CLIMATE RISKS AND DEBT SUSTAINABILITY

A GREENS/EFA STUDY

THE GREENS/EFA
in the European Parliament

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Acknowledgments

This research was commissioned by Philippe Lamberts – Greens | EFA Group in the European Parliament. We would like to express our deepest appreciation to all them and to Francois Denuit for supporting this work. Many thanks go to Mathias Legrand and all the other developers for providing the basic template of this report – *The Legrand Orange Book*.

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Executive Summary

Executive Summary

The last IPCC's Report, released few days ago (4th April 2022), underlines the urgency of rapid and drastic interventions to limit the adverse effects of climate change on natural and human life. This calls government and public institutions to use any fiscal policy tool (such as taxes, subsidies and public investments) to contain climate damages. Of course, the issue of fiscal sustainability emerges together with the need to balance the social and the environmental goals. The EU is at the forefront in planning actions to boost the efficient use of resources, by moving to a cleaner energy power generation, and to achieve a just and inclusive transition, as exemplified by the EU Green Deal. Looking at the scientific literature, the question of the most effective policy mix for climate change adaptation is relatively unexplored also due to the complexity and uncertainties that surround this issue. We aim at shed a light on the relation between public debt and climate risks.

In macroeconomics, there is a significant debate on the conditions to achieve long-term debt sustainability when its interactions with fiscal policy and economic growth are taken into consideration. Recent developments in endogenous growth theory suggest that a rise in the fraction of GDP devoted to public investment can improve debt. The aim of this report is to evaluate how climate change can influence debt sustainability and how adaptation policies can affect the probability of unstable debt dynamics. First, we introduce a simple theoretical framework to clarify the main relationships between alternative adaptation spending strategies. The analytical model results suggest that adaptation policies are expected to increase GDP growth and, also, debt sustainability if the effectiveness of adaptation expenditure is sufficiently high. Second, we employ the Eurogreen macrosimulation model to the Italian economy, to project the impact of climate change damage and adaptation policies on debt sustainability under different hypotheses.

We simulate and compare four scenarios. The first one takes the baseline developed in the Eurogreen model under the assumption of no climate damage to obtain a hypothetical reference scenario. The second scenario quantifies the impact of climate damage at industry level without the introduction of any adaptation policy. The same climate damage is applied to the following two scenarios. The third scenario assumes that, between 2021 and 2023 (3 years), the government intervenes by introducing additional public expenditure in adaptation strategies. The final scenario

assumes that the government spends the same budget as in the previous case in a more gradual way, over a time period of 30 years (from 2021 to 2050).

The main results may be summarised as follows. Although the economic damage, in terms of GDP fall, is limited until 2050, following climate damage projections based on the current literature, the impact in terms of debt-to-GDP ratio is larger, thus increasing the risk of insolvency. The main driver of this outcome is the reduction of government revenues (e.g., reduction in value added and corporate income taxes). Although overall climate damage increases with temperature, thus gradually, the risk of extreme events calls for urgent action. The fast adaptation scenario is able to offset most of the negative effects, while the slow adaptation strategy, with gradual interventions, is less effective. The considerable increase in the public deficit under the fast adaptation scenario, for years 2021-2024, does not prevent debt sustainability; rather, it avoids increasing debt dynamics close to the end of the simulation period (2050).

These results suggest that tight fiscal rules for highly indebted economies may prevent these countries to take the necessary actions to improve debt stability in the coming decades, with the paradoxically result of undermining the debt sustainability that those rules are intended to achieve.

1. Debt Sustainability

1.1 Introduction to debt sustainability

The concept of *debt sustainability* is rather elusive. From the theoretical point of view it implies that, excluding the possibility to finance public expenditure by *fiat money*, Government is respecting its *intertemporal budget constraint*, i.e. the sum of expected revenues, discounted by adequate discount rates, are higher than the sum of expected expenditure, again discounted by adequate discount rates, where in the latter is included also the actual stock of public debt (see Section 1.2 for technical details). Debt sustainability is therefore to be thought in a very long-run horizon and depending from other factors, as the long-run trends in productivity growth and primary balances.

In practice, the uncertainty in the several key variables, among which the most important are the long-run dynamics of GDP, interest rates and the commitment of Government to long-run fiscal policy, makes very difficult for investors, policy makers and international institutions the use the concept of debt sustainability defined above. This explains why economists and practitioners have suggested less precise but more operative alternatives. Among them, Blanchard et al. (2021) argue that:

> a working definition is that debt is sustainable so long as the probability of a debt explosion, and thus of eventual debt default, remains very low;

while International Monetary Fund (2013) that

> public debt can be regarded as sustainable when the primary balance needed to at least stabilize debt under both the baseline and realistic shock scenarios is economically and politically feasible, such that the level of debt is consistent with an acceptably low rollover risk and with preserving potential growth at a satisfactory level. Conversely, if no realistic adjustment in the primary balance -— i.e., one that is both economically and politically feasible —- can bring debt to below such a level, public debt would be considered unsustainable.

To our scope of understanding the relationship between public debt and climate change the right horizon is the long run. Therefore, it is important that the lack of debt sustainability (i.e.

insolvency or *default*) should not be confused with *illiquidity*, which is concept related to short run. In particular, illiquidity is a *temporary* excess of public expenditure over revenues, which a country cannot finance by issuing new debt and/or by financing using fiat money. The limited access to financial markets can therefore generate a temporary liquidity crisis, but it cannot take as a proof of no debt sustainability.

Unfortunately, the issue is more blurred. The lenders' beliefs of a possible next insolvency and/or an idle behaviour of the central banks can decide if a country goes through from a liquidity crisis to a default by stopping lending or not using fiat money to buy public debt, as in the case of Greek crisis (De Grauwe, 2013). The possibility of a phenomenon of self-fulling expectations leading to default from an illiquidity makes clear the importance to develop methods for assessing the debt sustainability. In this respect Section 1.2 will give a detailed analytical framework. In particular, we will show that an assessment of debt sustainability needs the forecast, among other variables, of the future fiscal policy over a potential infinite horizon. This raises two main issues: first, since commonly methodologies to evaluate the debt sustainability are based on the assumption that the far future will be similar to the past (see, e.g., Bohn (1998)), the forecasted fiscal policy is subject to *true uncertainty*; for example, COVID-19 crisis was absolutely unexpected but its effect on fiscal policy will be deep. Moreover, by the announce of an appropriate future fiscal policy, any government could be considered solvent, regardless on its existing debt. Taking into account past experience can only partially circumvent this issue, because a some arbitrariness in the evaluation of the actual future adoption of fiscal policy always remains.

Given these difficulties in the evaluation of debt sustainability, economists have developed a set of operational criteria and procedures (Debrun et al., 2019). In particular, one of the main tools is the *Debt Sustainability Analysis* (DSA), which aims at answering the key question of when a country's debt is becoming so big that it will not be fully serviced (Wyplosz, 2011). DSA follows a procedure which can be summarized in three steps(Corsetti, 2018):

- *Diagnosis*: this is a preventive step, where DSA is a useful tool for policy maker to evaluate the financial vulnerability of a country's public debt and the possible causes of its vulnerability. Once identified the imbalances, policies and reforms should be implemented to deal with these.
- *Programme activation*: once a country enters a financial assistance programme, DSA is useful to verify whether the debt will be sustainable under such programme.
- *Debt restructuring*: in the case previous measures fail to fix the not sustainability of debt, DSA is fundamental to define how to manage official lending.

The evaluation of European Commission of Member States' debt sustainability is based on a fiscal sustainability framework (European Commission, 2020b) grounded on two main instruments: the DSA and some *fiscal sustainability indicators*, used to enrich the evaluation and to address some of DSA's limitations. Key results are reported in an overall summary heat map of fiscal sustainability risks. This multidimensional procedure considers risks across time (from short to medium term) and across countries in order to design an appropriate policy response. The DSA used in the European Commission is based on the forecasts of fiscal variables that affect the level of debt (i.e. real GDP growth rate, inflation, primary balance, interest rates, exchange rate and stock-flow adjustment).

A detailed discussion of the methods and limitations of DSA goes well beyond the scope of this report[1]. However, it is worth noticing that some important issues and potential problems within this framework are exacerbated by climate change impacts. As Wyplosz (2011) *provocatively* points out, debt sustainability analysis is impossible. Furthermore, the outset probability distributions are valid for a particular time horizon. However, since DSA provides projections for a maximum of ten years, taking into consideration climate change calls for a different approach, where government

[1] See, for instance, Debrun et al. (2019) for an overview of the different methodology developed.

decisions can have long-term effects on economic growth and debt dynamics.

1.2 Public debt sustainability and illiquidity

In this section we will present a theoretical framework to evaluate the sustainability of public debt as opposed to illiquidity. The model, defined in Blanchard et al. (2021) as the "Pure Public Finance View", ignores the impact of fiscal policy on aggregate demand and so, consequently, on output. This is a strong simplifying assumption, because the presence of price rigidities and potential constraints on monetary policy can prevent the latter from keeping output at its potential level in case of a negative fiscal policy shock on actual output. Nonetheless, it is useful to apply this simplified framework to study basic elements and constraints of public debt dynamics.

Public debt evolves over time according to:

$$B_{t+1} = (1 + r_{t+1})B_t + I^p_{t+1} + C^p_{t+1} - \tau_{t+1}Y_{t+1}, \tag{1.1}$$

where B_t is the stock of public debt, r_t the average real interest rate paid on actual stock of public debt, I^p the real expenditure in public investments, C^p the real expenditure in public consumption, τ_t the average tax rate on GDP, and Y_t the real total GDP at time t. *Inflation rate* is not present in equation (1.1) but it can crucially affect the dynamics of public debt by changing its real value: the debt, as well as the interest rate, are generally fixed in nominal terms and therefore their real values negatively depends on inflation rate. Equation (1.1) also neglects the possibility of *monetary financing of public debt*, a factor now increasingly present in most Western economies. Finally, equation (1.1) excludes extraordinary measures of public finances, such as debt repudiation or one-shot contribution to international institutions as the European Stability Mechanism.

Equation (1.1) points out that the dynamics of debt is the result of two opposing forces: a positive force driven by the interests paid on the actual stock of debt, and a negative force represented by the *primary budget*, defined by $\tau_{t+1}Y_{t+1} - I^p_{t+1} - C^p_{t+1}$, a key indicator of the type of fiscal policy adopted by the Government.

Dividing both sides of equation (1.1) by Y_{t+1} it follows:

$$b_{t+1} = \frac{1 + r_{t+1}}{1 + g_{t+1}} b_t + i^p_{t+1} + c^p_{t+1} - \tau_{t+1}, \tag{1.2}$$

where $b_{t+1} \equiv B_{t+1}/Y_{t+1}$ is the public debt/GDP ratio, g_{t+1} is the growth rate of real GDP , $i^p_{t+1} \equiv I^p_{t+1}/Y_{t+1}$ the public investment rate, and $c^p_{t+1} \equiv C^p_{t+1}/Y_{t+1}$ the ratio public consumption/GDP at period $t+1$. The dynamics of the public debt/GDP ratio crucially depends on three main variables, real interest rates, the growth rate of real GDP and the primary budget/GDP ratio. In particular, assuming that all variables in equation (1.2) are time constant, it is possible to show that if $g > r$ and $i^p + c^p > \tau$ (there exists a primary deficit), then the public debt/GDP ratio converges in the long run to:

$$b^E = \frac{1+g}{g-r}\left(i^p + c^p - \tau\right). \tag{1.3}$$

In other words, a higher growth rate of GDP balances results in continuous primary deficits. Differently, if $r > g$ but $i^p + c^p < \tau$ (there exists a primary surplus) b^E in equation (1.3) represents a threshold for the dynamics of debt, i.e. an initial public debt/GDP greater than b^E tends to explode in the long run, while, on the contrary, an initial public debt/GDP lower than b^E tends to converge to zero (or negative). Finally, if $r < g$ but $i^p + c^p < \tau$ then public debt/GDP will tend to converge to zero (or negative) independent of the initial level of public debt/GDP ratio. See Cariola and Fiaschi, 2021 for further details on the characterization of the equilibrium.

However, the dynamics of public debt/GDP ratio does not define the sustainability of debt but its *(il)liquidity*. In order to evaluate *public debt sustainability* we have to introduce the *intertemporal budget constraint* of the Government, that is

$$(\tau - i^p - c^p)\sum_{t=1}^{\infty}\left(\frac{1+g}{1+r}\right)^t > \frac{B_0}{Y_0} = b_0 \tag{1.4}$$

where b_0 is the public debt/GDP ratio at period 0. Equation (1.4) points out that in presence of a positive primary surplus (i.e. $\tau - i^p - c^p > 0$ and $g > r$) ensures that public debt is always sustainable independent of initial level of public debt/GDP ratio (the sum goes to positive infinity as t approaches infinity). Otherwise, if $g < r$ then sustainability requires that

$$(\tau - i^p - c^p)\left(\frac{1+g}{r-g}\right) > b_0. \tag{1.5}$$

This means that primary surplus must be sufficiently high to compensate the relatively high real interest rate with respect to the growth of GDP. Finally, if $\tau - i^p - c^p < 0$, i.e. there exists a primary deficit, public debt is never sustainable. The latter result explains the extreme attention given to primary budget in the evaluation of public debt sustainability. To conclude, we observe that the stability of public debt/GDP ratio over time does not ensure that public debt is sustainable (consider the case of $g > r$ and $\tau - i^p - c^p < 0$).

These last results are useful to highlight some important issues arising once climate targets are taken into account. In mainstream models used to assess debt dynamics,[2] interactions between economic and climate variables are usually neglected, preferring a strong focus on primary budget and debt/GDP ratios. This prevents DSA to consider long-run effects of fiscal policies, such as public expenditure in adaptation, on climate and in turn feedback effects that the latter has on GDP growth. These policies can increase public debt, but at the same time this negative effect can be more than compensated by a reduction of climate damages, with positive effects on GDP growth and public revenues in the long run.[3].

1.3 Debt sustainability and fiscal policy

In this section we present a brief literature review on the effects of fiscal policy on debt sustainability. European Commission has dealt with the issue of debt sustainability of Member States with an approach more oriented to practical implementation than driven by a sound, but blurred in terms of policy prescriptions, theoretical framework (De Grauwe, 2020). Starting from the Maastricht Treaty (1992) and the Stability and Growth Pact (SGP,1997), members of the European Monetary Union are required to respect two main fiscal constraints:

- a public debt to GDP ratio < 60%
- a public budget deficit to GDP ratio < 3%

These two rules have been modified over the years, especially in consequence of events such as the 2007/2008 global financial crisis and, more recently, the COVID-19 pandemic. One of the results of such reforms is the introduction of some flexibility clauses. An example is the 'general escape clause' which states that "*in periods of severe economic downturn for the euro area or the Union as a whole, Member States may be allowed temporarily to depart from the adjustment path towards the medium-term budgetary objective, provided that this does not endanger fiscal sustainability in*

[2] For more details about the methodology used by European Commission, see Annex 6 in European Commission (2020c).

[3] For more details see Chapter 3.

the medium term" (European Commission, 2020a). They are referred to bad economic periods of Member States. In this case fiscal adjustment can be reduced or even suspended (Blanchard et al., 2021).

However, several economists highlights that the interplay between fiscal policy and economic growth makes the relationship between debt sustainability and fiscal policy less clear. In particular, at the centre of the debate there are the contrasting views about the effects of a high public debt on growth, and consequently about which fiscal policy is the most suitable in case of an increase in public-debt-to-GDP ratio. As Heimberger (2021) and Cariola and Fiaschi (2021) argue, these views can be summarized with the following:

- *the conventional view*, which is called conventional because held by most economists and policy-makers, as Elmendorf and Mankiw (1991) pointed out, emphasizes that there is a trade-off between the positive short-run effects of increasing public expenditure and its long-run negative effect on investments and GDP growth Elmendorf and Mankiw (1991). This is due to the "classical" crowding-out effect: even if in the short run an increase in budget deficit can stimulate aggregate demand and so growth through an increase in households' disposable income, in the long run public savings falls, and the increase in private ones fails to compensate it due to the increase of interest rate on debt. The negative effect on growth can be made worse by the effect on investors, that can react negatively to an increase in uncertainty and expectations of higher inflation and financial repression. In this view fiscal consolidation is desirable to reduce debt and increase output.
- a more "unconventional" view highlights the effect of *hysteresis*, for which an increase in aggregate demand in the short run has a positive effect also in the long run because positive shocks are not only temporary, but they can persist over time. By analyzing the available evidence on the extent of hysteresis, DeLong and Summers (2012) find that financial crises and demand-induced recessions appear to have an impact on potential output, even after normal conditions are restored. So they conclude that measures that mitigate their effects would have long-run benefits.

From the empirical point of view, applying a meta-analysis on 48 studies, Heimberger (2021) finds lack of evidence of a negative causal effect of higher public-debt-to-GDP ratio on growth. More precisely, he finds that: i)*there is little (if no) evidence of a threshold beyond which public-debt-to-GDP-ratio leads to a fall in growth.* Previous studies (Reinhart and Rogoff, 2010, e.g.,) presented a threshold around 90% or above.[4] The author points out that existing threshold estimates of the public-debt-to-GDP ratio are within a range between 8.4% and 147.5% of GDP, and they are strongly influenced by choices in terms of data and econometric approaches: these thresholds can be endogenous, and actually there is a lack of evidence on existing uniform debt thresholds, that can depend on country-specific factors; ii) *there is no evidence of a negative causal effect of higher public debt on growth.* The literature also reports a number of cases of zero or positive correlation between these two variables (Panizza and Presbitero, 2014, e.g.,). Problems of endogeneity and reverse causality are important, but results vary with the econometric strategy used.[5] This can be a signal of the presence of publication bias in favour of studies that highlight a negative effect on debt on growth. In this case, some factors such as journal editors with a tendency for publishing those results that are statistically significant, and researchers deciding not to report statistically insignificant findings that would contradict accepted theory, can affect publication,

[4] Unfortunately, in the following it was discovered that such finding was severely biased by a mistake present in the dataset used in the analysis.

[5] The endogeneity problem refers to the fact that when estimating the relationship between two variables, a third variable not considered can simultaneously affect the other two, invalidating the results obtained. The reverse causality problem instead considers the fact that the causal relation between two variables can run also in the opposite direction to that alleged, or it can be a two-way one (so in this case, it can be that growth affects public debt, or that they influence each other).

so that statistically significant results are overall treated more favourably than non statistically significant results.

Other studies highlight the presence of a possible positive effect of an expansionary fiscal policy on growth in periods of recession, while fiscal consolidation can be dangerous in case of low interest rate and massive unemployment (DeLong and Summers, 2012). Contractionary policies can harm the long-run growth rate and also raise the path of debt. As highlighted by Cottarelli and Jaramillo (2013), fiscal austerity has a negative effect on aggregate demand through the fiscal multiplier, whose effect results to be higher during downturns.[6] This leads to the instability of financial markets and to an increase in expenditure for automatic stabilisers (e.g. unemployment benefits).[7]

Dosi et al. (2016) compares the effects of a Keynesian counter-cyclical fiscal policy with fiscal austerity. The results show that austerity policy, as the one prescribed in the Stability and Growth Pact (SGP), is self-defeating both in the short and in the long run. This is due to two mechanisms operating during a recession: in the short run a reduction in public spending leads to a reduction in aggregate demand, reflected in lower private investment and so in lower output. The result is a more volatile GDP and an increase in unemployment rate; while in the long run there is persistency of the short run effect due to lower investment in R&D. This slows the diffusion of technology, leading to a technological lock-in. Finally, Carvalho et al. (2021) studies the fiscal policy response to the COVID-19 crisis. Using a microeconomic approach, by studying internet data about economic agents, the paper shows that an increase in 1% of public spending relative to GDP leads approximately to the same increase in weekly economic activity in OECD countries.

We can therefore conclude that in general fiscal policy has an ambiguous relationship with debt sustainability, and only in specific circumstances positive. In the next section we will show that if fiscal policy focuses on the alleviation of the effects of climate change this relationship may turn to be positive.

[6] Fiscal multiplier is generally defined as the ratio of a change in output (ΔY) to a discretionary change in government spending or tax revenue (ΔG or ΔT). Thus, it measures the effect of a 1 € change in spending or a 1 € change in tax revenue on the level of GDP. As it can be seen from this definition, an accurate estimation of this element is crucial to measure the relationship between GDP and fiscal policy, in order to plan and forecast the effect of policy actions. (Batini et al., 2014)

[7] Automatic fiscal stabilisers are elements of the government budget that reduce fluctuations in economic activity without the need for discretionary actions. Sources of automatic fiscal stabilisation can be cyclical or non-cyclical. The former are those components which react immediately to shocks in order to reduce economic fluctuations. An example on the revenue side can be tax progressivity, that in case of a negative income shock reduces volatility of disposable income. On the expenditure side, unemployment benefits represent the most relevant automatic stabiliser of this type. On the other hand, non cyclical sources work in the opposite way : in case of economic downturns for example, Government does not reduce immediately already approved expenditure (such as wages, transfers and intermediate consumption) stabilising the economy in the face of a drop in output (Bouabdallah et al., 2020).

2. Debt sustainability and climate change

2.1 Economic losses from climate change

Concerns related to the severe impacts of climate change on economic activity and human well-being were once again confirmed in the last Conference of the Parties (COP26), held in Glasgow last year, based on up to date scientific literature (see, for instance Burke et al., 2015) and the last projections published by the Intergovernmental Panel on Climate Change (IPCC). The Sixth Assessment Report (AR6)[1] acknowledges, beyond any level of reasonable doubt, that climate change due to anthropogenic activity is widespread and intensifying. The list of risks Europe is subject to, on a medium confidence level, includes: risk to people, economies and infrastructures due to coastal and inland flooding; stress and mortality to people due to increasing temperatures and extreme heat; disruption of marine and terrestrial ecosystems; water scarcity to multiple interconnected sectors; losses in crop production, due to compound heat and dry conditions, and extreme weather.

In numbers, the European Environmental Agency claims that climate-related extremes economic losses add up to an estimated EUR 487 billion in the EU-27 Member States between 1980 and 2020, and could result in even greater losses in the coming years.[2] Moreover, a relatively small number (3%) of unique events was responsible for a large proportion (around 60%) of the economic losses, resulting in high variability from year to year. The highest losses per capita were recorded in Switzerland, Slovenia and France, and the highest losses per area in Switzerland, Germany and Italy.

Looking at the expected impact on GDP, by using a multi-sector, multi-country computable Climate assessment General Equilibrium Model (CaGE model), Szewczyk et al. (2020) estimate the expected losses under different scenarios (1.5, 2, and 3°C of global warming compared to pre-industrial level) for Europe. The economic analysis was done for seven impact categories: river floods, coastal floods, agriculture, energy supply, droughts, windstorms and human mortality from extreme heat and cold. Exposing present economy to global warming of 3°C would result in an annual welfare loss of at least 175 €billion (1.38% of GDP). Under a 2°C scenario the welfare loss

[1]"Climate Change 2021: The Physical Science Basis", see `https://www.ipcc.ch/report/ar6/wg1/`.

[2]See `https://www.eea.europa.eu/ims/economic-losses-from-climate-related`.

would be 83 €billion/year (0.65% of GDP), while restricting warming to 1.5°C would keep welfare losses at about 42 €billion/year (0.33% of GDP).

A broader concept of climate damage is defined as Loss and Damage (Roberts and Huq, 2015). It considers impacts from both extreme events such as floods, droughts and heatwaves and slow-onset events due to athropogenic activity like sea level rise and loss of biodiversity. Moreover, it also includes both economic and non-economy damages. Among the most relevant forms of economic losses, which have a direct impact on markets, we may list damages to housing and infrastructure, changes in agricultural production and tourism patterns. Non-economic losses include biodiversity loss, human life, human health and human mobility. These also have indirect economic impacts on crops, migration, and human displacement following extreme weather events. A broader contextualization of climate damages allow us to better appreciate the level of uncertainty related to measuring it and explain the large variation between different damage functions (Russell et al., 2022).

Some models project divergent climate damage trajectories between southern and northern Europe (Burke et al., 2015, p. x). Attempts to counter greater damages with public investment on adaptation could, therefore, impose a double burden on southern European countries due to reduced revenue from taxes and increased expenditures to either reduce future damages or rebuild communities affected by extreme weather events. For instance, Italy is expected to face a reduction of more than 25% by the end of the century under the business-as-usual scenario, in which temperatures will increase up to +4.2 Celsius degree.

2.2 Climate-related fiscal risks

Although current estimates on the impact of climate change on European economies are severe in some regions and sectors but overall limited, there are reasons to believe that impacts on public finance can be more distressing. Despite the relevance of these effects, climate-related fiscal risks are generally disregarded in climate-economy models and they are only recently considered in the fiscal sustainability frameworks of official institutions (see, for instance, European Commission, 2020b). Climate change directly affects government deficit through the cost to replace damaged public infrastructure, social transfers to households and insurance schemes backed by state guarantees. Moreover, indirect costs can have substantial fiscal impacts, such as, the reduction of tax revenue due to a slow down in economic activity, the increase in health care spending, the support to financial institutions in distress due to extreme climate-related events. Economic losses due to climate change will also diminish economic growth, particularly in southern European countries, worsening debt sustainability indicators (i.e., debt-to-GDP and deficit-to-GDP). This in turn can lead to an increase in interest rates, further deteriorating public balances (Zenios, 2021).

Public investments in mitigation and adaptation policies will interact with debt dynamics. This determines a trade-off between current debt sustainability and future climate risks. Mitigation and adaptation policies can, at least potentially, lead to an increase in the rate of economic growth in the long run through an increase in the quality and quantity of production factors, a rise in productivity and a reduction of market failures Hallegatte et al. (2012). Under these circumstances, adaptation and mitigation can positively affect debt sustainability, even if debt increases initially. The scenario analysis performed in the Section 3 aims at evaluating these trade-offs in a systemic way.

According to IPCC (2001), mitigation policies are interventions aiming at reducing the sources or enhancing the sinks of greenhouse gases. They commonly include carbon taxes, emission trading schemes and public subsidies for clean energy transition. Their effects on government revenues and on debt sustainability can be different in the short and in the long run. Adaptation takes into consideration adjustment in natural or human systems in response to actual or expected climatic shocks and their effects by moderating damages. These include public investment in climate-proofing infrastructure, water management, and different kinds of subsidies aiming at, for instance, supporting changes in crop varieties, relocation from coastal areas and general "rainy day" funds. Mitigation and adaptation policies are strictly related, since mitigation reduces all impacts of climate change thus reducing the adaptation challenge. Moreover, some policy measures can be seen both as adaptation and mitigation (e.g., enhancing building efficiency). However, mitigation has global advantages, but its benefit depends on the decisions of a sufficient number of major global emitters. By contrast, adaptation acts at a country or regional scale and its effectiveness can be assessed assuming a global scenario, for instance, on the basis of the Representative Concentration Pathways (IPCC, 2007).

The potential of adaptation policies is well documented in the literature. Fabio and Evi (2021) suggest that timely response to disasters can reduce their impact and that States with more flexible budgeting rules are able to respond better to climate damages. Catalano et al. (2020) show that preventive intervention leads to higher GDP growth rates, strength resilience to shocks and alleviation of financial constraints, rather than either taking no action or waiting until remedial action is necessary.

2.3 Insights from a simple model

In this section, we present a simplified framework for analyzing how climate change and adaptation policies interact with debt sustainability. For this purpose, we slightly modify the model presented in Section 1.2. The points made here serve as a theoretical reference through which to understand the simulation results obtained using the EUROGREEN model, discussed in the next Section.

2.3.1 Setup

Consider a two-period economy in which production takes the form:

$$Y_t = A_t K_t, \qquad t = 0, 1 \tag{2.1}$$

where Y and K denote aggregate output and capital, respectively, and A is a positive productivity coefficient. In equation (2.1), capital should be understood in a broad sense, i.e. as consisting of both physical and human capital (Rebelo, 1991). Productivity at time 0 is equal to $\bar{A}$, while productivity at time 1 can take values less than $\bar{A}$ due to adverse climate events, such as droughts and floods. More specifically, in the absence of policy measures aimed at protecting the economy from climate damages, productivity at time 1 is a random variable:

$$A_1^D \sim U\left[\underline{A}, \bar{A}\right],$$

the time-0 expected value of which is:

$$\mathbb{E}_0\left[A_1^D\right] = \frac{\underline{A} + \bar{A}}{2}.$$

The underlying assumption here is that climate change affects the economy only through the productivity channel. This assumption is admittedly strong; however, taking other effects into consideration would complicate the analysis and provide limited new insights.

At time 0, the government can choose to spend a certain amount S^A on climate change adaptation. The higher the adaptation spending, the less harsh the damages from climate change. The effectiveness of adaptation spending is captured by a parameter $\beta > 0$, with greater values corresponding to a higher effectiveness. The joint effect of climate change and adaptation measures is such that:

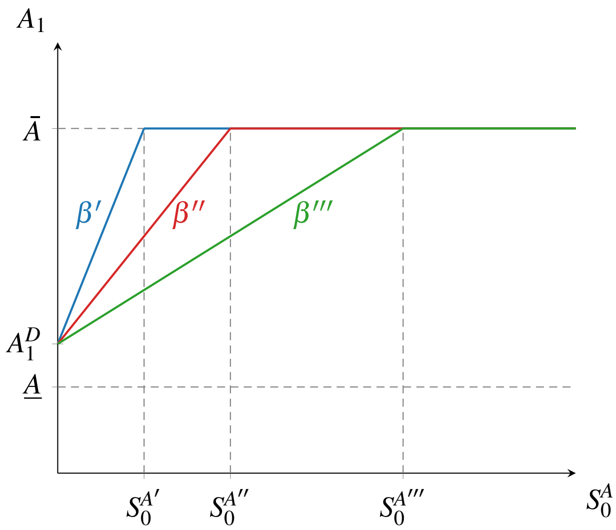
$$A_1 = \min\left\{A_1^D + \beta S_0^A; \bar{A}\right\}, \tag{2.2}$$

meaning that adaptation spending can at most nullify climate damages. The expected productivity at time 1 is therefore:

$$\mathbb{E}_0\left[A_1\right] = \min\left\{\mathbb{E}_0\left[A_1^D\right] + \beta S_0^A; \bar{A}\right\} = \min\left\{\frac{\underline{A} + \bar{A} + 2\beta S_0^A}{2}; \bar{A}\right\}. \tag{2.3}$$

Figure (2.1) shows how A_1 varies with S_0^A starting from a given value of $A_1^D \in \left[\underline{A}, \bar{A}\right]$. If adaptation spending is zero, then $A_1 = A_1^D$. As spending increases, productivity increases as well up to a maximum level of $\bar{A}$. Higher values of β, corresponding to steeper curves, allow to reach $\bar{A}$ at a lower cost.

Figure 2.1: Effect of adaptation spending on productivity for different values of β



Investment spending at time 0 is:

$$I_0 = sY_0\left(1-\tau\right) + I_0^P, \tag{2.4}$$

where $s \in (0,1)$ and $\tau \in (0,1)$ are the saving rate and the income tax rate, respectively, while I^P denotes public investment. The accumulation of physical capital is given by:

$$\begin{aligned} K_1 &= \left(1-\delta\right)K_0 + I_0 \\ &= \left(1-\delta\right)K_0 + sY_0\left(1-\tau\right) + I_0^P, \end{aligned} \tag{2.5}$$

where $\delta \in (0,1)$ is the capital depreciation rate. The expected aggregate income at time 1 is therefore:

$$\mathbb{E}_0\left[Y_1\right] = \mathbb{E}_0\left[A_1\right]K_1 = \mathbb{E}_0\left[A_1\right]\left\{K_0\left[1-\delta+s\bar{A}\left(1-\tau\right)\right] + I_0^P\right\} \tag{2.6}$$

and the expected income growth rate is:

$$\mathbb{E}_0\left[g_1\right] \equiv \frac{\mathbb{E}_0\left[Y_1\right]-Y_0}{Y_0} = \frac{\mathbb{E}_0\left[A_1\right]}{\bar{A}}\left[1-\delta+\bar{A}\left(s\left(1-\tau\right)+i_0^P\right)\right]-1, \tag{2.7}$$

where $i_0^P \equiv I_0^P/Y_0$. Finally, letting $\left[1-\delta+\bar{A}\left(s\left(1-\tau\right)+i_0^P\right)\right] \equiv \gamma$, equation (2.7) can be rewritten:

$$1+\mathbb{E}_0\left[g_1\right] = \frac{\gamma\mathbb{E}_0\left[A_1\right]}{\bar{A}}. \tag{2.7'}$$

For simplicity, assume no inflation and let the price index be 1. Public debt at time 0 is:

$$B_0 = \bar{B} + S_0^A, \tag{2.8}$$

where $\bar{B}$ is the initial debt net of adaptation spending. Public debt at time 1 is instead:

$$B_1 = B_0(1+i) + C_1^P + I_1^P - \tau Y_1, \tag{2.9}$$

where C^P is government consumption, i is the interest rate on debt, and τY denotes tax revenues. In expectation we therefore have:

$$\mathbb{E}_0[B_1] = B_0(1+i) + C_1^P + I_1^P - \tau \mathbb{E}_0[Y_1]. \tag{2.10}$$

2.3.2 Impacts of adaptation spending

Without any loss of generality, let $I_0^P = I_1^P = C_1^P = 0$. Moreover, suppose that the government can be of two types, named T1 and T2. A Type-1 government chooses adaptation spending so as to have $\mathbb{E}_0[A_1] = \bar{A}$, that is to maximize expected productivity at time 1. This implies:

$$S_0^A\big|_{T1} = \frac{\bar{A} - \underline{A}}{2\beta}. \tag{2.11}$$

Conversely, a Type-2 government implements no adaptation measure:

$$S_0^A\big|_{T2} = 0. \tag{2.12}$$

Equation (2.11) shows that, if the government seeks to minimize the negative expected impact of climate change, then it will choose a level of adaptation expenditure which is increasing in the expected damage (the difference $\bar{A} - \underline{A}$) and decreasing in the effectiveness of adaptation (β).

The expected incomes of the two types of government are:

$$\mathbb{E}_0[Y_1]\big|_{T1} = \mathbb{E}_0[A_1]\big|_{T1} K_1 = \bar{A}\left[(1-\delta)K_0 + sY_0(1-\tau)\right] \tag{2.13}$$

and

$$\mathbb{E}_0[Y_1]\big|_{T2} = \mathbb{E}_0\left[A_1^D\right] K_1 = \frac{\left(\bar{A} + \underline{A}\right)}{2}\left[(1-\delta)K_0 + sY_0(1-\tau)\right], \tag{2.13'}$$

while the expected growth rates are:

$$\mathbb{E}_0[g_1]\big|_{T1} = \gamma - 1 \tag{2.14}$$

and

$$\mathbb{E}_0[g_1]\big|_{T2} = \frac{\gamma\left(\bar{A} + \underline{A}\right)}{2\bar{A}} - 1. \tag{2.14'}$$

It is easy to see that since $\left(\bar{A} + \underline{A}\right)/2\bar{A} < 1$, the inequality $\mathbb{E}_0[g_1]\big|_{T1} > \mathbb{E}_0[g_1]\big|_{T2}$ is always satisfied, meaning that climate adaptation always results in a higher expected growth rate of income. Moreover, the difference between the two growth rates is lager when climate damages are severe (i.e. when $\underline{A}$ is small) and when γ is high. Here it is worth noting that γ positively depends on the share of public investment on GDP.

Since in the model adaptation is financed by deficit spending, in the second period a Type-1 government may end up suffering from a heavier debt burden than a Type-2 government. Substituting equations (2.11) and (2.13) into equation (2.10), the expected debt of a Type-1 government can be written:

$$\mathbb{E}_0[B_1]\big|_{T1} = \left(\frac{2\beta\bar{B} + \bar{A} - \underline{A}}{2\beta}\right)(1+i) - \tau\bar{A}\left[(1-\delta)K_0 + sY_0(1-\tau)\right], \tag{2.15}$$

while from equations (2.12), (2.13') and (2.10) we get that the expected debt of a Type-2 government is:

$$\mathbb{E}_0\left[B_1\right]\big|_{\mathrm{T2}} = \bar{B}\left(1+i\right) - \tau\left(\frac{\bar{A}+\underline{A}}{2}\right)\left[\left(1-\delta\right)K_0 + sY_0\left(1-\tau\right)\right]. \tag{2.15'}$$

Finally, it can be verified that the inequality $\mathbb{E}_0\left[B_1\right]\big|_{\mathrm{T1}} \leq \mathbb{E}_0\left[B_1\right]\big|_{\mathrm{T2}}$ holds if and only if:

$$\beta \geq \frac{1+i}{\tau\left[\left(1-\delta\right)K_0 + sY_0\left(1-\tau\right)\right]}, \tag{2.16}$$

that is, since S_0^A is decreasing in β, if and only if the increase in public deficit necessary to maintain expected productivity steady at $\bar{A}$ is sufficiently small. Put differently, the expected debt of a Type-1 government is lower than the expected debt of a Type-2 government whenever adaptation costs are smaller than the foregone revenues incurred in the case of no adaptation.

Some points are worth noting here. First, the condition in (2.16) is sufficient but not necessary for the expected debt of a Type-1 government to be more sustainable than the debt of a Type-2 government: if $\mathbb{E}_0\left[Y_1\right]\big|_{\mathrm{T1}}$ exceeds $\mathbb{E}_0\left[Y_1\right]\big|_{\mathrm{T2}}$ by a considerable margin, then the expected debt-to-GDP ratio of a Type-1 government may be lower than that of a Type-2 government even when $\beta < \left(\bar{A}+\underline{A}\right)/2\bar{B}$, i.e. when $\mathbb{E}_0\left[B_1\right]\big|_{\mathrm{T1}}$ is greater than $\mathbb{E}_0\left[B_1\right]\big|_{\mathrm{T2}}$. Second, the adaptation spending function given in (2.11) does not guarantee that a Type-1 economy will not suffer from climate damages: a low realization of the random variable A_1^D, which corresponds to extreme climate events, will still result in a loss of income. Finally, the government may well be underestimating the *true* costs of climate change; for example, it may believe that the support of A_1^D is $\left[\underline{A},\bar{A}\right]$, whereas it is actually $\left[\underline{A}',\bar{A}\right]$, with $\underline{A}' < \underline{A}$. If this is the case, then adaptation spending will be systematically lower than is necessary to keep productivity from falling, possibly resulting in more severe losses.

The model sheds light on some important points concerning the relation between debt sustainability and climate change. First, adaptation policies are expected to increase overall productivity, therefore contributing to reduce the negative impact of climate change on growth. Second, adaptation effectiveness (here represented by the parameter β) is crucial in determining how heavy is the burden of adaptation spending on public finances: a higher β allows to reduce the expenditure necessary to minimize expected damages, and therefore help avoiding the negative consequences of adaptation on debt. Third, the condition in equation (2.16 does not depend on the current level of debt; this implies that if at time 0 a Type-1 government is constrained by strict fiscal rules (often related to the initial Debt-to-GDP ratio), then it will choose a sub-optimal adaptation expenditure level, with negative consequences in terms of growth and debt at time 1.

The model is perhaps best understood when framed in terms of current and future generations. From this viewpoint, the results also have significance in relation with the issue of intergenerational equity. Indeed, the literature on climate change mitigation investigates the intergenerational trade-offs between the welfare cost of reducing emission today and the climate change damages incurred by future generations. This discussion — generally referred to as the discounting debate (see e.g. Heal and Millner, 2014) — focuses on how to evaluate today the welfare of future generations. This issue is of paramount important, since the decision on optimal mitigation effort crucially depends on how the future is discounted.

By contrast, adaptation does not seem to pose this kind of dilemma. The additional deficit produced today can improve the welfare of future generations by increasing productivity and making debt more sustainable. It is the introduction of limitations on government expenditure today (with rules based on the past) which can produce a conflict between the current and future generations.

The analytical model presented above provides an useful illustration of how public expenditure on adaption may not deteriorate and might actually contribute to debt sustainability when climate damage is taken into consideration. It still fails, however, to provide meaningful insights on other important effects that adaptation expenditure. How is climate damage expected to affects income distribution and how would adaptation policies mitigate this effect? How much does current deficits contribute to GDP growth in the long term? What is the difference in terms of public deficits, in the short and long term, of performing the same adaptation expenditure fast or spread through a longer period? To answer these questions and quantify the actual size of climate damage and adaptation policies in the economy we project different simulation scenarios in the next chapter.

3. Damage, adaptation and debt sustainability

The previous sections clarify that the impact of climate change damages on debt sustainability is crucially mediated by the presence of several channels and feedback loops. Moreover, the choice of adaptation policies will introduce additional intertemporal trade-offs that increase complexity. To provide a reliable analysis of policy options, we employ an extended version of the Eurogreen model (D'Alessandro et al., 2020) applied to Italy. Italy is a interesting case of a country with a high public debt and possible severe impact of climate change (Burke et al., 2015; Szewczyk et al., 2020). Indeed, Italy is one of the European countries most exposed to the negative consequences of climate change, linked for example to floods, droughts, extreme heat waves and important infrastructures that are at hydrogeological risk. At the same time, after the financial crisis of 2007-2009, Italy has more than once been the focus of attention for its large public debt and the government's lack of efforts to control public spending by European Commission. This exemplifies how rigid fiscal frameworks may constrain adaptation policies and produce a unsustainable long term debt dynamics.

3.1 Methodology

Eurogreen is a system-dynamics macrosimulation model based on Post-Keynesian and ecological economics. It simulates a national economy between 2010 and 2050. Its previous versions were applied to France (D'Alessandro et al., 2020; Cieplinski et al., 2021) and Italy (Cieplinski et al., 2021). The simulations presented in the following sections replicate the Italian economy. Data for the main outcome variables between 2010 and 2019/20 was used to calibrate key parameters of the model. Moreover, to replicate the effects of the COVID19 pandemic we included exogenous shocks to private consumption, investment, exports and imports in 2020 and 2021.

The remainder of this section provides information on the debt dynamics and climate change damage, already implemented into the model, and how we introduce an adaptation policy. Figure 3.1 show the main variables and the main causal relations of the model. Full documentation is available on request.

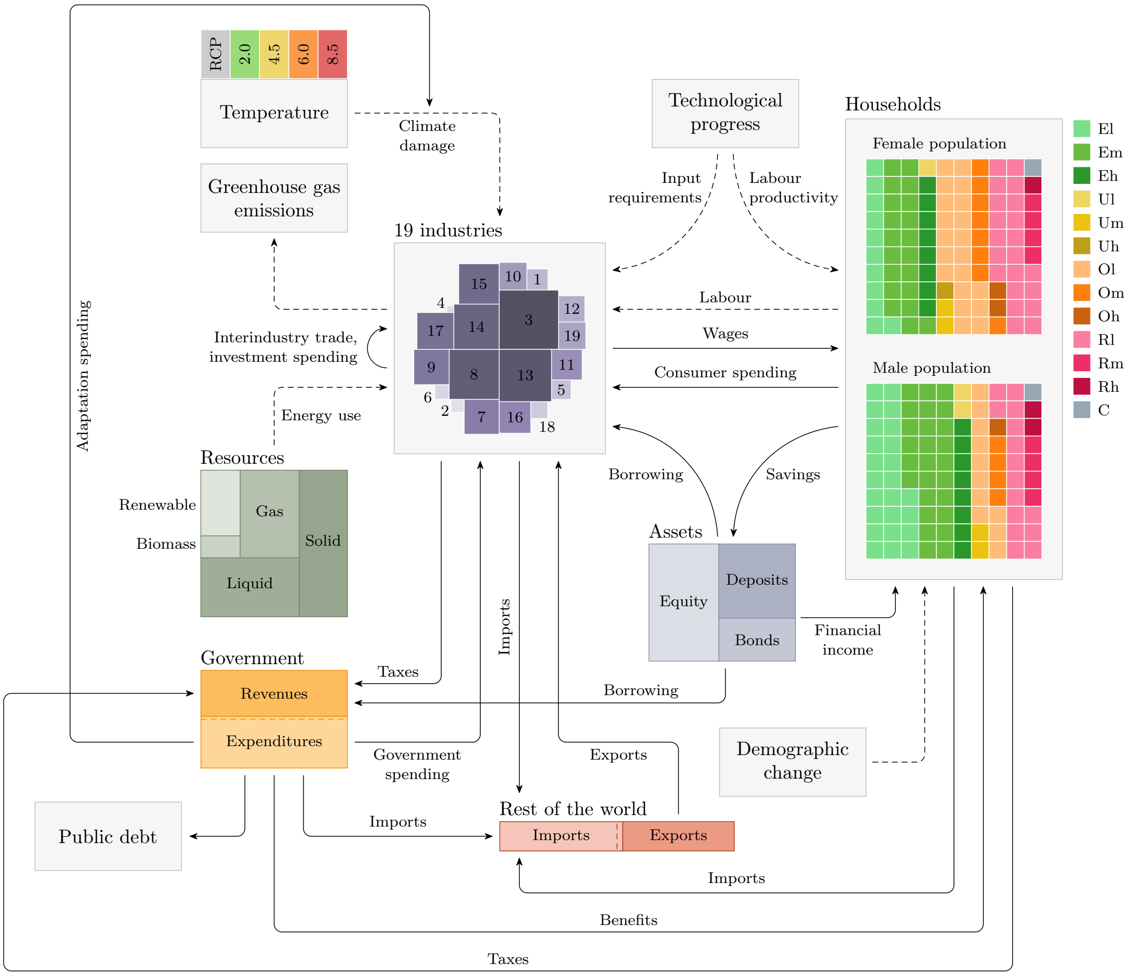


Figure 3.1: Eurogreen overview. The solid and dashed arrows represent monetary and non-monetary flows, respectively. The Households, Industries, Resources, Assets, Government, and Rest of the world boxes summarily represent first-period simulation results. The dashed lines in the Government and Rest of the world boxes are drawn for reference and cut the area of the rectangles in half. Abbreviations in the Households box describe the following groups: E = employed; U = unemployed; O = out of labour force; R = retired; l = low-skilled; m = middle-skilled; h = high-skilled; C = capitalists. List of industries: 1 = Agriculture, forestry and fishing; 2 = Mining and quarrying; 3 = Manufacturing; 4 = Coke and refined petroleum products; 5 = Electricity, gas and steam; 6 = Water supply; 7 = Construction; 8 = Wholesale and retail trade; 9 = Transportation and storage; 10 = Accommodation and food service activities; 11 = Information and communication; 12 = Financial and insurance activities; 13 = Real estate activities; 14 = Professional, scientific, technical, administrative and support service activities; 15 = Public administration and defence; 16 = Education; 17 = Human health and social work activities; 18 = Arts, entertainment and recreation; 19 = Other.

3.1.1 Climate change damage

Climate damage is defined as the fraction by which production varies relative to what it would be in the absence of global warming. Since the model only projects national emissions, the evolution of temperatures depends of Representative Concentration Pathways (RCPs), which can be chosen exogenously. The simulations presented henceforth adopt RCP 6.0 which project global temperature increases between 3 and 3.5ºC by 2100 (IPCC, 2007). In every simulation period (year) industry specific damages are drawn from beta distributions similar to those applied in Desmet and Rossi-Hansberg (2015). The climate damages extracted, for every industry, from the distribution increase their respective technical coefficients in the input-output. Hence, it is equivalent to an increase in the amount of inputs necessary to produce the same output. Thus, to meet a certain level of final demand, industries affected by climate change must increase their demand for intermediate products. So the output of upstream industries may also increase. In this respect, the model is able to take into account some distributional impact at industry level and some positive effects of climate change, i.e. an input-output version of the defensive growth theory (see, e.g., Bartolini and Bonatti, 2002).

The change in industry's output will induce a direct change in employment. Thus, at the aggregate level, the impact of climate change on unemployment and inequality is not straightforward. However, the production system is loosing efficiency, which results in a decline in value added and profits.

Other possible impacts of climate change, mentioned in Section 2, are not explicitly accounted for here. For instance direct capital losses, or change in the demographic structure. However, many impacts are considered indirectly. For instance, since industries include also the public sector and services, additional cost of public expenditure for health care enter the dynamics through a reduction of efficiency in that industry. Other changes that affects current government expenditure are due to change in tax revenues – due to the dynamics of income, value added and profits – as well as the change in unemployment benefits – due to labour market dynamics.

3.1.2 Debt dynamics

Public debt increases with government deficits. The public sector revenue in Eurogreen is a function of social security contributions, carbon taxes, value added taxes, income taxes, financial income taxes and corporate income taxes. Government expenditures include unemployment and other social benefits, pensions, public investments, public expenditures on goods and services, and interest on the public debt. Therefore, there is a reinforcing cycle on public debt: deficits increase future expenditure on interest and, thus, favour further increases in public debt. However, public expenditure and investments also have a multiplier effect on growth that increases future taxes which can more than compensate for the future expenditures on debt interest.

From the discussion above on the impact of climate change on production, it is clear that many variations will effect public expenditure and revenues. However, while on the government expenditure we expect small changes, since the effects are minor and contribute in opposite direction, the impact on government revenue is relevant, since the reduction in value added and profits directly reduce tax revenues as shown clearly in the model presented in section 2.3. Note that the minor impact on government expenditure depends on the assumption that climate change only affect technical coefficients without taking into account other direct cost associated to social security or reception of climate migrants. This means that the cost of climate change included in the model is a conservative estimate of the impact of climate change on government expenditure.

3.1.3 Adaptation policies

Section 2 discusses the different aims of mitigation and adaptation policies. Since we are assuming that Italian mitigation policies cannot affect world RCP and, thus they cannot affect climate change dynamics, we model and analyse only alternative adaptation strategies. However, the baseline scenario takes into account the current mitigation policies employed in Italy which are planned to meet the 2030 target. Cieplinski et al. (2021) show that applying the Eurogreen model to the Italian economy, current mitigation measures are expected to achieve a reduction of emissions of about 40% by 2030. Here, we develop a new simple module to project adaptation policies by introducing an additional type of public expenditure. Besides directly increasing the public deficit, the adaptation policy also reduces climate damage. Our model includes a generic expenditure that reduces damage as a simplifying assumption. In practice, it could represent more public investments on climate resilient infrastructure such as buildings with improved thermal isolation, urban infrastructure to resist extreme weather events such as floods, and structures to reduce water waste or desalination plants to withstand prolonged draughts. The key assumption for our policy is the adaptation sensitivity parameter. It determines how much the severity of climate damage is reduced for every euro spent on mitigation. In other terms, we assume that adaptation policies are not able to change the probability of occurrences, but only to moderate (and in principle fully avoid) the negative effects on technical coefficients of the input-output.

Let us define $a_{i,j,t}$ the technical coefficient representing the relation between sector j's output and its input from sector i. Introducing a sectoral climate damage multiplier $\left(1-\Lambda_{j,t}\right) \in [0,1]$, in every period we have that the technical coefficient is $\frac{a_{i,j,t}}{1-\Lambda_{j,t}}$. The adaptation policy proportionally reduces the magnitude of $\Lambda_{j,t}$ by means of a parameter α_t, thus the impact of climate change become $\frac{a_{i,j,t}}{1-\alpha_t\Lambda_{j,t}}$, with

$$\alpha_{t+1} = \alpha_t - \beta S_t, or \quad (3.1)$$

$$\Delta\alpha_t = -\beta S_t, \quad (3.2)$$

where S_t is the adaptation expenditure in billion and β is the effectiveness of adaptation expenditure, or the efficiency of the adaptation strategy. We further assume that $\alpha \in [0,1]$. The calibration of the relation in equation 3.2 is a very difficult task. To overcome this uncertainty in the simulations we consider quite large range for parameter β, included between 0.017 to 0.027. This means that one billion expenditure in adaptation will reduce the severity of climate change in a range between 1.7 to 2.7 percent.

This additional expenditure will lead to an increase in deficit and debt with further increase in the interest on debt for future periods. As shown in the simple theoretical model, this increase in future debt can be more than compensated by the reduction of future climate damage.

3.1.4 Scenarios

To highlight the impact of climate change and the effectiveness of adaptation policies we simulate four scenarios:

1. **No Damage**. This scenario takes the baseline developed in the Eurogreen model and sterilizes the climate change impact to obtain a reference (and hypothetical) scenario without damage.
2. **Damage**. This scenario considers the impact of climate change at industry level without the introduction of any targeted adaptation policy.
3. **Adaptation Fast**. From 2021 to 2023 (3 years), government introduces a new expenditure in adaptation with a budget of 10 billion per year.
4. **Adaptation Slow**. From 2021 to the end of the simulation period (30 years), government introduces adaptation expenditure with a budget of 1 billion per year.

The comparison between the first two scenarios clarifies the impact of climate change on the socioeconomic system and debt sustainability. Furthermore, the last two scenarios allow for an explicit investigation of the trade-off between increasing the deficit today (and interest on debt

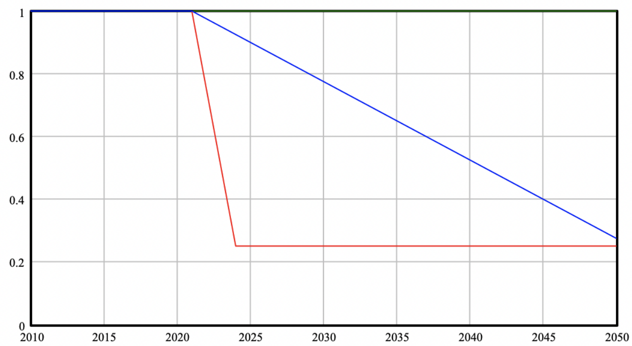


Figure 3.2: Effectiveness in adaptation to climate change. The dynamics of adaptation (see 3.2) with $\beta = 0.025$. Red refers to scenario "Adaptation fast" (AF), Blue to "Adaptation slow" (AS)

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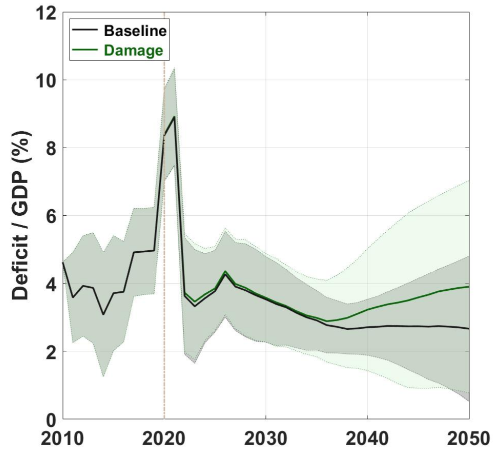
tomorrow) with the aim of a fast reduction in climate damage and a strategy which tends to be more conservative on fiscal balance today but delays adaptation to climate change.

The budget of 30 billion of euro for the implementation of the adaptation strategy is derived from an estimate based on the resources that can be mobilized in the next few year with the Italian Recovery and Resilience Plan. Indeed, one of the missions is to foster the ecological transition and the green revolution. The whole mission should account for 60 billion of euro. However, a significant share of the funds are directed to mitigation (23 billion for energy transition) and other objectives not directly linked to adaptation policies. However, the plan highlight a budget of 15 billion for "protection of land and water resources", 15 billion for "energy efficiency" and 5 billion for "circular economy and sustainable agriculture". Most of this budget is obtained issuing new debt. Thus, the assumption that 30 billion can be devoted to adaptation in three years, as new government spending, is a reliable amount. However, the agreement for the availability of this budget between the European Commission and the Italian government was signed in a very special contingent situation, in which the Stability Pact was suspended. On the contrary, the slow adaptation scenario mimic a situation in which Italy could not access to this exceptionally conditions and the country is committing one billion a year for the next thirty to tackle the negative consequences of climate change. Figure 3.2 shows how the two adaptation scenarios project the reduction of the severity of climate change in the economy assuming a value of $\beta = 0.025$.

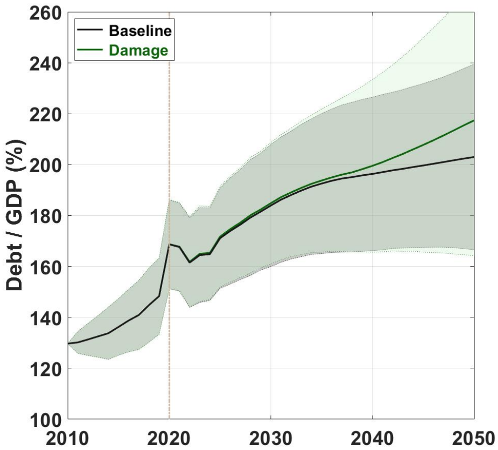
3.2 Results

The pathways presented are the average of 500 simulations for each scenario. Indeed, innovation dynamics in the Eurogreen model have a random component which determines the availability of new technologies, the probability of which depends on the relative cost of intermediate goods and labour. The lowest cost technology will be adopted by the industry resulting in labour or resource saving. Furthermore, in the last two scenarios we take into consideration also the possibility of different degrees of efficiency in adaptation policies.

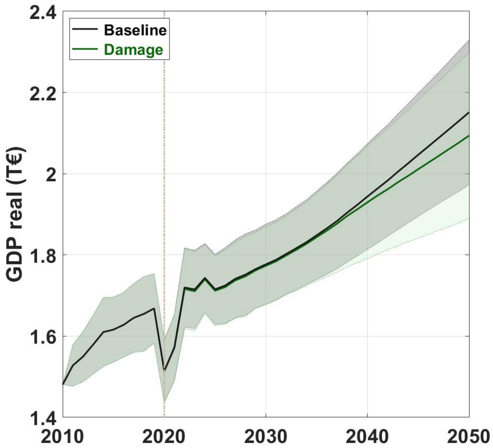
Figure 3.3 compare the dynamics of the no damage scenario (Baseline in the Figure) with the damage scenario. The effects of climate change on real GDP up to 2050 appear relatively small at around 2% at the end of the period. This is not surprising since the calibration of the damage function are based on Desmet and Rossi-Hansberg (2015). This variation is however higher than the one reported in Szewczyk et al. (2020) for Southern Europe (about 0.65% with 3 degree increases excluding fatalities that are not taking into account in this study). Moreover, such limited reduction of GDP leads to a significant difference in term of deficit-to-GDP (a rise up to almost



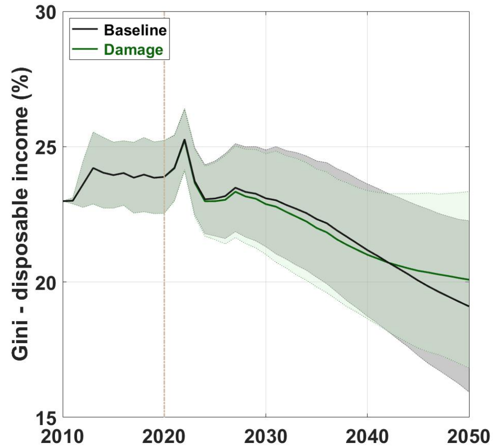
(a) Deficit-to-GDP Ratio



(b) Debt-to-GDP ratio



(c) Real GDP

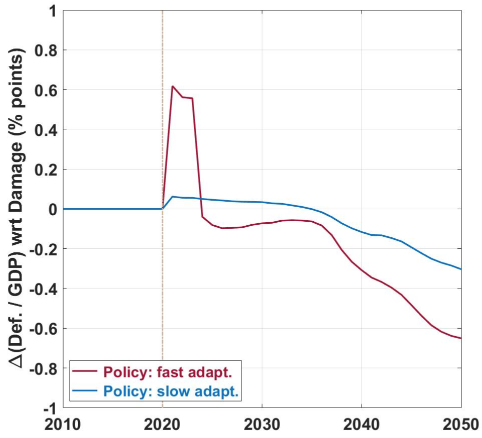


(d) Gini Coefficient

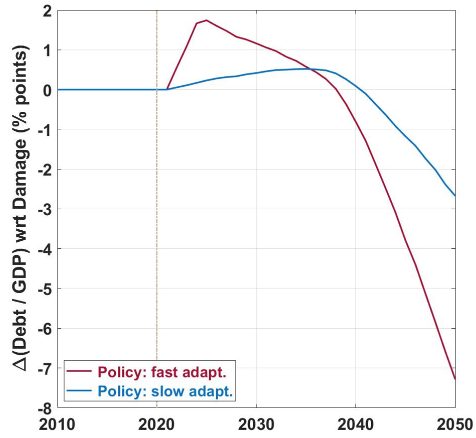
Figure 3.3: Main macroeconomic indicators. The lines plot the means from 500 *simulations for each scenario and the shaded areas around them their respective 95% confidence intervals. Black line: Baseline, i.e. the no damage scenario, Green line: Damage (RCP6) scenario. Panel 3.3a: Deficit-to-GDP ratio, Panel 3.3b: Debt-to-GDP ratio, Panel 3.3c: Real GDP, Panel 3.3d: Gini coefficient of disposable income.*

2 percentage points) and debt-to-GDP (up to more than 15 percentage point in 2050). Above all, the divergence appears marked and increasing only at the end of the simulation period when the temperature rise has a higher impact on the economy. Most importantly, why withouth climate damage the debt-to-GDP ratio is high but quite stable, climate change produce a market positive slope of this indicator. As we pointed out in the methodology (Section 3.1), Eurogreen captures the impact of climate change on the technical coefficients of the input-output matrix through a reduction of productivity. Thus, the increase in deficit and debt is mainly due to the reduction in tax revenues from value added and profits, which are affected earlier and more intensively. This features explains also the dynamics of inequality measured by the Gini coefficient (Panel 3.3d) which remains lower in the damage scenario until 2042. However, in the last year of the simulation period also inequality and unemployment (not reported here) tend to worsening. In other words, the

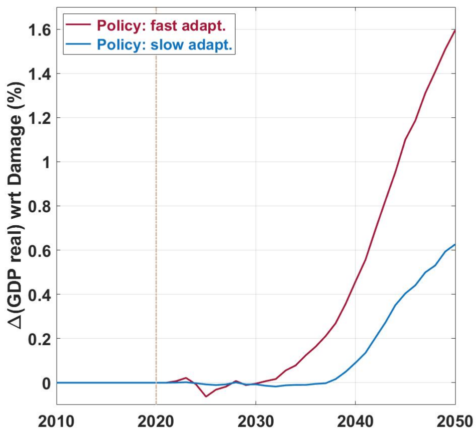
negative impact of climate change propagates throughout the economy following in a accelerating pattern. It is worth to mention that the no damage scenario is a useful hypothetical scenario to better understand the impact of climate change but does not represent a reliable pathway. For this reason, the effectiveness of adaptation policies is assessed by contrasting the fast and slow adaptation scenarios with the damage scenario (our reference scenario without adaptation policies). Hence, the paths represented in Figures 3.4 and 3.5 are obtained by taking the difference between the average of two adaptation scenarios and the damage one.



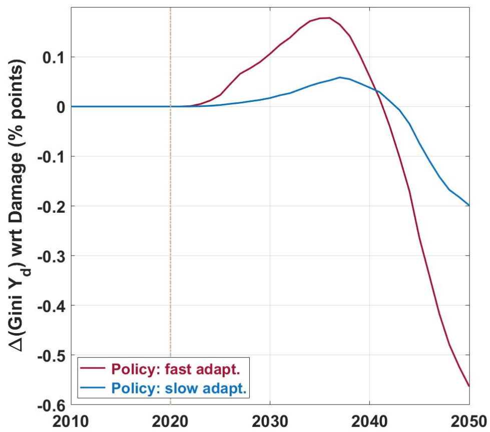
(a) Deficit-to-GDP Ratio



(b) Debt-to-GDP ratio



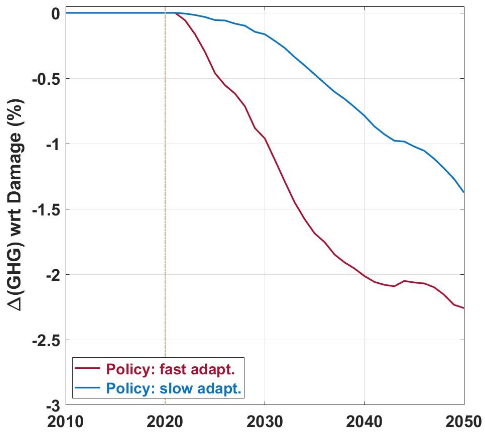
(c) Real GDP



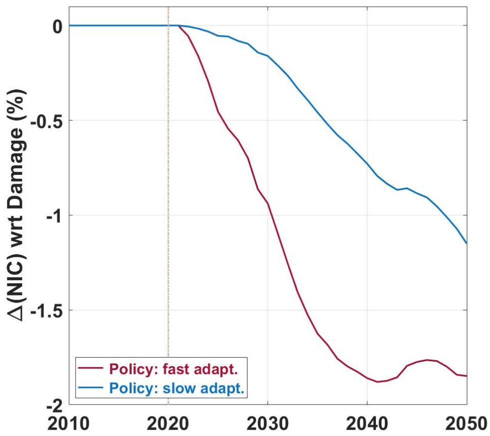
(d) Gini Coefficient

Figure 3.4: Adaptation Effectiveness (1). The lines plot the differences of the means from 500 *simulations for each scenario between the fast adaptation scenario and the no adaptation scenario (red) and between the slow adaptation scenario and the no adaptation case (blue). Panel 3.4a: Deficit-to-GDP ratio , Panel 3.4b: Debt-to-GDP ratio, Panel 3.4c: Real GDP, Panel 3.4d: Gini coefficient of disposable income.*

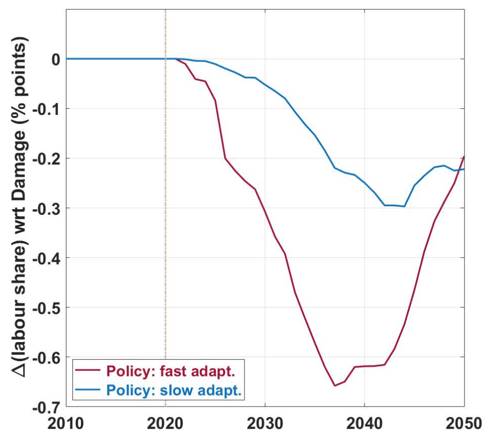
Figures 3.4a and 3.4b display the main result of the study. The fast adaptation scenario achieves a reduction of debt-to-GDP ratio by approximately 7.5 percentage in 2050 (from about 218% to 202%). This reduction more than double the reduction obtained by the slow adaptation scenario. This holds despite the dramatic increase in deficit between 2021 to 2024 (Panel 3.4a). The fast adaptation policy results to be extremely more effective in controlling debt dynamics. Note that while the debt-to-GDP assumes very high value in all the scenarios, the deficit-to-GDP ratio in the last 10 years of the simulation period assume values below 3% (see Panel 3.3a) in the fast adaptation scenario. The high value of the debt-to-GDP ratio is also due to low GDP growth rates projected in Eurogreen (in average below the 1 percent per year in all the scenarios). Panel 3.4c corroborate the result of the simple model provided in Section 2.3. Indeed, the growth rate of the economy is higher in the fast adaptation scenario than in the no adaptation one. Furthermore, Panel 3.4d suggests that fast adaptation will initially slightly increases inequality but prevent its increase in the last few years of the simulated period.



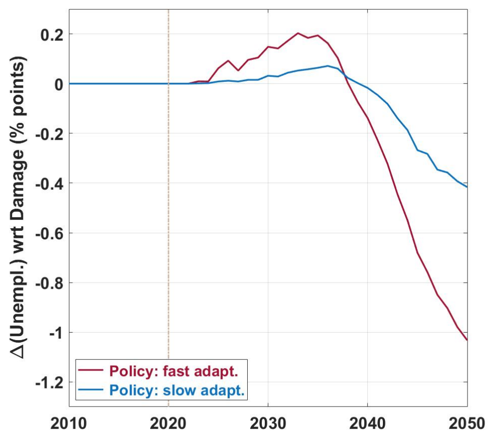
(a) GHG Emissions



(b) Energy Net Inland Consumption (NIC)



(c) Labour Share



(d) Unemployment rate

Figure 3.5: Adaptation Effectiveness (2). The lines plot the means from 500 *simulations for each scenario between the no adaptation case (blue). Panel 3.5a: Deficit-to-GDP ratio , Panel 3.5b: Debt-to-GDP ratio, Panel 3.5c: Real GDP, Panel 3.5d: Gini coefficient of disposable income.*

Climate change affects industries in asymmetric way. The most affected are trade and agriculture, with a loss in the value added at the end of the simulation period of approximately 24% and 14%, respectively. On the contrary, in other industries, climate change damage is negligible, also because the reduction in efficiency in the sectors mentioned above, creates an additional demand of intermediate products for unit of output which compensates for the reduction of total output.

For instance, in manufacturing, adaptation increases the value added but reduces the output with respect to the no adaptation case. Interestingly, the dynamics of value added affect functional income distribution, between wages and profits. Excluding the last few years where the damages of climate change are evident and tend also to increase inequality, before 2045, climate change tends to slightly increase the labour share (see, Panel 3.5c) and inequality (see Figure 3.3d). This result corroborates the argument provided above that the impact of climate change can harm added values and profits first, inducing a significant reduction of tax revenues. On the labour market negative and positive effects seem compensate each other. The difference displayed in Panel 3.5d are almost negligible until 2045.

It is worth highlighting that adaptation policies are able to slightly reduce GHG emission and net inland consumption of energy with respect to the no adaptation scenario (see Figure 3.5a). Two effects tend to offset each other. On the one hand, the reduction in GDP and economic activities induce a reduction in emissions. On the other hand, making production less efficient, climate change result in an increase in intermediate inputs and related emissions. However, in our simulation, the overall effect of fast adaptation on GHG emissions produces a relative reduction of emissions and energy consumption by approximately 2.4 and 1.9%, respectively. Table 3.1 summarises the main results in terms of the social, economic, fiscal and energy&environment indicators obtained with the EUROGREEN model.

Scenario	*Social*	*Economic*	*Fiscal*	*Energy & Environment*
No damage	+	+	+	∅
Climate Damage	-	-	- - -	-
Fast adapt.	+	++	++	+
Slow adapt.	∅	+	-	∅

*Table 3.1: **Summary of the main scenario results.** The results range vary between a maximum of "Highly positive" (+ + +) to a minimum of "Highly negative" (- - -), in terms of desirable outcomes (∅ means no significant impact). Social refers to the distribution of income (Gini) and unemployment, Economic to the economic growth (GDP), Fiscal to the public debt and deficit dynamics, and Energy & Environment to the use of energy (NIC) and emissions (GHG).*

3.3 Limitation and discussion

There are many limitations to this study. Probably the most relevant one is the assumption that climate change only affect industries' productivity. We are not considering many other important channels through which climate change can affect the prosperity of people. However, even in this conservative approach, our results suggest that adaptation policies are an effective tool to avoid uncontrolled debt growth due to climate change. In terms of sustainability approach, this also means to not compromise the ability of future generations to meet their own needs. Interestingly, the lack of an explicit investigation of the direct impact of climate change on the life of people (not mediated by the impact on the production side) means that adaptation policies can increase inequality until the damage of climate change is sufficiently severe (after 2040 in our simulations). It is clear that not including damage to households (e.g., flood) we are loosing some features that hit the most vulnerable people. However, adaptation policies aimed at protecting land and water resources will be very effective to support vulnerable communities and people, so reducing inequality. On the contrary, the mitigation policies currently implemented in many European countries tend to reward the most advantaged classes (see, e.g., Owen and Barrett, 2020; Sovacool, 2021). For example, the Italian government recently incentivised the purchase of electric cars (which have a high average price), and the efficiency of buildings. Data collected by the Italian parliament's research offices show that the vast majority of these subsidies went to the richest households, increasing the inequality on living standard (Larcinese et al., 2021).

A second important limitation of this study is that the simulation model is applied to a single country, Italy. We briefly pointed out at the beginning of Section why Italy is an interesting case to investigate the relationship between debt, climate change and adaptation policies. The main results of the scenarios are qualitatively robust in term of changes in parameters, temperature scenario, effectiveness of adaptation, and so on. However, there is the possibility that a country less indebted may find different trade-offs or that the negative impact of climate change may propagate to debt dynamics sooner or later. More importantly, the impact of climate change is expected to be very different among European countries and this has to be tested with the available data.

Finally, integrated assessment models has to deal with many uncertainties. Especially in these absurd times with a pandemic that has scarred our lives and a war on Europe's doorstep, it is very difficult to think how a mathematical model can present a credible scenario for the next 30 years. However, the relevance of this approach is not to predict the future, but to understand how alternative actions today can help or hinder the achievement of certain common goals. From this perspective, the main result of this analysis is to show, both through a simple theoretical model and through a quite rich set of simulations, that introducing stringent constraints on governments' ability to spend in adaptation to climate change increases the chances of incurring, within a few decades, serious and unfair situations, and of undermining the debt sustainability that those constraints are intended to achieve.

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