of debt to be repaid at t, which is decided in the previous period $t-1$. The consolidated government budget constraint is given by:

$$B_t = B_{t-1}R^d_{t-1} - S_t, \tag{28}$$

S_t denotes the "consolidated" total primary surplus (excluding default transfers and expenditure):

$$S_t = T_t + \tau^E_t E_t - G_t - s^A_t A_t - A^g_t = \{\tau_t + \tau^E_t \xi_t(1-m_t-m^g_t) - g - \theta_1 s^A_t m_t^{\theta_2} - \theta_3(m^g_t)^{\theta_4}\}Y_t \tag{29}$$

where g represents the exogenous public expenditure as a fraction to GDP, assumed constant, and $A^g_t = \theta_3(m^g_t)^{\theta_4}Y_t$ public abatement costs, which we assume to be less convex than private costs: $\theta_4 < \theta_2$.[13]

Since the return promised on government bonds R^d_t has to satisfy the FOC (25), total borrowing proceeds can be written as:

$$B_t \equiv b_t Y_t = \frac{D_{t+1}}{R^d_t} \equiv \frac{d_t Y_t}{R^d_t} = \frac{d_t Y_t}{R_t}(1 - f\vartheta \mathsf{PD}_{t+1}),$$

Therefore, we recover b_t from the government budget constraint as:

$$b_t = \frac{b_{t-1}Y_{t-1}R^d_{t-1} - S_t}{Y_t}, \tag{30}$$

and the face value of debt-to-GDP d_t implicitly from:

$$b_t = \frac{d_t}{R^d_t} = \frac{d_t}{R_t}(1 - f\vartheta \mathsf{PD}_{t+1}).$$

We add a debt stabilisation rule on the lump-sum tax rate τ_t, as in Corsetti et al. (2013) and Darracq Pariès, Jacquinot, and Papadopoulou (2016), adapted in order to take into account our transition

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[12] The same effect is ruled out in the model by Corsetti et al. (2013) with heterogeneous agents (savers and borrowers) and asymptotic risk sharing, and in Schabert and Wijnbergen (2014), through an offsetting lump-sum transfer that, in case of a sovereign default, compensates bondholders for losses associated with the default, even if not proportionally to the size of an individual's holdings of government debt.

[13] First, the public administration can implement bigger scale economies than in private firms. Secondly, the typical type of public green investment require greater initial investments and lower future operative costs, than in private mitigation efforts. This simple assumption on convexity aims to capture these observations. Further justification in the case of France is provided in the next section on calibration.

scenario from an initial brown to a final green steady state:

$$\tau_t = \tau(b_t, b_{t-1}, b_*, \tau_{t-1}, \tau_*, f, y_{0,f}). \tag{31}$$

where $y_{0,f}$ represents the initial steady-state for the detrended GDP, and f reflects our assumption in terms of the damage function for the particular scenario. $\tau(\cdot)$ will be a function which reacts to the deviation of b_t from its final steady state value b_*, and to its deviation from the previous period. This debt stabilisation rule will be further discussed in Section 3.

Resource constraints The market clearing condition for the final goods market is obtained integrating the household budget constraint, combined with the government constraint:

$$Y_t = C_t + I_t + G_t + G_t^d + A_t + A_t^g \tag{32}$$

3 Calibration

The calibrated parameters of our model are shown in Table 1. Our reference time frequency period is one quarter. The calibration for the traditional aspects of our real Neoclassical model follows the existing literature. For the transition set-up, global greenhouse gas cumulative emissions until 2023, H^G_{-1}, are estimated to have been around 3497 Gt in CO_2-equivalent.[14] The abatement cost function coefficients are calibrated to match a (detrended) long-term carbon tax for France of US$ 1000 per ton of CO_2, in the case of a transition to 1.5°C with 67% probability, achieved only through carbon pricing. This is in line with the evidence provided by D'Arcangelo et al. (2022) and Quinet et al. (2019).

We assume that abatement costs are relatively higher for the public sector than for the private sector. This translates into a lower degree of convexity, i.e. $\theta_4 < \theta_2$. This assumption is based on sectoral estimates of abatement costs, which show that sectors that typically require public investment (such as electricity and building renovation) are those with the highest costs (Criqui, 2023). For example, in the cement production sector in France, where large private companies operate, it is estimated that one-third of emissions could be reduced at low economic cost - between €0/t CO_2 and €40/t CO_2. On the other hand, the assessment of the cost of decarbonizing the electricity system, which must take into account not only the production costs of each type of power plant but also all the associated "system costs", puts the abatement cost at around €400/t CO_2. In France, as in most countries, this sector is dominated by the public sector, and the costs of maintaining and adapting the electricity system (about 15% of the decarbonization of electricity), which include the costs of modifying generation profiles, short-term balancing of supply and demand, and network reconfiguration, can only be borne

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[14] Data source: Greenhouse gas emissions, ourworldindata.org

by a public operator (RTE-Réseau de Transport d'Electricité, in the case of France). Similarly, in the residential sector, extending the renovation from 6 million to 12 million buildings would increase the abatement cost from about 150 to 400 €/t CO_2 (Criqui, 2023). The role of the public sector in supporting private efforts, but also in renovating public buildings and social housing, is therefore key. Its contribution is estimated at more than half in the case of France to reach net zero emission targets (Pisani-Ferry and Mahfouz, 2023).

The temperature objective at 1.5°C with 67% probability corresponds to a global carbon budget of 240 Gt CO_2 (IPCC (2023)). According to a fair per-capita criterion, this entails a national budget of 1.9, 1.7 and 2.4 Gt CO_2 for, respectively, France, Italy and Germany. The other country-specific parameters are calibrated to match national characteristics.[15]

Parameters		Value		Description
κ		0.33		Capital share of GDP
β		0.99		Discount factor
σ_l		1		Inverse of the Frisch elasticity of labor supply
μ_L		19.841		Disutility of labor
δ		0.025		Depreciation rate of capital
ι		15		Capital adjustment cost coefficient
σ_B		0.08		Parameter of the probability of default
ϑ		0.7		Haircut in case of public default
f		0.3		Post-default government expenditure as a fraction of lost value
$\phi_{\tau,*}$		0.25		Parameter of the stabilization function for $\phi_{\tau,t}$
$\phi_{\tau,y}$		0.9		Parameter of the stabilization function for $\phi_{\tau,t}$
ϕ_b		0.2		Parameter of the stabilization function
θ_1		0.023		Private abatement cost function coefficient
θ_2		1.8		Private abatement cost function convexity parameter
θ_3		0.023		Public abatement cost function coefficient
θ_4		1.044		Public abatement cost function convexity parameter
$\bar{E}_0^G$		240		IPCC global carbon budget 2024 in Gt CO_2-e, 1.5 degrees scenario at 67% probability
H_{-1}^G		3497		Cumulative GHG emissions in in Gt CO_2-equivalent until 2023
p		0.5		Mitigation function parameter
γ_0		1.3950e-3		Damage function parameter (Annicchiarico and Di Dio (2015))
γ_1		-6.6722e-6		Damage function parameter (Annicchiarico and Di Dio (2015))
γ_2		1.4647e-8		Damage function parameter (Annicchiarico and Di Dio (2015))
γ_3		0.02		Damage function parameter (Dietz and Venmans (2019))
γ_4		0.000749		Damage function parameter (Dietz and Venmans (2019))
	France	Italy	Germany	
$\bar{D}$	1	0.89	1.07	TFP in the steady state
z	0.5%	0.25%	0.5%	GDP growth rate
g	5.75%	4.75%	5%	Exogenous public expenditure as fraction of GDP
$d_0 = d_*$	1.1	1.4	0.6	Steady state debt-to-GDP
b_M	1.35	1.7	1.2	Fiscal limit
$\bar{E}_0^n$	1.9	1.7	2.4	Carbon budget 2024 (per capita basis) in Gt CO_2-e
ξ_0	0.17	0.19	0.27	GDP carbon intensity
ω	0.5%	0.25%	0.5%	Average degrowth rate (quarterly) in GDP carbon intensity 1990-2020

Table 1: Parametrization (quarterly)

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[15] We normalize the constant TFP for France to 1 and select the Italian and German parameters to reflect their respective total factor productivity ratios with respect to France (Bergeaud, Cette, and Lecat (2016)). The carbon intensity of GDP is taken from ourworldindata.org, the public expenditure ratio to GDP from data.worldbank.org.

We define the debt stabilization function (31) as:

$$\begin{aligned} \tau_t &= \phi_{\tau,t}[\tau_{t-1} + \phi_b(b_t - b_{t-1})] + (1-\phi_{\tau,t})[\tau_* + \phi_b(b_t - b_*)] \\ \text{where} \quad \phi_{\tau,t} &= \frac{1}{1+\phi_{\tau,*}\tau_*} + \mathbb{1}_{D_f(H_t^G)\neq\bar{D}}\phi_{\tau,y}(y_{0,\mathrm{NC}} - y_{0,n})(b_{t-1} - b_*), \end{aligned}$$

In the long-run this rule guarantees $\tau_t = \tau_*$, which is the lump-sum tax consistent with the final steady state value of borrowing-to-GDP b_*. The function's parametrization aims to capture the generally limited tax buoyancy in the short-term, highlighted by the empirical literature on tax responsiveness (e.g., recently Cornevin, Flores, and Angel (2023)). The parameter ϕ_b represents the response of τ_t to debt-to-GDP values; $\phi_{\tau,t}$ represents a smoothness weight on past values of taxes and indebtedness. The baseline value of this smoothness parameter is defined to be decreasing in the long-term lump-sum tax value τ_*: if higher public financing needs through taxes are planned in the long-run, taxation changes are less difficult. In the presence of climate damages, we allow $\phi_{\tau,t}$ to be time-varying, and reacting to the distance of the current debt level to its steady state, $(b_{t-1} - b_*)$. This creates additional difficulty in dealing with high debt in the presence of climate challenges.[16]

The parameters of the log-normal probability of default are determined in order to match government risk premia with current evidence. The national values for the fiscal limits are (conservatively) in line with the evidence provided by Collard, Habib, and Rochet (2015) and Seghini (2023). Despite the selection of a quite high haircut $\vartheta = 0.7$, this is balanced by the parameter f, representing the post-default government expenditure as a fraction of investors' lost value $\vartheta_t R^d_{t-1} B_{t-1}$. Therefore, we can interpret the product $f\vartheta = 0.21$ as a consolidated haircut, whose value is, in the end, reasonably conservative for advanced economies.

4 Results

We present first our benchmark results calibrated for France, assessing how sensitive they are to key parameters like public abatement costs or redistribution of carbon tax proceeds. Second, we include climate damages into the model to account for the potential impact of physical risks on public finances. Third, we differentiate our results according to the initial indebtedness situation by complementing the results calibrated on France with two alternative countries, a highly indebted country (Italy) and a low-debt country (Germany). Finally, we add financial spillovers to the model by linking the cost of private investment to the sovereign risk premium.

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[16] We calibrate the total weight on this time-varying term to be proportional to the distance in initial output from the output in the absence of climate damages $y_{0,\mathrm{NC}}$. We aim to capture, in this way, the difficulties of a poorer economy, because of climate change, to increase its taxation in response to higher debt ($\phi_{\tau,y} > 0$).

4.1 Benchmark results and sensitivity to key parameters

We use our model to analyse the impact on GDP and debt levels of three polar policies that would enable a successful transition, within the carbon budget:

(1) carbon tax (green line);

(2) direct public investment (red line);

(3) carbon tax with subsidies at 90% (blue line).

We ignore for now climate damages ($f =$ NC), to highlight the impact of transition policies only. Given our mitigation rule (11), the transition to net zero emission will be completed in around 35 years and all three scenarios satisfy the carbon emissions' path consistent with the imposed carbon budget. In Figure 11, we show the financial and macroeconomic implications of these policies. In scenario (1), the transition is implemented only through the carbon tax, which increase to around US$ 1000 per ton of CO_2. The carbon tax leads to a sharp temporary increase in annual carbon revenues (up to 5% of GDP) and allows a temporary reduction on the lump-sum tax imposed on households, thus partially substituting classical forms of taxation (see additional graphs in Appendix). On the macroeconomic side, when the transition only involves carbon taxation, the costs are the largest on GDP and consumption. We observe an important permanent and negative impact on GDP (-1%) and on consumption (-3.5%). There is also a some eviction effect on investment (i.e. investment excluding abatement-related efforts), which is decreased by around 3.5%. On the contrary, the effect on public finances is positive, as public debt-to-GDP is reduced by 6 percentage points. As a result, the 1-year interest rate of public debt declines and the annual probability of sovereign default is temporary lower and almost null, as shown in Figure 3. The figures also includes a variant of this carbon tax scenario, investigating the effects of some recycling of the tax proceeds through higher government expenditures. The macroeconomic effects are hardly changed, with only a slightly less negative impact on GDP. The public finances are however affected as the reduction in public debt is halved, limiting the decline in interest rates on public bond and the sovereign default probability. By contrast, in scenario (2), when the mitigation effort is made only through public investment ($\theta \approx 1$ in scenario (2)), the impact on GDP is positive, at the expenses of an increase in public debt-to-GDP, and its probability of default. Owing to accelerator effects, private investment - excluding abatement-related capital - also benefit from higher GDP. However, we notice some eviction effect as far as consumption is concerned, primarily explained by the need for higher investment levels. In this second scenario, the main result concerns the impact on public finances. Public debt-to-GDP increases by 7 percentage points and, consequently, the annual probability of default on public debt rises to 10%. The interest rate on sovereign bonds also increases by around 60 basis points. The large impact on public debt and the threat to debt sustainability is partly explained by the assumption that abatement costs are higher in the beginning of the transition for the public sector compared to private effort. This is due to a lower convexity of mitigation costs for the public sector, which implies higher total costs, given a certain abatement effort $m \in [0,1]$.

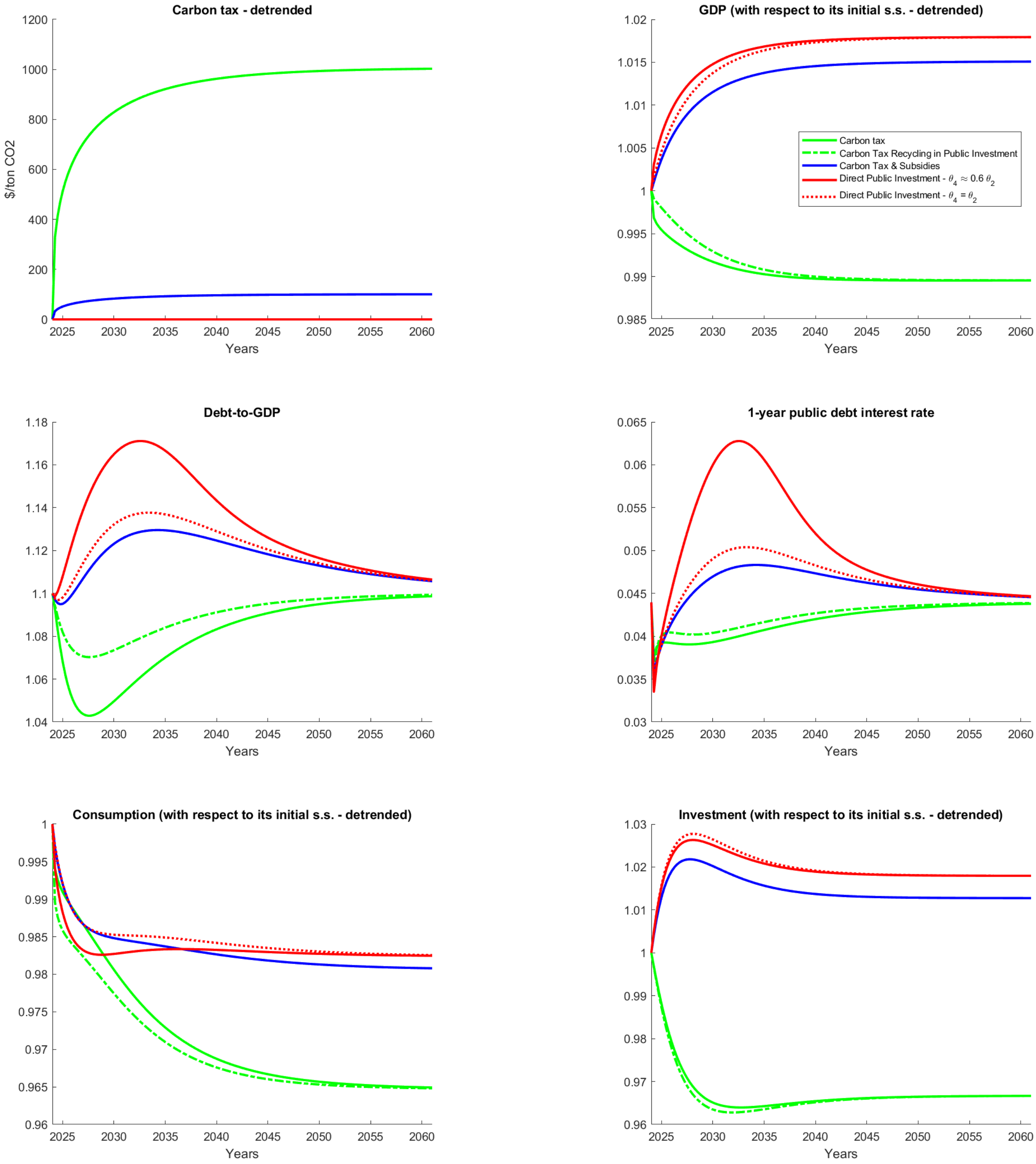

Figure 2: The financial and macro-economic impact of 3 transition scenarios: (1) carbon tax (green lines); (2) direct public investment (red lines); (3) carbon tax with subsidies at 90% (blue line).

However, to gauge the sensitivity of our results to this assumption, we simulate the model with two alternative abatement costs for the public sector, the benchmark being labelled "high public abatement costs" and the alternative "medium/low public abatement costs". This variant does not change the

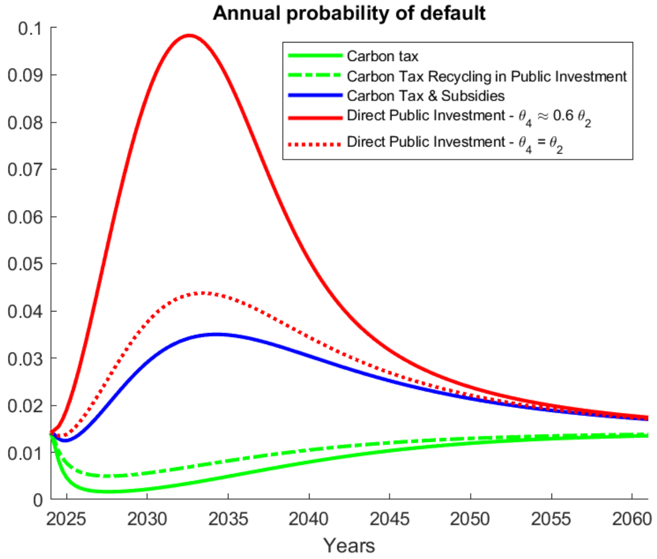

Figure 3: Annual probability of default. (1) carbon tax (green lines); (2) direct public investment (red lines); (3) carbon tax with subsidies at 90% (blue line).

main results but reduces somehow the size of the impacts. This is particularly the case on the public debt-to-GDP level, although it remains higher than the starting point by 4 percentage points (from 7 in the benchmark scenario). In this more favorable variant, the probability of sovereign default still increases, reaching 4% by 2035.

Finally, scenario (3), where carbon taxes are combined with public subsidies for private-sector reduction efforts, provides intermediate results. The impact on GDP is positive, albeit to a lesser extent than in the previous scenario, and the increase in public debt relative to GDP is also lower (2 percentage points of GDP). The negative impact on consumption is very similar to scenario (2), which shows that a combination of a small increase in carbon tax (around \$100 per ton of CO_2) and subsidies to the private sector limit the negative impact on households while minimizing the pressure on the public finance sustainability. Indeed, in this scenario, the increase in sovereign interest rates is limited to 50 basis points and the probability of default only increases to 3%.

4.2 Adding climate damages to the model

The physical consequences of climate change could also put pressures on public finances by reducing economic growth, making therefore public debt unsustainable. To assess such effects, we include in the model damage functions. To gauge how sensitive our results could be to the type of damage functions, we run our simulations with two specifications, one from Annicchiarico and Di Dio (2015) and one from Dietz and Venmans (2019). Figure 4 shows how our benchmark results are affected by adding climate damages to the model. In all scenarios, the real effects are more negative (see Figure 4), with lower GDP, consumption and investment. For instance, in the carbon tax scenarios (scenario (1)), the decline in GDP goes from -1% in the benchmark results to -2% with the damage function by

Dietz and Venmans (2019) and -5% with the function proposed by Annicchiarico and Di Dio (2015). Similarly, the positive impacts on GDP of the two other scenarios are lower or even turn negative with the second damage function.

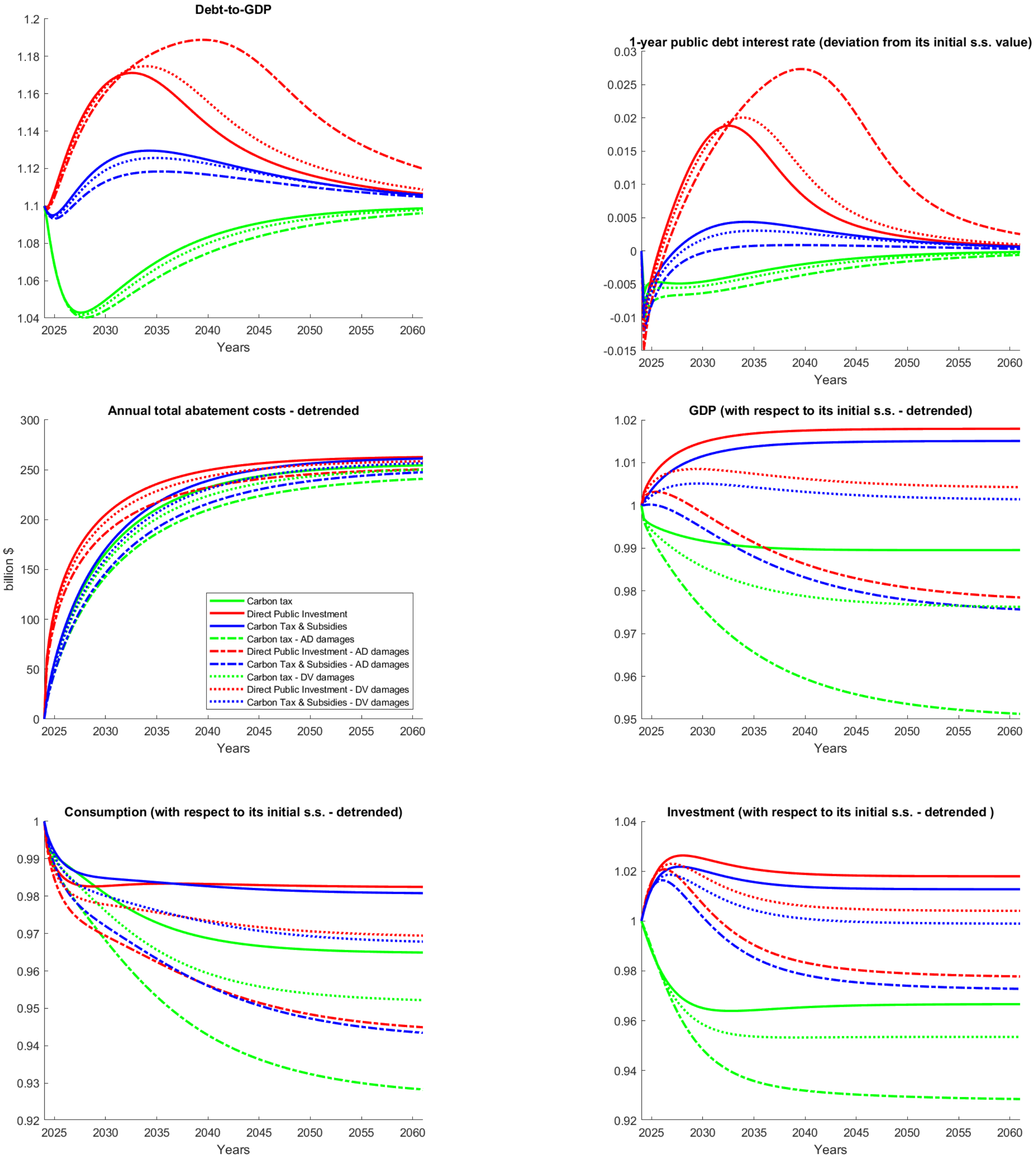

Figure 4: The impact on fiscal and macroeconomic variables of climate change according to two alternative damage functions in 3 carbon budget-consistent scenarios: (1) carbon tax (green line); (2) direct public investment (red line); (3) carbon tax with subsidies at 90% (blue line).

Interestingly, the impact on public finances is broadly unchanged in the case of scenarios (1) and (3), but are more adverse in the case of the public investment scenario (scenario (2)). In particular, using the Annicchiarico and Di Dio (2015)'s damage function, the maximum impact on debt-to-GDP ratio increases from 117% to close to 120%, although the further increase arises 10 years later. This leads as a result to higher probability of default (peaking at 15% in 2040) and higher interest rates (up to 300 basis points in 2040 compared to the initial steady-state value, i.e. almost 100 basis points more from its maximum without considering damages).

4.3 Debt-to-GDP levels and the transition

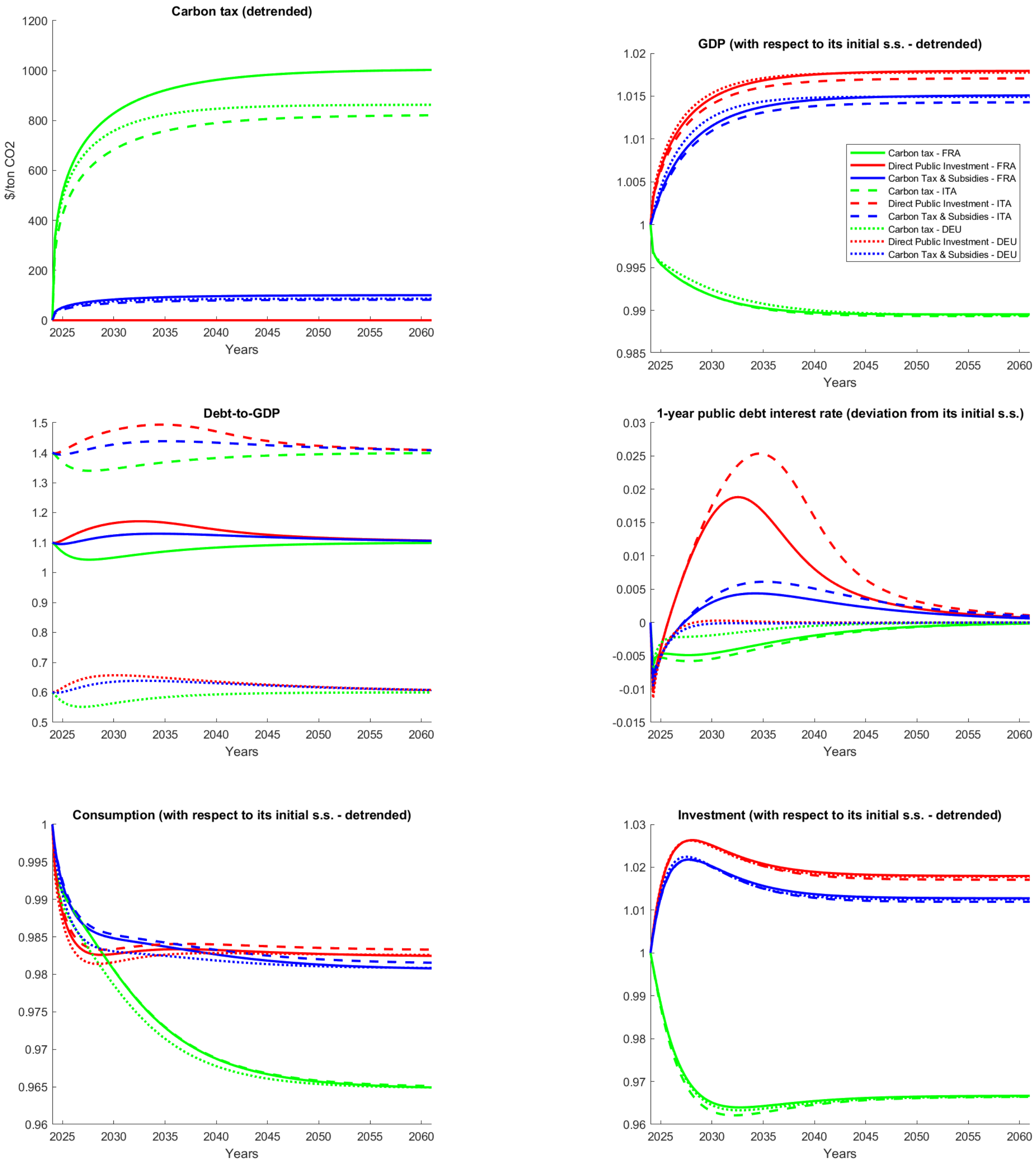

Figure 5: The role of initial debt levels. Macroeconomic and fiscal developments in Italy, France and Germany for 3 carbon budget- consistent scenarios: (1) carbon tax (green line); (2) direct public investment (red line); (3) carbon tax with subsidies at 90% (blue line).1

The next exercise involves examining the initial debt situation to differentiate the impact of transition policies on public finances according to whether the country is low or high debt. Zenios (2022) underlines that the high indebtedness of a country (Italy in his study) can be even more problematic in terms of public finance sustainability when the government tackles climate change issues. To do this, we run the previous simulations with calibrations applied to high-debt and low-debt countries, Italy and Germany respectively. First of all, it should be noted that the impacts on real GDP, consumption and investment are broadly similar, despite different levels of carbon tax (in scenario (1)) and public abatement expenditures (in scenarios (2) and (3)). These differences can be explained by different carbon budgets and carbon intensities. However, the initial public debt situation has an impact on the future of public finances, and the lower the public debt, the less detrimental it is for debt sustainability. While the favorable scenario for public finances (scenario (1) with carbon tax only) leads to a similar drop in the probability of default for all countries (see Appendix D), the trajectory of scenario (2), i.e. with direct public investment, is particularly unfavorable for highly indebted countries, with in our case a further increase from 10% in our benchmark economy (France) to 14% in the case of Italy. The increase in Italian sovereign bond interest rates from current level is close to 250 basis points compared to less than 200 basis points in the case of France and almost no change in the case of Germany. These results show therefore the sensitivity of interest rates on public debt to the initial conditions. A highly indebted country will experience tensions on the sovereign debt market, paying large risk premia when the transition policy implies, as in scenario (2), a further increase in public debt.

4.4 Financial spillovers of high debt

Our final sensitivity analysis concerns the possible financial impact of higher government debt on private sector financing conditions. To do this, we create a link between the interest rate on government bonds, which is influenced by debt sustainability issues, and the cost of capital for the private sector. By following Burriel et al. (2020), we therefore modify equation (24) as follows:

$$R_t = \frac{1}{q_t^k \mathbb{E}_t\left[\lambda_{t+1}\right]} \left\{ \mathbb{E}_t\left[\lambda_{t+1} R_{t+1}^k\right] + (1-\delta)\mathbb{E}_t\left[\lambda_{t+1} q_{t+1}^k (1-\omega_q f \vartheta_t \mathsf{PD}_{t+1})\right] \right\}, \tag{33}$$

where we calibrate $\omega_q = 0.5$. Figure 6 depicts the spillover mechanism. To study the case where interest rates are the most sensitive to the initial debt situation, we assess such financial spillovers in the case of Italy. Most of the effects are visible on the macroeconomic variables. The increase in the rental rate of capital coming from the transmission of debt sustainability issues on financial markets is around 60 basis points in the direct public investment scenario (scenario (2)). The tightening of financing conditions for the private sector leads to negative effects on investment and consumption that are amplified by the contraction in demand. Overall, GDP contracts by almost 1.5% in 2032,

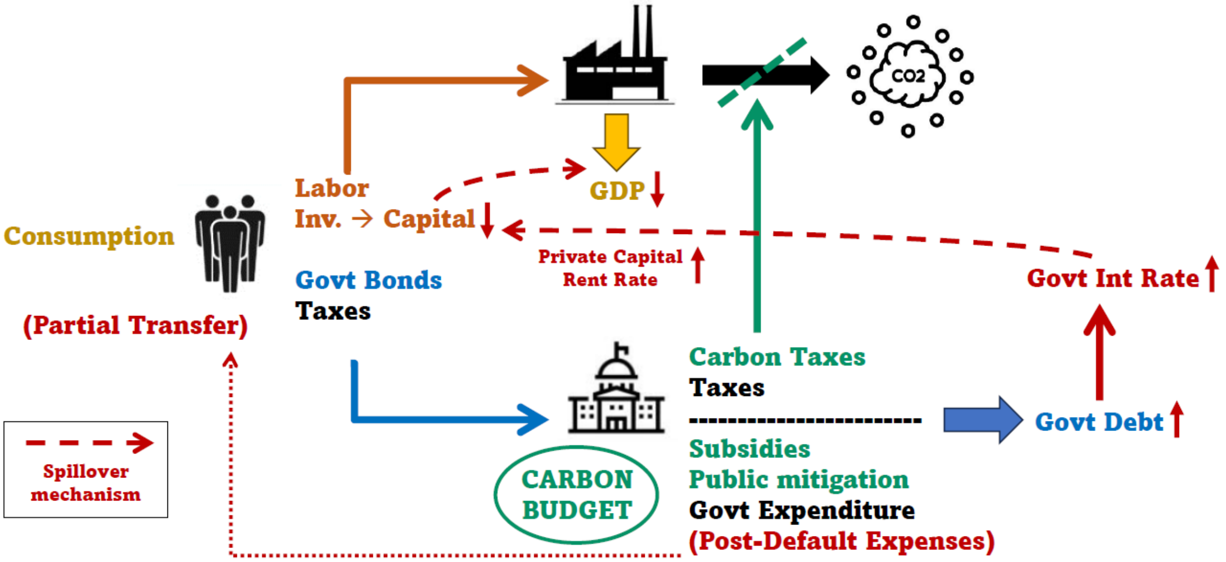

Figure 6: The financial impact of higher government debt on private sector financing conditions. Variables between parentheses are not null only in case of default on government debt.

while it increases when neglecting such financial spillovers (by 1.5%). Consumption reaches a low of -3% by 2040 while investment dynamics is quicker and more adverse with a decline by -9% in 2030. The deterioration in economic conditions also affects public finances. Although the maximum increase in debt and the probability of default are broadly similar whether or not spillover effects are taken into account, amplification by the private sector plays more a role in the dynamics, as these increases occur earlier and faster if spillover effects are taken into account. The impact of financial spillovers in the other two scenarios is more benign, although the positive effect on GDP of subsidies (scenario (3)) is much lower and the demand component dynamics are worse, including a temporary decline in investment and lower consumption. By contrast, the financial spillovers absorb part of the negative effect of carbon taxation on the macroeconomy. Due to a greater drop in the cost of capital, the decline in investment and consumption is more moderate. The overall effect on GDP is also less negative during the transition. For example, in 2035, GDP falls by around 0.5%, whereas it falls almost twice as much in the absence of spillover effects.

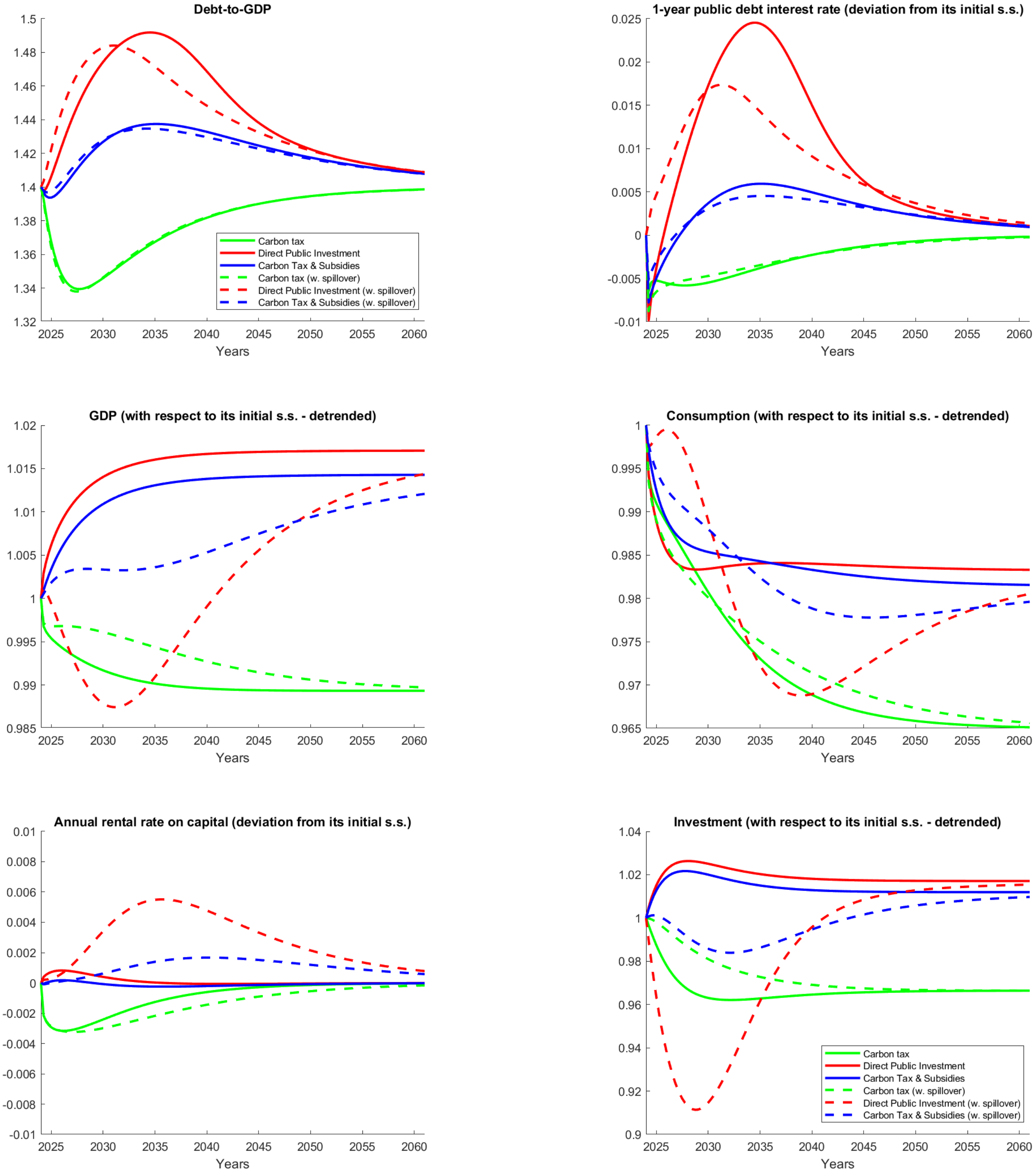

Figure 7: Spillover of high public risk to the the private sector. Fiscal and macroeconomic developments in Italy for 3 carbon budget-consistent scenarios: (1) carbon tax (green line); (2) direct public investment (red line); (3) carbon tax with subsidies at 90% (blue line).

5 Welfare maximization and the optimal public abatement

To complete our analysis, we propose to define the optimal share of public abatement in a welfare maximization exercise. The previous results show that there is a trade-off for the policymaker between placing the cost of transition on the private sector, with the risk of undermining the country's economic performance, and bearing part of these costs through public spending, with the risk of making public debt unsustainable. Here, we propose to define optimally the degree of intervention of the government in order to maximize the welfare of the citizens.

We define the social planner's problem as the committed choice of the share of government direct investment in total abatement efforts, θ_t, in order to maximize welfare, defined as the present discounted value of utility:

$$\max_{\theta_t} V_t = \left(\ln C_t - \mu_L \frac{L_t^{1+\sigma_l}}{1+\sigma_l} \right) + \beta \mathbb{E}_t V_{t+1}, \tag{34}$$

subject to all the equations describing the competitive equilibrium.

We start by defining the optimal share of public abatement by ignoring the possibility for the government to subsidize the private effort. We also neglect spillover effects through financing costs in a first exercise.

The results in Figure 8 show that to keep public debt on a sustainable path, the effort should be borne by the private sector at the beginning of the transition, implying a sharp increase in the carbon tax. This triggers some economic costs with a decline of about 0.4% of GDP. This immediate involvement of the private sector is related to the fact that, at the beginning of the transition, when the effort to decarbonize is still minimal, abatement costs are lower for the private sector.[17] As the transition path progresses, the abatement effort increases and becomes more costly, even more so for the private sector. To limit these costs and their impact on welfare, the government should increase gradually its contribution. This intervention through public investment limits the cost in terms of GDP, which even benefits from public investment from 2030-35, and stabilizes the decline in consumption at around 2%. The optimal share of public mitigation is around 40% at its highest, from 2040 onwards. By relying initially more on the private sector, public debt can be stabilized and the pressure on interest rates on government bonds remains limited.

The long-term equilibrium share of public mitigation, in line with the evaluation proposed by Pisani-Ferry and Mahfouz (2023) in the case of France, depends on public finance conditions and relative mitigation costs. In Appendix F, we provide some sensitivity of this optimal share to different relative abatement costs between the public and private sectors and to the share of public spending in GDP. The results show that changing the convexity parameter of mitigation costs (θ_4) changes both the steady state of the optimal public share of abatement and its transition path. When the parameter is assumed to be the same for both sectors (while it is lower by 40% in our benchmark results), the optimal public share of abatement rises immediately to 45%, while it rises more gradually to 40% in our benchmark results. Regarding the share of public expenditure in GDP, the higher the level of government consumption, the lower the optimal public share of abatement in the steady state (from 45% with public expenditure at 10% of annual GDP to 35% when it is at 45%). These results show

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[17] Recall that the private abatement cost curve is more convex than the public curve.

that for countries with high levels of public consumption, the remaining fiscal space is more limited to take on a larger share of mitigation efforts.

In terms of cross-country differences, we find very little variation in the optimal share of public abatement between France, Germany, and Italy. The fact that France already has a favorable energy mix implies a later involvement of the public sector, but a higher level of carbon tax to incentivize the private sector to decarbonize even more. Italy's high initial public debt does not prevent the government from investing public funds in the transition, but it does lead to higher interest rates on government bonds to keep the debt under control. In all countries, the cost in terms of lost consumption is relatively similar (around -2%) and relatively contained compared to previous scenarios involving only the private sector, while remaining broadly in line with the loss that occurs when only the public sector bears the cost of the transition.

The last exercise considers the possibility for the government to subsidize private abatement efforts and includes spillovers from higher public debt costs to economy-wide financing conditions. Figure 9 presents results in the case of France under various degrees of subsidies. Figure 18 compares the role of spillovers in the case of Italy. A number of interesting results emerge. First, the inclusion of subsidies in the policy mix increases the optimal share of public abatement and implies more positive effects on GDP. Second, the higher involvement of the public sector puts pressure on debt sustainability and, therefore, the economic costs become larger when financial spillovers are taken into account. Overall, this welfare-maximizing exercise shows that to be optimal, the abatement effort can be shared equally by the public and private sectors, thereby limiting the welfare costs while keeping public debt in check.

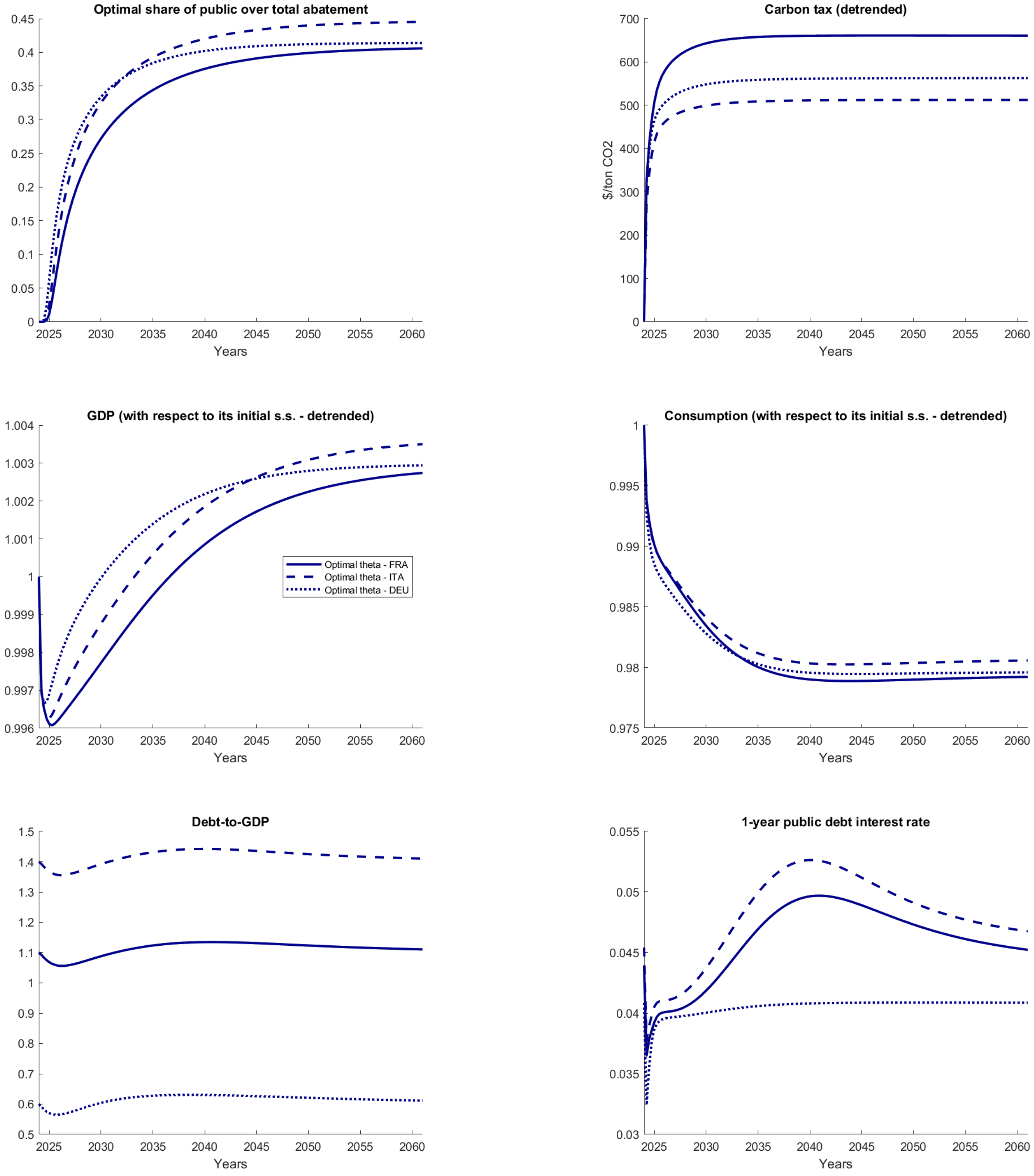

Figure 8: Optimal public over total abatement. Fiscal and macroeconomic developments in France, Germany and Italy, under zero subsidies and no spillover.

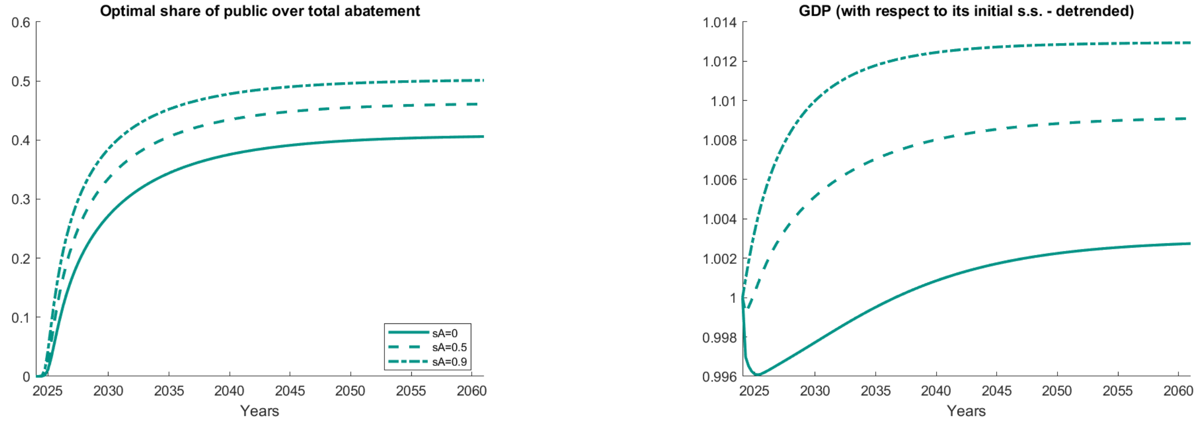

Figure 9: Optimal public over total abatement and economic output in France, under various degrees of subsidies.

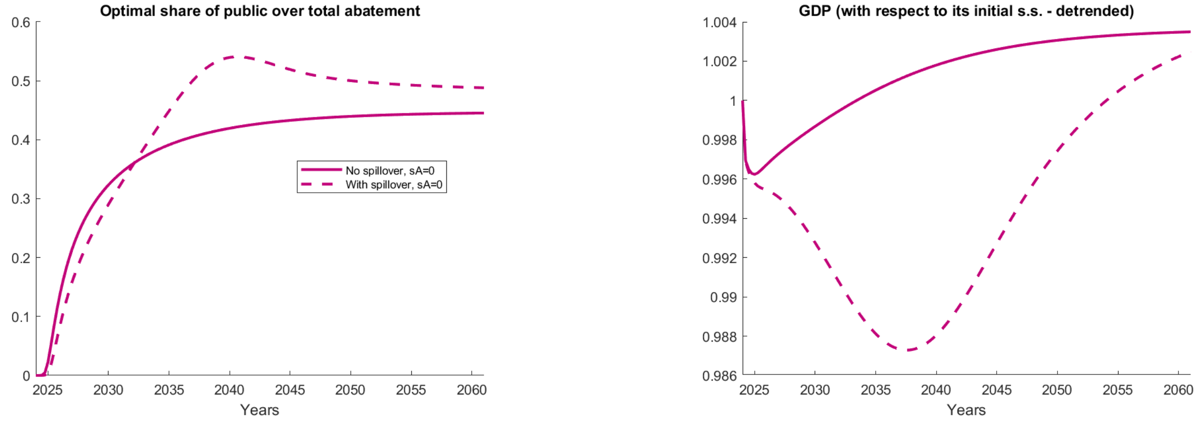

Figure 10: Optimal public over total abatement and economic output in Italy, without and with spillover.

6 Conclusions

In conclusion, this paper sheds light on the intricate dynamics between the imperative of the green transition, the delicate balance of public finances, and the potential macroeconomic ramifications. Based on a Neo-classical model including the environmental component and risky government debt, our findings underscore a critical paradox: while transition policies are pivotal for steering economies towards a low-carbon future, those entailing an increase in public debt pose important challenges. The risk of making public debt unsustainable or precipitating higher financing costs is significant, hampering the very transition they aim to facilitate. Moreover, the incorporation of climate-related damages into our model worsens the situation, nullifying the positive macroeconomic effects that public expenditure-driven policies might otherwise have on aggregate demand.

In addition, the paper highlights the key role of initial debt conditions, explaining that highly indebted countries are the most likely to suffer the negative repercussions of transition policies on public finances. This vulnerability amplifies the urgency of adopting prudent fiscal strategies to effectively manage the transition. Finally, taking into account the spillover of increased public debt riskiness on private financing conditions reveals a more worrying macroeconomic impact, accentuating the importance of financial interactions.

Strategies based on carbon taxation, on the other hand, are costly for the macroeconomy, particularly for households who reduce their spending to finance transition costs and limit pressure on public finances. However, intermediate strategies, such as recycling carbon tax revenues by increasing public spending, or carbon pricing policies combined with public subsidies for private-sector abatement efforts, have more neutral effects on macroeconomic variables, while making public debt more sustainable. Our welfare-maximizing exercise supports indeed a balanced approach, where the share of the mitigation effort undertaken by the public sector ranges from 25% to 40% between 2030 and 2050.

Our analysis relies on a debt stabilization rule that prevents public debt from being unsustainable in the long term. This rule uses lump-sum taxes as a way to stabilize public debt. A more complex model could account for diverse tax sources and include distortionary taxes, like income tax, capital tax or VAT, that could potentially modify the optimal policy mix. For instance, Barrage (2020) shows that optimal carbon tax schedules are 8–24% lower when there are distortionary taxes, compared to the setting with lump-sum taxes considered in the literature and in this paper. Another possible extension could consider the role of frictions in market adjustments, leading climate policies to impact price dynamics. In such a framework, it would be interesting to study how monetary policy could interact with fiscal policy in the macroeconomic dynamics of the green transition. Finally, the aim of our paper is to describe illustrative and normative scenarios, rather than empirical and positive ones. However, a more complex approach could also consider the role of the rest of the world in a small open economy setting, taking into account the role of divergent mitigation strategies across countries. In the European context, it would also be particularly important to consider the interaction between European and national policies when designing optimal decarbonization strategies for governments. Such extensions are however left for future research.

In light of the findings of this paper, policymakers are urged to exercise prudence in designing transition policies, recognizing that their fiscal implications extend far beyond the immediate macroeconomic effects. A balanced approach that safeguards public finances, recognizes initial debt conditions and anticipates spillovers is essential to ensure the effectiveness and sustainability of the green transition. The imperative of a low-carbon future should not blind us to the complex fiscal landscape that surrounds it, as a misstep in this area could undermine the very goals we seek to achieve.

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Appendix

A Summary of equilibrium equations

Lower case letters denote detrended variables, starred variables denote steady-state values.[18]

$$c_t = \frac{\mathbb{E}_t\left[c_{t+1}\right]}{\bar{\beta} R_t}$$

$$w_t = c_t \mu_l L_t^{\sigma_l}$$

$$1 = q_t^k \left[1 - \frac{\iota}{2}\left(\frac{i_t e^z}{i_{t-1}} - e^z\right)^2 - \iota\left(\frac{i_t e^z}{i_{t-1}} - e^z\right)\frac{i_t e^z}{i_{t-1}}\right] + \frac{\bar{\beta}}{\lambda_t^z}\mathbb{E}_t\left[\lambda_{t+1}^z q_{t+1}^k \iota\left(\frac{i_{t+1} e^z}{i_t} - e^z\right)\left(\frac{i_{t+1} e^z}{i_t}\right)^2\right]$$

$$R_t \equiv \frac{\lambda_t^z}{\bar{\beta}\mathbb{E}_t\left[\lambda_{t+1}^z\right]} = \frac{1}{q_t^k \mathbb{E}_t\left[\lambda_{t+1}^z\right]}\left\{\mathbb{E}_t\left[\lambda_{t+1}^z R_{t+1}^k\right] + (1-\delta)\mathbb{E}_t\left[\lambda_{t+1}^z q_{t+1}^k\right]\right\}$$

$$k_t = \frac{(1-\delta)}{e^z} k_{t-1} + i_t\left[1 - \frac{\iota}{2}\left(\frac{i_t e^z}{i_{t-1}} - e^z\right)^2\right]$$

$$y_t = D_f(H_t^G) k_t^\kappa L_t^{1-\kappa}$$

$$R_t^k = \frac{\kappa}{1-\kappa}\frac{L_t}{k_t} w_t$$

$$1 = \frac{{w_t}^{1-\kappa} {R_t^k}^\kappa}{D_f(h_t^G)\kappa^\kappa(1-\kappa)^{(1-\kappa)}} + (1 - s_t^A)\theta_1 m_t^{\theta_2} + \xi_0 P_t^E (1 - m_t)$$

$$m_t = \left[\frac{\xi_0 P_t^E}{(1 - s_t^A)\theta_1\theta_2}\right]^{1/(\theta_2 - 1)}$$

$$y_t = c_t + i_t + g y_t + f\vartheta_t b_{t-1} y_{t-1} e^{-z} R_{t-1}^d + \theta_1 m_t^{\theta_2} y_t + \theta_3 (m_t^g)^{\theta_4} y_t$$

$$e_t = \xi_0 (1 - m_t) y_t$$

$$h_t^G = h_{t-1}^G + \frac{\bar{E}_0^G}{\bar{E}_0^n} e_t$$

$$D_{\mathrm{DV}}(h_t^G) = \bar{D}\exp\left\{-\frac{\gamma_3}{2}\left[\gamma_4 h_t^G\right]^2\right\}, \quad D_{\mathrm{AD}}(h_t^G) = \bar{D}(1 - \gamma_0 - \gamma_1 h_t^G - \gamma_2 h_t^{G^2}), \quad D_{\mathrm{NC}}(h_t^G) = \bar{D}$$

$$b_t = \frac{b_{t-1} R_{t-1}^d y_{t-1}}{y_t e^z} - [\tau_t + \xi_0 P_t^E (1 - m_t) - g - s_t^A \theta_1 m_t^{\theta_2} - \theta_3 (m_t^g)^{\theta_4}]$$

$$\tau_t = \phi_{\tau,t}[\tau_{t-1} + \phi_b(b_t - b_{t-1})] + (1 - \phi_{\tau,t})[\tau_* + \phi_b(b_t - b_*)]$$

$$\phi_{\tau,t} = \frac{1}{1 + \phi_{\tau,*}\tau_*} + \mathbb{1}_{D_f(H_t^G) \neq \bar{D}} \phi_{\tau,y}(y_{0,\mathrm{fr}} - y_{0,n})(b_{t-1} - b_*)$$

$$b_t = \frac{d_t}{R_t}[1 - f\vartheta \mathsf{PD}_{t+1}]$$

$$\sum_{t=0}^{+\infty} e_t = \bar{E}_0^n \Longrightarrow m_t + m_t^g = \left(\frac{h_{t-1}}{\bar{E}_0^n}\right)^p; \quad m_t^g = \theta(m_t + m_t^g)$$

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[18] The rules of rescaling are:

$$x_t \equiv \frac{X_t}{e^{zt}} \quad \text{for } X = \{C, Y, \Pi, K, I, W, A, S, V\}, \quad b_t^z \equiv \frac{B_t}{e^{zt}} = b_t y_t, \quad \lambda_t^Z \equiv \lambda_t e^{zt},$$

$$P_t^E \equiv \tau_t^E e^{-\omega t}, \quad e_t \equiv \frac{E_t}{e^{(z-\omega)t}}, \quad h_t^G \equiv \frac{H_t^G}{e^{(z-\omega)t}}, \quad \bar{\beta} \equiv \frac{\beta}{e^z}$$

B Additional results - Benchmark

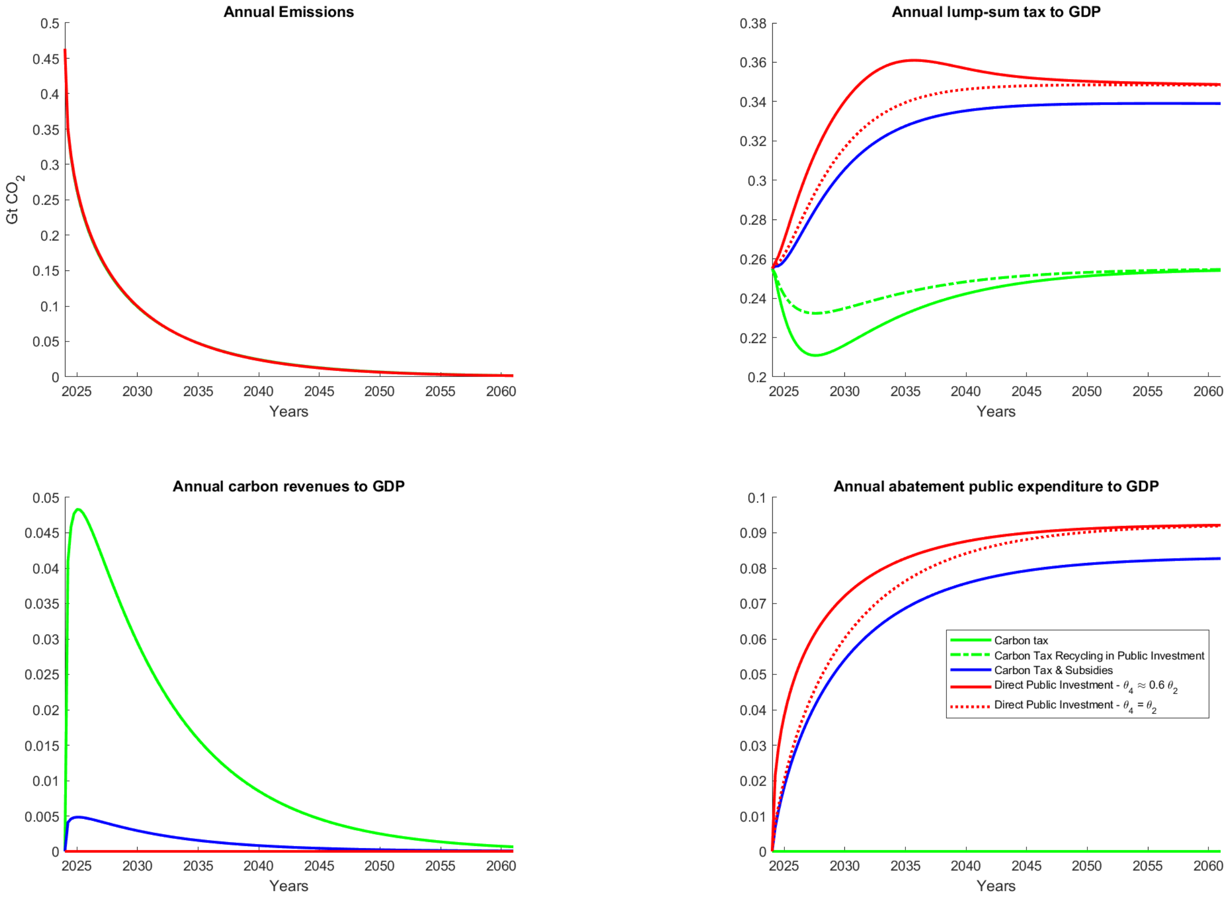

Figure 11: Carbon emissions' path respecting the carbon budget, and the fiscal impact of 3 path-consistent scenarios: (1) carbon tax (green lines); (2) direct public investment (red lines); (3) carbon tax with subsidies at 90% (blue line).

C Additional results - Adding climate damages

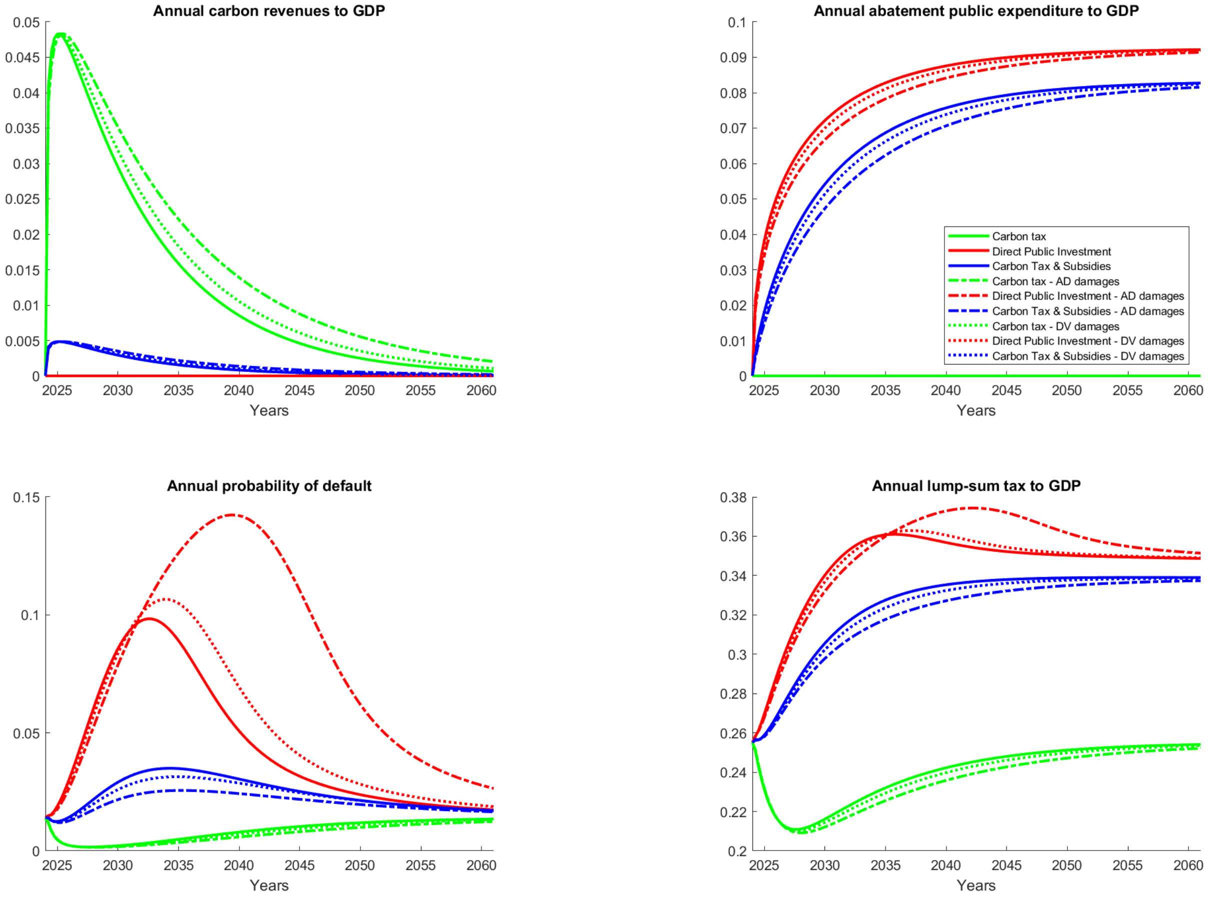

Figure 12: The impact on fiscal variables of climate change according to two alternative damage functions in 3 carbon budget-consistent scenarios: (1) carbon tax (green line); (2) direct public investment (red line); (3) carbon tax with subsidies at 90% (blue line).

D Additional results - Cross-country differences

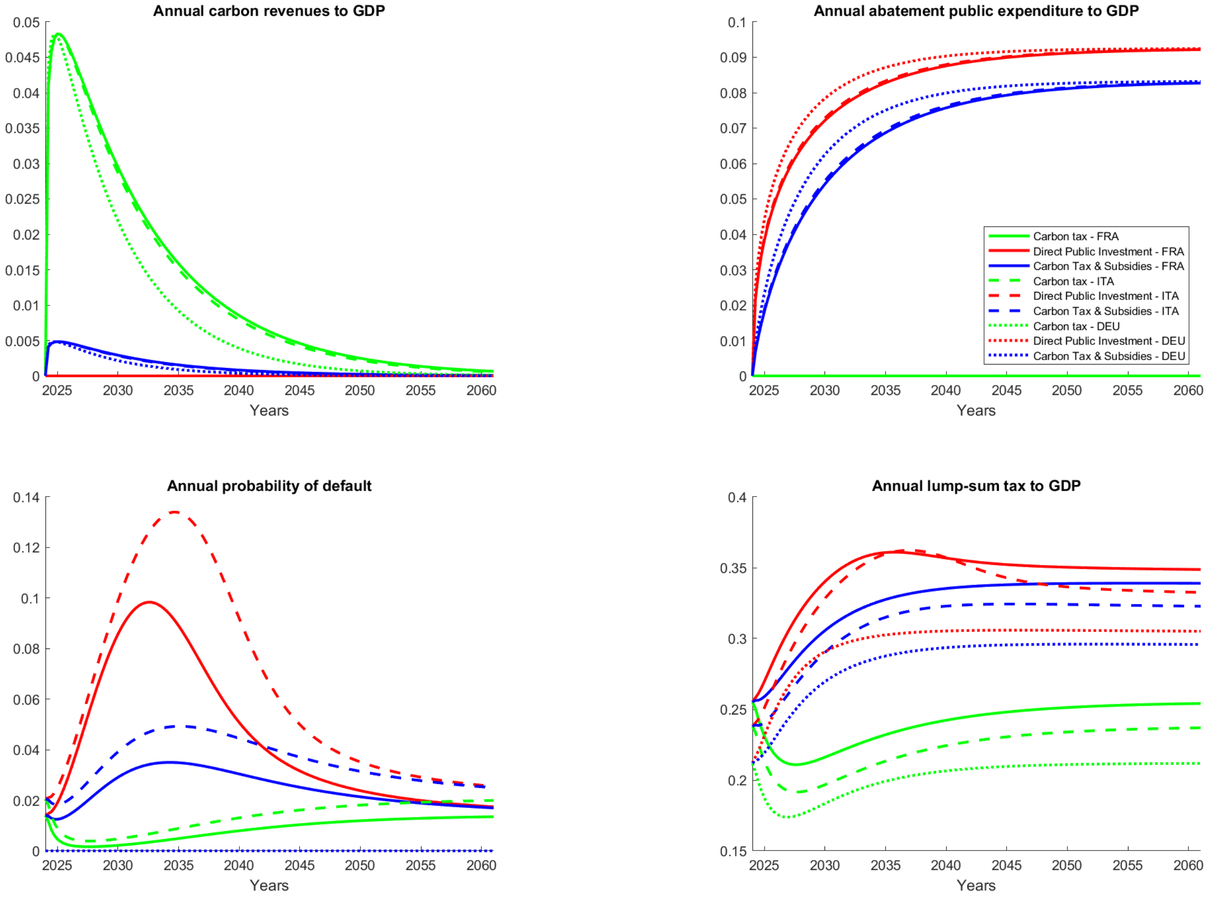

Figure 13: The role of initial debt levels. Fiscal developments in Italy, France and Germany for 3 carbon budget- consistent scenarios: (1) carbon tax (green line); (2) direct public investment (red line); (3) carbon tax with subsidies at 90% (blue line).

E Additional results - Financial spillovers

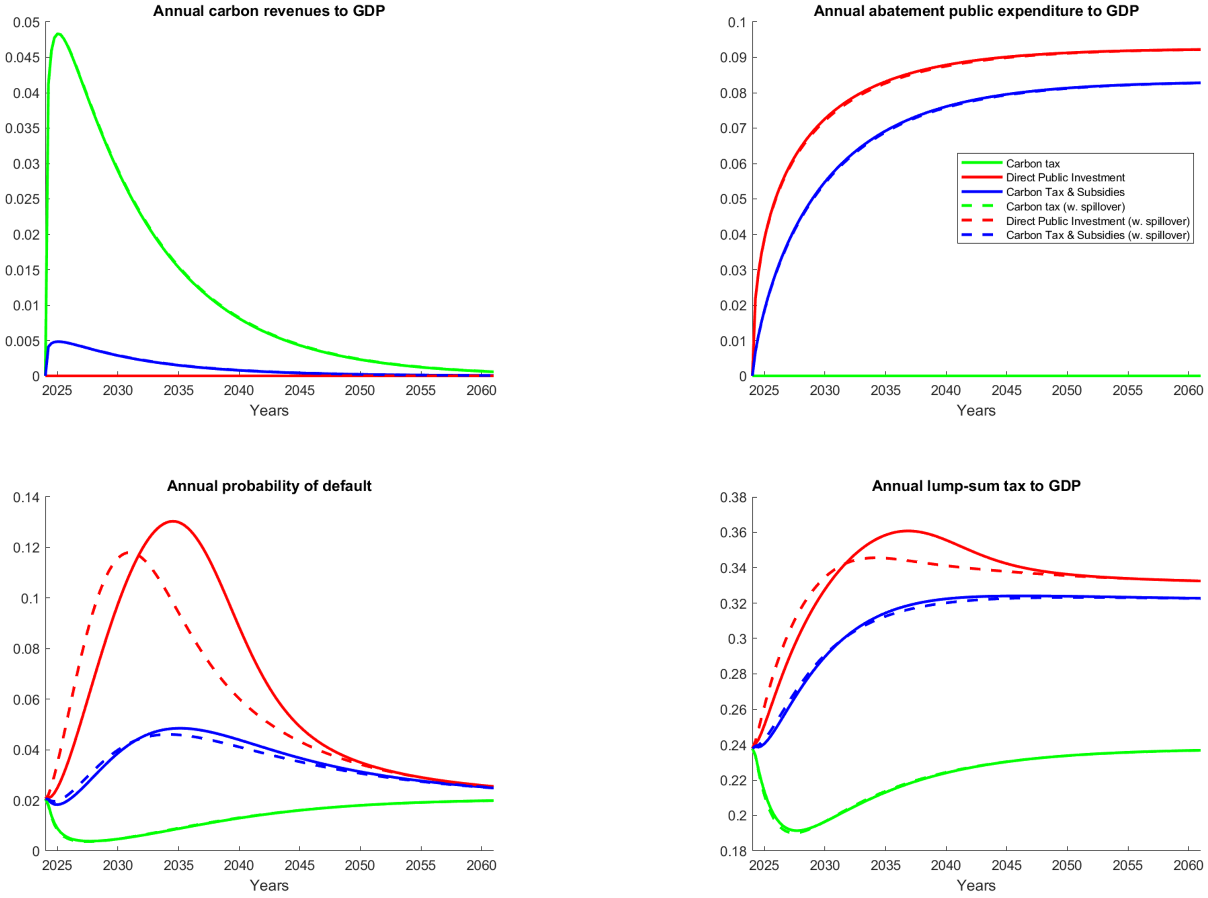

Figure 14: Spillover of high public risk to the the private sector. Fiscal and macroeconomic developments in Italy for 3 carbon budget-consistent scenarios: (1) carbon tax (green line); (2) direct public investment (red line); (3) carbon tax with subsidies at 90% (blue line).

F Additional results - Welfare maximization

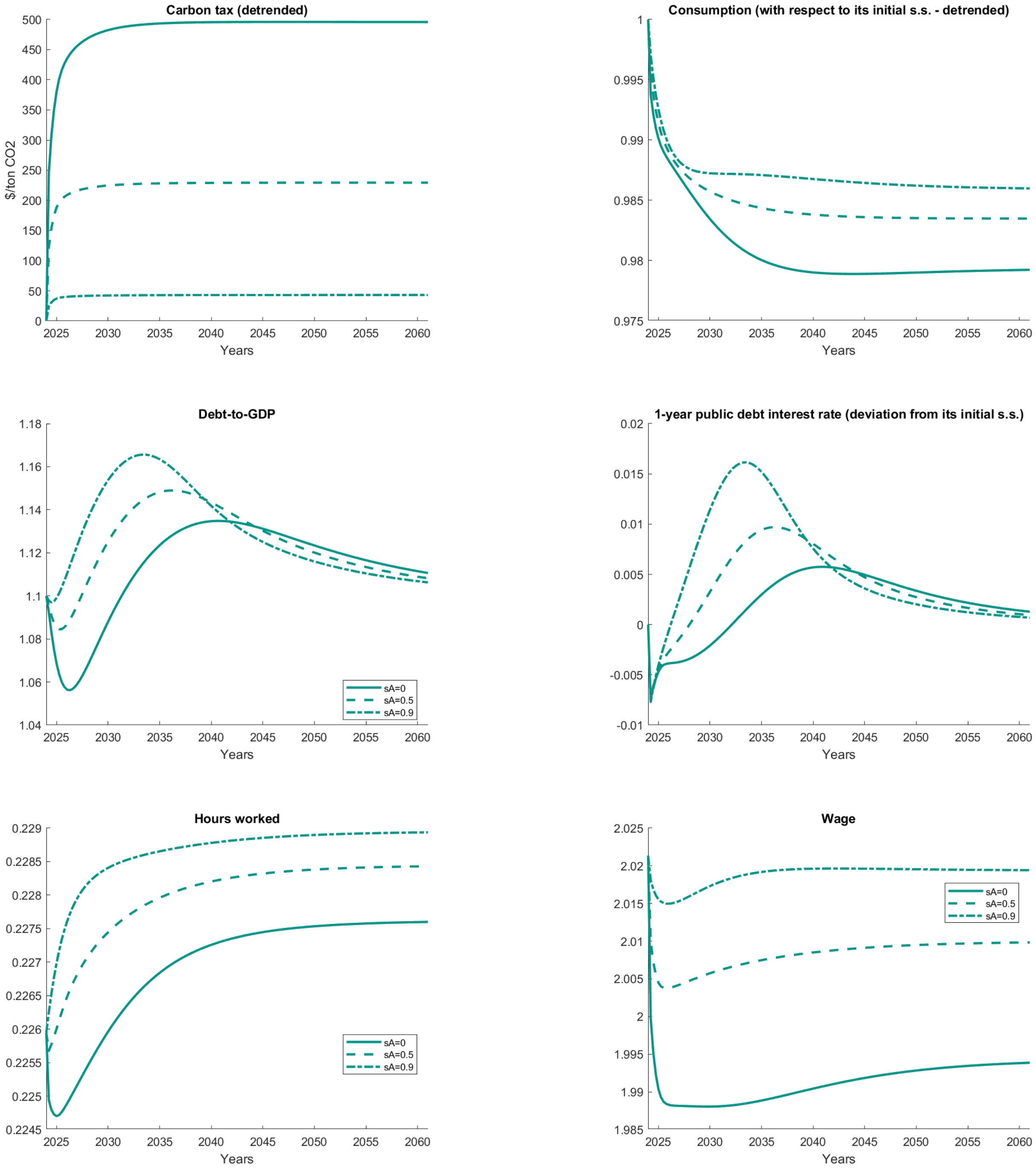

Figure 15: Optimal public over total abatement. Fiscal and macroeconomic developments in France, under various degrees of subsidies.

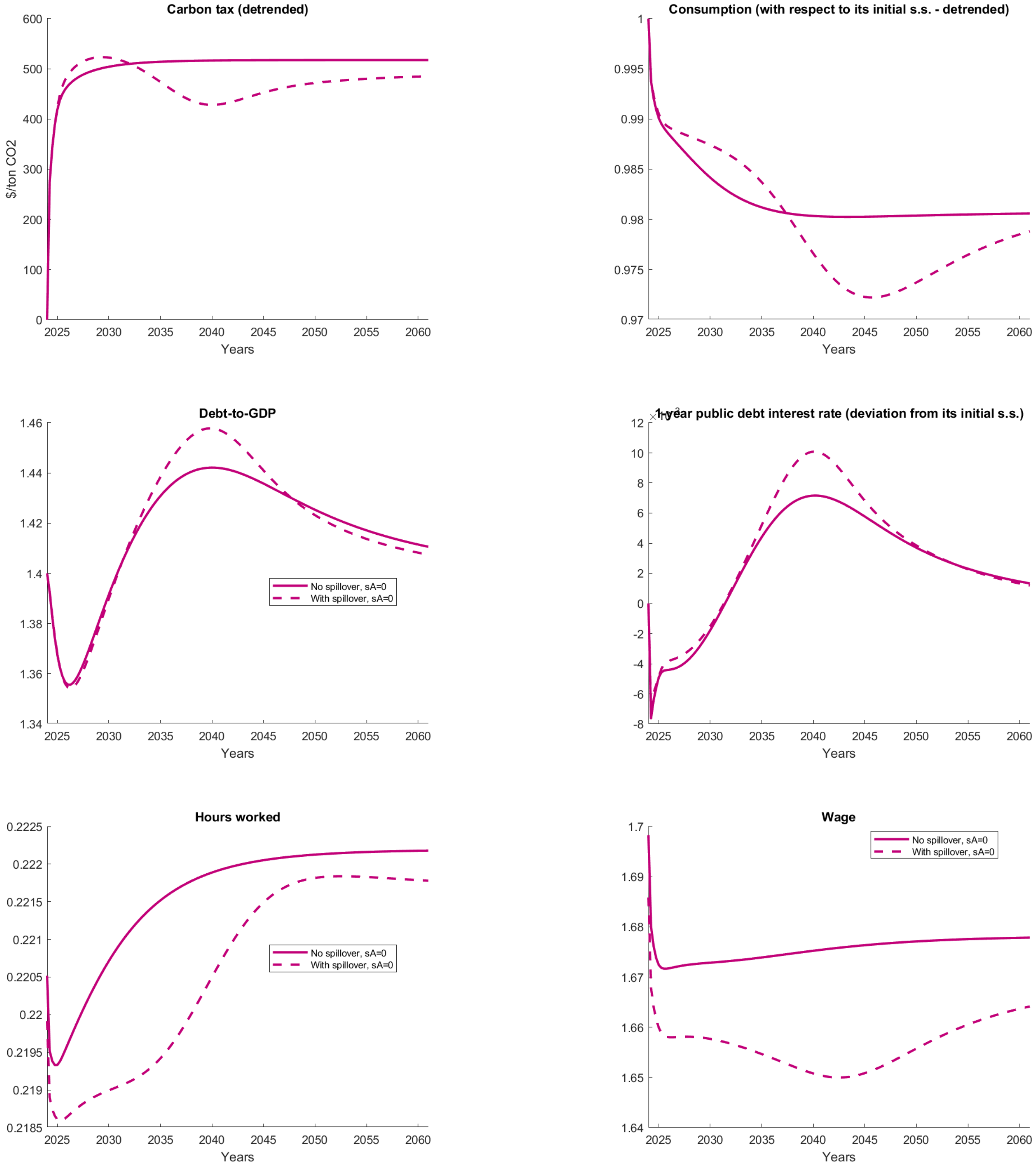

Figure 16: Optimal public over total abatement. Fiscal and macroeconomic developments in Italy, with and without spillover.

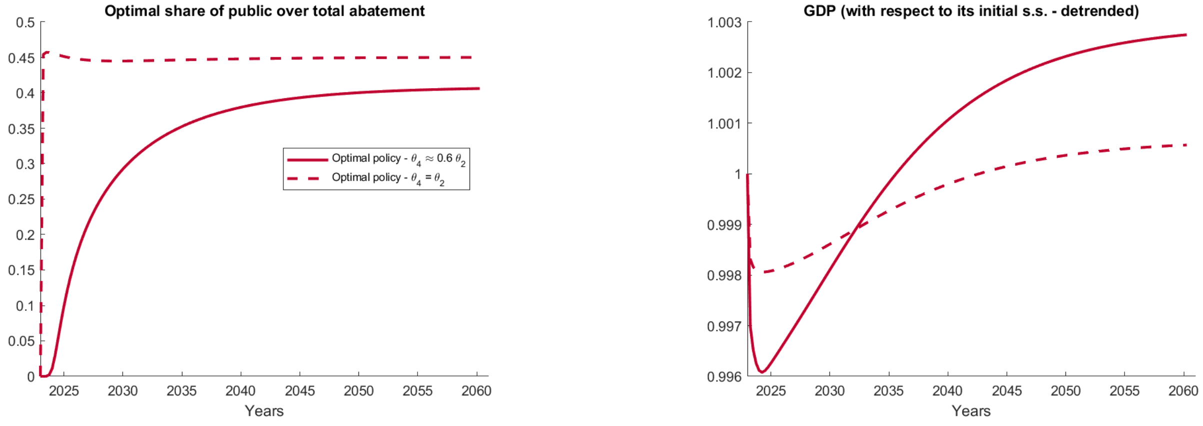

Figure 17: Optimal public over total abatement and economic output in France, with alternative convexity of abatement costs.

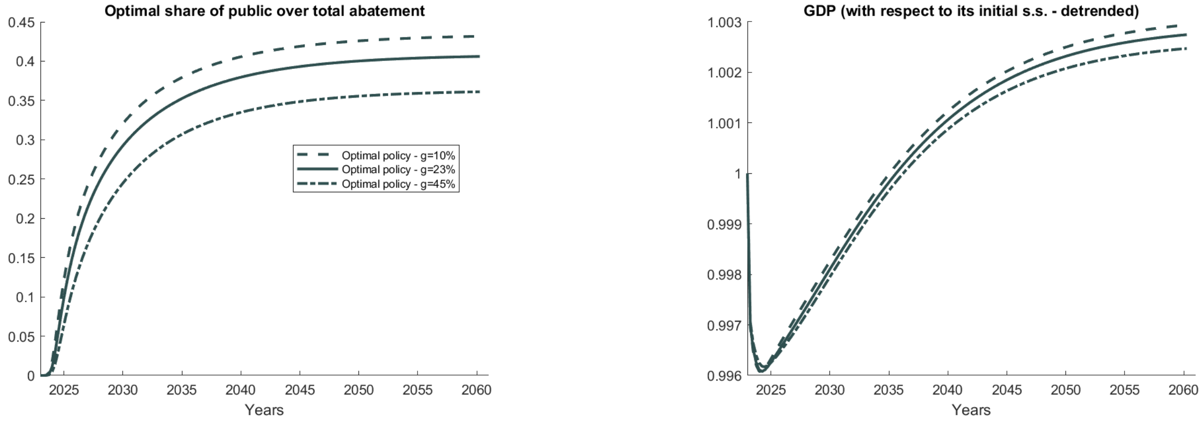

Figure 18: Optimal public over total abatement and economic output in France, with alternative fractions of public expenditure over GDP.