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Marwil J. Dávila-Fernández
Germana Giombini
Edgar J. Sánchez-Carrera

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Climateflation and monetary policy in an environmental OLG growth model*

Marwil J. Dávila-Fernández[†] · Germana Giombini[‡]

Edgar J. Sánchez-Carrera[‡]

[†] *Department of Economics and Statistics, University of Siena, Italy*
[‡] *Department of Economics, Society, and Politics, University of Urbino, Italy*

Abstract

Recent empirical evidence is challenging the conventional paradigm in macroeconomics, which assumes money is neutral in the long run. On the other hand, central banks are gradually acknowledging that climate change can potentially impact price stability, and the term *climateflation* has entered the vocabulary of policymakers. This paper contributes to current developments between these two major themes. We present an Overlapping Generations (OLG) model to study the interplay between conventional monetary policy and the environment in a context where the so-called "independence hypothesis" does not hold. Individuals are assumed to derive utility from consumption and environmental quality. Firms operate in a competitive market, but output is weighted by a damage function reflecting a negative externality from ecological degradation. We innovate by linking the environment to inflation through inflationary expectations in a modified Phillips curve. Central banks set the nominal interest rate using a generalised Taylor rule. They affect wealth composition via the individual's intertemporal optimisation problem. Numerical experiments allow us to assess the robustness of the trade-off between environmental quality and economic activity when (i) expectations are more responsive to *climateflation*, (ii) the monetary authority is more inflation-averse, (iii) the central bank increases the inflation target, and (iv) fiscal policy is less stringent.

Keywords: Monetary policy; Inflation targeting; Green transition; OLG.

JEL: E52, E60, O44.

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1 Introduction

The assumption that productive capacity is independent from monetary policy stands as the dominant macroeconomics paradigm. It lies at the basis of the inflation-targeting framework used by most central banks (see Blanchard, 2018). While such a consensus was never unanimous – and there have always been some dissent voices outside more mainstream circles (Minsky, 1993) – recent empirical evidence is challenging the view that money is neutral in the long run (e.g. Jordà et al., 2023; Ma and Zimmermann, 2023). The topic is increasingly receiving attention as data seems to support the relevance of hysteresis effects on economic performance (see, for example, Summers, 2015; Girardi et al., 2020; Furlanetto et al., 2023; Fazzari and Gonzalez, 2023).

On the other hand, central banks are gradually realising that climate change can potentially impact prices and financial stability. As a result, scholars and policymakers have started to explore different channels through which monetary policy and environmental targets interact. For example, climate transition expenditures require large upfront costs, making them susceptible to changes in credit accessibility. Variations in interest rates have measurably contributed to the "levelised cost of electricity" (LCOE) of renewable energies (Schnabel, 2023). There has been a special concern on transmission mechanisms related to physical and transition risks (see NGFS, 2019; ECB, 2021). Recent efforts include the pioneering proposal of a climate-augmented monetary policy rule (Chen et al., 2021; Bacchiocchi et al., 2023) and how quantitative instruments, as well as credit allocation programmes, could minimise climate change-related financial distress (e.g., Campiglio, 2016; Dafermos et al., 2018).

Our research question lies in the intersection between these two major themes. We are interested in the interplay between conventional monetary policy and the environment in a context where the so-called "independence hypothesis" does not hold, i.e. money is not neutral in the long run. For this purpose, we rely on an Overlapping Generations (OLG) framework as it has the realist feature of treating government debt as net wealth. This attribute allows for a natural set-up in which monetary policy has real consequences because it determines the composition of the public's portfolio between government debt and other assets (for a comprehensive discussion, see Hu et al., 2023). Despite not being the main workhorse model to deal with monetary policy, OLGs have been used to study inflation and savings dynamics (see Bernasconi and Kirchkamp, 2000; Sterk and Tereyro, 2018), optimal monetary policy rules (Crettez et al., 2002; von Thadden, 2012; Hiraguchi, 2014), rational asset price bubbles (as in Galì, 2014), and the non-neutrality of monetary policy (e.g., Braun and Ikeda, 2021; Hu et al., 2023). Moreover, they are a popular tool among scholars interested in green-growth dynamics (e.g. John and Pecchenino, 1994; Zhang, 1999; de la Croix and Gosseries, 2012; Wei and Aadland, 2022; Jaimes, 2023).

We assume agents live for only two periods: young and old. They work during the first phase and save all income in capital or government bonds. In the second period, they consume their previous savings. Building on John and Pecchenino (1994), individuals derive utility from consumption and environmental quality (see also Caravaggio and Sodini, 2023). The former hurts the environment, which feeds a damage function that reduces economic activity. Firms operate in a competitive market, so wages correspond to the marginal productivity of labour weighted by the externality from ecological conditions (as in Brock and Taylor, 2010). We innovate by linking ecological degradation to inflation through a modified Phillips curve. It is argued that people incorporate *climateflation* resulting from physical and transition risks into their expectations. Central banks set the nominal interest rate using a generalised Taylor rule that responds to such price pressures. Finally, interest rates affect wealth composition through individuals' intertemporal optimisation problem.

Among our main findings, we document the existence of a trade-off between environmental quality and economic performance related to the shape of the damage function. We perform a set of numerical experiments under four main scenarios. In the first, we assume agents become more responsive to *climateflation*. The monetary authority needs to increase the interest rate to keep expectations anchored. This move raises the share of wealth through public debt and reduces capital accumulation. There is a reduction in economic activity and ecological pressure, allowing for an improvement in environmental quality. Still, the magnitude of the last effect is not enough to curve inflation expectations, which remain above the baseline case. The second scenario corresponds to a situation where the central bank becomes more inflation-averse. Given that the inflationary pressure from environmental degradation exists but is stable, and the monetary authority strongly responds to deviations of current inflation from the target, agents reduce overall savings to maintain a certain level of conservation activities. Less capital implies a reduced output, leading to lower consumption and improving environmental quality. The main difference from the previous experiment is that fundamentally, the bonds-capital ratio and the inflation rate do not change.

In the third scenario, we assume the central bank understands *climateflation* as a “fact”, and the correct response would be to adopt a more lenient monetary policy by increasing the inflation target. Not surprisingly, agents now prefer physical assets relative to public bonds. Still, as they value environmental quality, we observe a reduction in capital accumulation, allowing for a marginal contraction in output in favour of some improvement in environmental conditions. Finally, we address the model's response to a more flexible fiscal policy. If the government does not actively boost environmental quality, it is the most dangerous case. A public deficit increase leads to a robust switch towards that asset, bringing capital accumulation down. Consequently, output is also strongly reduced. The contraction in economic activity is so large that it reduces the pool of resources available for conservation purposes, creating a lose-lose situation. Alternatively, adopting an expansive green fiscal policy lowers inflationary expectations by reducing the negative externality from environmental degradation. The mitigation of climate-related risks also benefits economic activity. Therefore, the environment-production trade-off is broken with both variables moving together.

The remainder of the paper is organised as follows. Section 2 brings a general overview of the phenomenon of *climateflation*, including definitions and reactions from policymakers to the concept. Section 3 presents our OLG growth model with a detailed explanation of its main transmission channels. It will be calibrated in Section 4 to provide a more concrete view of its main dynamic properties, including the four main scenarios previously discussed. Some final considerations follow.

2 Main notions and stylized facts

Climateflation is a term increasingly being used to describe price increases directly resulting from climate change. It has gained attention from central banks as they acknowledge the potential negative impact of global warming on economic stability. It has become a central issue addressed by the ECB's Governing Council. They have identified five main transmission mechanisms connecting monetary policy and climate-related risks: The interest rate, as uncertainty about policy responses increases risk premia and affects the natural rate of interest; a credit channel, given that delinquent loans restrict the supply of credit; an asset price channel, since they generate capital destruction and lower company valuations; the exchange rate, considering that the adjustment of the carbon frontier can interrupt global value chains in terms of prices; and expectations, as less predictable transition policies that are inconsistent over time reduce the credibility of monetary policy.

Indeed, the relatively large upfront costs incurred in green capital-intensive expenditures make them particularly susceptible to changes in the cost of credit. For example, low and declining interest rates have measurably contributed to the fall in the LCOE of renewable energies (see Schnabel, 2023). While price stability is a prerequisite for a sustainable transition, recent inflation dynamics threaten it. On the one hand, central banks usually tight monetary policy to keep inflation under control and consequently, financing conditions become more restrictive. Since fossil fuel-based power plants have comparably low upfront costs, a persistent rise in the cost of capital may discourage efforts toward rapid decarbonisation.

On the other hand, unless GHG emissions are cut rapidly, the economic system is likely to remain exposed to the risks of "climateflation" and "fossilflation".[1] The former is directly linked to the cost of climate change: As the number of natural disasters and severe weather events rises, so does their impact on economic activity and prices. For example, Parker (2018) finds that natural disasters may have had substantial and persistent upward effects on the price levels of developing countries. Faccia et al. (2021) suggest that very hot seasons have a marked impact on prices over the medium term. Summers with temperatures above the long-term average are associated with an increase in food prices of around 0.2 percentage points. Arguably, estimations along those lines reflect the legacy cost of the dependency on fossil energy sources, which has not been reduced forcefully enough over the past decades (e.g. Schnabel, 2022). To some extent, the green transition is an additional factor contributing to making fossil fuels more expensive. Thus, climate change is related to various supply shocks threatening inflation stability.

Insights on how successfully different countries have been in improving environmental conditions can be obtained from the Environmental Performance Index (EPI), which is a composite indicator developed by the Yale Center for Environmental Law & Policy and the Center for International Earth Science Information Network Earth Institute. It is a measure at the national level of how close countries are to the established environmental policy objectives. Using 40 performance indicators across 11 issue categories, the EPI ranks 180 countries on climate change performance, environmental health, and ecosystem vitality. Its range goes from 0 to 100, the highest possible performance.

We report in Fig. 1 (a) the scatterplot of the EPI in 2020 against expected 2024 inflation, as reported by the OECD. The dotted line marks the trend weighted by per capita Gross Domestic Product (GDP) in 2017 Purchasing Power Parity (PPP) international dollars. The colour of the circles is related to the CO2 per capita emissions in kilotons. We plot in grey the region corresponding to the 95% confidence interval. The curve's downward slope suggests a negative correspondence between the two variables. Fig 1 (b) plots the EPI versus the OECD-provided long-term interest rate, showing a negative correlation between them again. In the context of climate-related price pressures, inflation expectations and long-run interest rates are connected by environmental conditions and monetary policy. While both diagrams are only correlations, causality will likely run in both directions, reinforcing each other. The model developed in the next section aims to provide some insights into the mechanisms behind them.

In a recent document, the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) concludes that the impact of natural disasters might imply a potential long-term adverse effect on the global activity of up to minus 15 per cent (NGFS, 2022). Such uncertainty also harms economic growth, as global warming-related repercussions increase risk aversion and lead to unstable investment demand. Economic growth is

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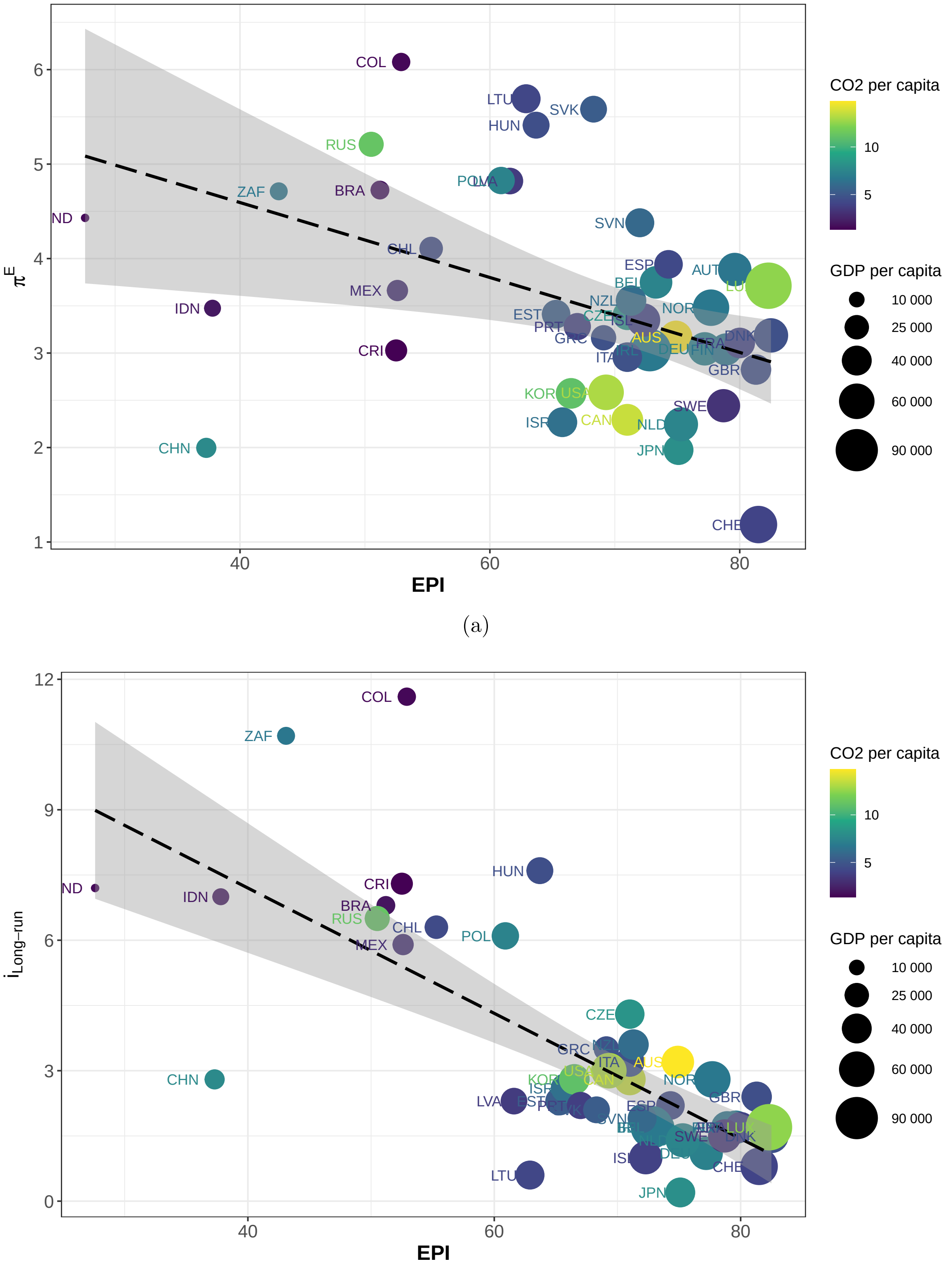
[1] A third category discussed in policy circles is "greenflation". Green technologies require large amounts of metals and minerals, such as copper, lithium and cobalt, especially during the transition period, pushing the demand for most metals and minerals, given the supply, and thus increasing prices. This paper uses the term *Climateflation* to capture all climate-change-related inflation pressures.



(a)

(b)

Figure 1: EPI, expected inflation, and long-run interest rates.

ultimately driven by improvements in productivity, which may be directly affected as innovation resources are diverted to rebuilding and adaptation to climate risks (as in Letta and Tol, 2019). This raises additional concerns regarding the divide between Global North and South, given that developed economies have lower inflation rates and somehow better environmental performance, while countries like India, Indonesia, and South Africa register the lowest EPI and highest inflation rates.

Whereas climate change may complicate the conduct of monetary policy, that is to say, guarantee price stability (Coenen et al., 2018), central banks are discussing whether to intervene by applying instruments that favour green production and investment (see Acemoglu et al., 2012; Schnabel, 2020; 2021). How monetary policy is carried out can influence the effectiveness of the transition. Scholarship assessing the climate change and monetary policy nexus is still relatively scant (e.g. Annicchiarico et al., 2018; Annicchiarico and Diluiso, 2019; Adjemian and Pariès, 2008; Solana, 2019). Authors such as Annicchiarico and Di Dio (2015) have explored what would be the optimal monetary policy response to climate change. Along similar lines, Economides and Xepapadeas (2018; 2019) develop a model that includes both climate change and monetary policy, pointing out that environmental degradation generates additional economic shocks that will affect the optimal conduct of the former. The second study by the same authors includes small-open-economy considerations in a New Keynesian model, suggesting that the loss of monetary policy independence does not matter for the long-term implications of climate change.

While the economic profession has provided important insights regarding the problem at hand, our reading of the relevant literature is that most of it continues to fundamentally rely on the so-called "independence hypothesis", i.e. money is neutral in the long run. In fact, the assumption that long-run economic performance and monetary policy are independent of each other stands as the dominant macroeconomics paradigm. It lies at the basis of the inflation-targeting framework used by most central banks. Considering the increasing evidence pointing out this might not be the case (e.g. Jordà et al., 2023; Ma and Zimmermann, 2023), we aim at developing a model that allows us to study the interplay between conventional monetary policy and the environment in a context where the former has real consequences.

3 The model

We consider an OLG economy where agents live for two periods: young and old. They work during the first phase and save all income in capital or government bonds. In the second period, they consume their previous savings. Our study builds on Caravaggio and Sodini's (2023) revisitation of the baseline environmental OLG growth model by John and Pecchenino's (1994) that has recently become quite popular among scholars interested in green-growth dynamics (e.g. Antoci and Sodini, 2009; Caravaggio and Sodini, 2022; Wei and Aadland, 2022; Jaimes, 2023). The present paper extends its framework in two different ways. First, we incorporate a damage function from emission externalities to output (see Brock and Taylor, 2010). Second, we link ecological degradation to inflation through a modified Phillips curve, allowing us to assess conventional monetary policy's environmental implications. It is argued that people incorporate *climateflation* resulting from physical and transition risks into their inflationary expectations. The monetary side of the economy is developed along similar lines to von Thadden (2012) and Hu et al. (2023). Our model joins recent efforts assessing the implications of including environmental goals into the monetary policy (for example, Dafermos et al., 2018; Chen et al., 2021 pioneering proposed a climate-augmented monetary policy rule).

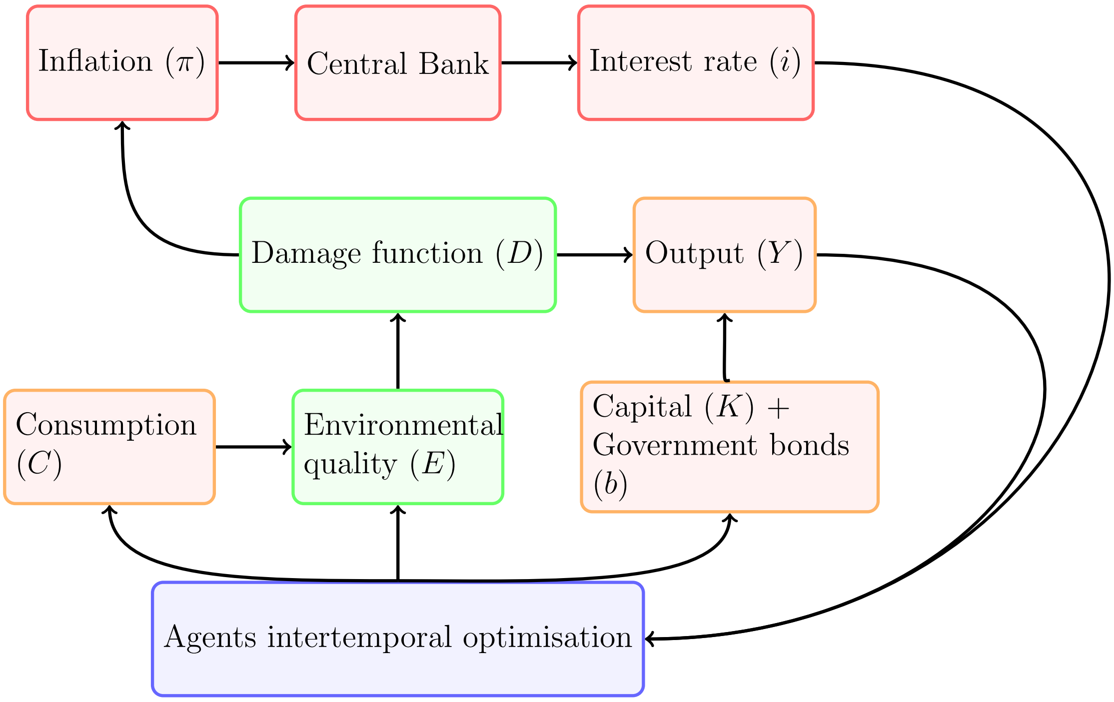


Figure 2: A summarising diagram of our environmental OLG model.

The OLG framework offers a natural setup where money is not neutral in the long run. As shown by Hu et al. (2023), even in the absence of any frictions, monetary policy has real effects because it determines the return on government debt, thus influencing the composition of the public's portfolio between government bonds and other assets. The "trick" consists in treating public debt as net wealth. Fig. 2 provides a summarising diagram of our environmental OLG model, which is divided in four main blocks of equations:

1. Production technology
2. Government's budget constraint
3. Lifetime choice problem
4. Inflation and monetary policy

Agents get utility from consumption and environmental quality. Consumption harms the environment, but as the public values the latter, people also devote resources to ecological conservation and recovery. Still, for each level of environmental quality, there is an externality on production in the form of a damage function. Environmental degradation is reflected in such a function, which further embodies physical and transition risks associated with climate change. As those climate-related risks accumulate, they constitute a sort of permanent supply shock. Agents respond by adjusting the inflation expectations. On the other hand, the monetary authority uses the interest rate to achieve price stability. We know there is an ongoing debate on the best instrument available to central banks to assess this kind of shock. However, given there is no consensus yet on the matter, we limit the analysis to a traditional Taylor rule. The choice of the interest rate feedbacks to the intertemporal optimisation problem of the agent, affecting her/his wealth composition. The amount of output produced – to be ultimately used either for consumption or to preserve the environment – depends on how much capital is accumulated.

3.1 Production technology

Firms adopt a production technology that combines capital (K) and labour (N), the latter corresponding to a constant number of identical two-period lived young agents. Climate change enters the picture as a negative externality on factors of production. Global warming damages the capital stock directly through natural disasters or indirectly through the fear that extreme events might happen, increasing investment risk and reducing its profitability. Moreover, the workforce is also affected by heat waves and other climate-change-related health problems. Such effects are represented by the function $D(\cdot) \in [0,1]$. In formal terms, we have:

$$Y_t = [1 - D(E_t)]F(K_t, N) \tag{1}$$
$$D_E < 0,\ F_K > 0,\ F_N > 0,\ F_{KK} < 0,\ F_{NN} < 0$$

where Y denotes output, $F(\cdot)$ is the standard neoclassical production function with constant returns to scale. Physical capital fully depreciates within the production process of one period. Climate-change-related externalities are an inverse function of an environmental quality index (E) such that high carbon emissions are associated with more ecological degradation, leading to lower output.

From Eq. (1), it follows that output per young agent (y) can be written as:

$$y_t = [1 - D(E_t)]F(k_t, 1) = [1 - D(E_t)]f(k_t) \tag{2}$$

where $y = Y/N$, capital per unit of labour is $k = K/N$ and $f(\cdot)$ corresponds to the production technology in percapita terms. As before, improving environmental conditions reduces the negative impact of the damage function, resulting in higher economic performance. By aggravating the climate emergency, higher emissions reduce per capita output.

We adopt a functional form for the damage function that comes with a smooth nonlinearity:

$$D(E_t) = \frac{1}{1 + \eta E_t} \tag{3}$$

where η is a parameter that intermediates the relationship between E and y, so that the larger η, the lower the impact of the environmental quality on the damage $D(E_t)$ and, therefore, on output y_t. This specification has some similarities with Dafermos et al. (2018), which build on previous work by Weitzman (2012). The main difference is that $D(\cdot)$ responds to an environmental quality index instead of global average temperatures in our setup.

Fig. 3 provides a more concrete view of its format, taking the EPI as a reference point, and measuring the output loss.[2] The blue, orange, and yellow lines indicate the sensitivity of the damage function to different values of η. The black dotted line marks the index value for Denmark (DNK), a country with one of the highest EPI scores, South Africa (ZAF), at the other extreme, and the United States (USA), as an intermediate case. It is shown that when the η value is low, in blue, the output loss is relatively high. In this situation, countries with the same production technology might experience large differences in output

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[2] While the EPI provides an interesting statistic to position leaders and laggards in terms of their environmental performance, its main problem lies in the positive relationship with Gross Domestic Product (GDP). Such a correlation is an issue because richer countries happen to be those that pollute more in per capita terms, creating an awkward situation where high carbon emitters present better environmental performance. They have also historically led the process of environmental degradation after the Industrial Revolution. Our results should be interpreted in the light of this limitation. We will use EPI and environmental quality interchangeably in the remainder of the paper.

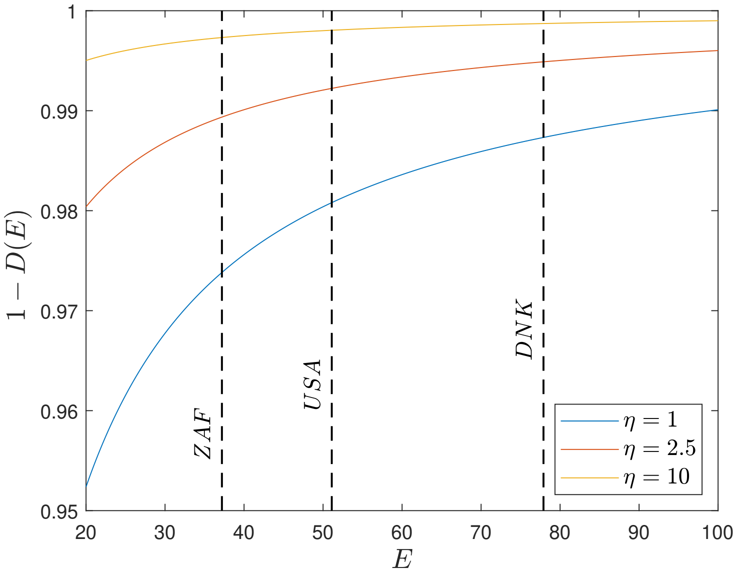

Figure 3: Sensitiveness of the damage function to different values of η. Environmental quality is *proxied* by the EPI that ranges between [0,100].

due to discrepancies in their environmental performance. Alternatively, when η is large, in yellow, countries with a similar $f(\cdot)$ encounter small differences in output even under large EPI gaps. Put differently, economies characterised by sectors with a high sensitivity to environmental quality experience the largest damage. Overall Fig. 3 delivers output losses similar to those reported by Dynamic Integrated Climate-Economy (DICE) models (for an overview, see Nordhaus, 2019).

We assume a Cobb-Douglas technology to keep the exercise simple and tractable from an algebraic point of view. This implies:

$$f\left(k_t\right) = Ak_t^{\alpha} \tag{4}$$

where $\alpha \in [0,1]$ is the correspondent technical coefficient and A is a scaling parameter capturing the so-called total factor productivity. Therefore, it immediately follows that the share of wages on income is $1-\alpha$. Given that production factors are remunerated according to their marginal productivity, from the profit-maximisation problem of the firm, we have that:

$$\begin{aligned} w_t &= \left[1 - D(E_t)\right]\left[f\left(k_t\right) - f_k\left(k_t\right)k_t\right] \\ &= (1-\alpha)[1 - D(E_t)]Ak_t^{\alpha} \end{aligned} \tag{5}$$

and

$$\begin{aligned} r_t &= [1 - D(E_t)]f_k\left(k_t\right) \\ &= \alpha[1 - D(E_t)]Ak_t^{\alpha-1} \end{aligned} \tag{6}$$

where w and r are the wage and profit rates in real terms. We would like to stress that it is assumed that capital fully depreciates within the production process of one period. Notice that the damage function implies that a deterioration of the environment due to carbon emissions reduces the remuneration of both production factors.

3.2 Government's budget constraint

The government consumes a share of nominal per capita output in each period without affecting households' utility. In this way, we abstract for the moment from the possibility of the public sector directly fighting climate change, for example, through carbon taxes or permits (for an application related to demography, see de la Croix and Gosseries, 2012; Cafferata and Davila-Fernandez, 2023). Of course, this does not mean such channels are not important, and we will come back to them later on. The primary balance (g) plus interest payments are financed through the emission of government bonds (b). Thus, the public sector budget constraint can be summarised as follows:

$$g_t + \left(\frac{i_{t-1}}{1+\mathbb{E}[\pi_t]} \right) b_{t-1} = b_t \tag{7}$$

where i is the one-period interest factor on government bonds per young agent and the operator $\mathbb{E}[\cdot]$ stands for expectations. Therefore, the real expected value of public bonds issued in $t-1$ is given by $b_{t-1}/(1+\mathbb{E}[\pi_t])$ with π as the inflation rate. All government spending, including its debt service net of taxes, must be financed by issuing new bonds. They are supposed to mature within one period. Hence, b should be understood as a one-period debt constantly being rolled over.

Debt targets can serve as a fiscal policy anchor to ensure the sustainability of fiscal policy and that there is sufficient policy room to cope with adverse shocks (e.g. von Thadden, 2012; Fall and Fournier, 2015). They provide a commitment tool that reassures markets, thereby diminishing risk premiums. To guarantee the stability of public debt, the fiscal agent is assumed to follow a rule that keeps the primary balance as a proportion to output (θ) constant. Considering that our goal here is not to derive the best fiscal policy but to study the side effects of a given type of policy, we take θ as exogenously determined. Making use of Eqs. (2) and (4), we have that bonds in a certain period are such that:

$$\begin{aligned} \frac{g_t}{y_{t-1}} &= \theta \\ g_t &= \theta[1-D(E_{t-1})]Ak_{t-1}^{\alpha} \end{aligned} \tag{8}$$

In this way, public debt becomes a function of environmental quality. By fuelling the damage function, high emissions reduce output. Thus, the primary balance compatible with the fiscal target will also be lower.

Substituting Eq. (8) into (7) and leading the resulting expression by one period, we obtain the dynamics of public debt as:

$$b_{t+1} = \theta[1-D(E_t)]Ak_t^{\alpha} + \left(\frac{i_t}{1+\mathbb{E}[\pi_{t+1}]} \right) b_t \tag{9}$$

such that the evolution of public debt responds to the environment, capital stock, and monetary policy. The latter matters in the form of interest and inflation rates.

3.3 Lifetime choice problem

We assume agents derive utility only from consumption (c) and environmental quality. Each representative individual born at time t has preferences defined over c and E at $t+1$, i.e. old age. To keep the algebraic steps as simple as possible, suppose an additively separable logarithmic utility function represents them. Accordingly, the lifetime choice problem consists in:

$$\begin{aligned} &\max_{c_{t+1},E_{t+1}} \; U\left(c_{t+1}, E_{t+1}\right) \\ U\left(c_{t+1}, E_{t+1}\right) = \; &\ln c_{t+1} + \ln E_{t+1} \end{aligned} \tag{10}$$

subject to

$$\begin{aligned} \text{Portfolio constraint: } & w_t = (1+\mathbb{E}[\pi_{t+1}])(k_{t+1}+b_{t+1}) + n_t \quad (11) \\ \text{Budget constraint: } & c_{t+1} = k_{t+1} + b_{t+1} \quad (12) \\ \text{Environmental quality: } & E_{t+1} = (1-d)E_t - \beta c_t + \gamma n_t \quad (13) \end{aligned}$$

where $0 < d < 1$ measures the speed of reversion of environmental quality to this level, while β and γ capture the sensitivity of EPI to consumption and conservation efforts (n). From the portfolio constraint, all wage income young agents receive is saved or used to improve the environment. They can supply their savings to firms or acquire public bonds. On the other hand, the budget constraint indicates that the old generation consumes all previous savings. This is a simplification introduced by Caravaggio and Sodini (2023) and substitutes the original specification in which the old generation only consumed income derivated from previously saved assets. Finally, the last expression recalls the evolution of environmental conditions (see John and Pecchenino, 1994; Antoci and Sodini, 2009; Caravaggio and Sodini, 2022, among others).

Combining Eqs. (11) and (12), consumption in $t+1$ can be written as the difference between wages and resources devoted to preserving and recovering the environment adjusted by inflation:

$$c_{t+1} = \frac{w_t - n_t}{1+\mathbb{E}[\pi_{t+1}]} \tag{14}$$

Following John and Pecchenino (1994), we assume agents take wages, the profit rate, and the EPI at the beginning of period t as given. Substituting Eqs. (13) and (14) into (10), the optimisation problem becomes:

$$\max_{n_t} \; \ln\left(\frac{w_t - n_t}{1+\mathbb{E}[\pi_{t+1}]}\right) + \ln\left[(1-d)E_t - \beta c_t + \gamma n_t\right] \tag{15}$$

A competitive equilibrium is characterised by agents maximising (15) satisfying firms maximising profits and markets clearing. Along the dynamic equilibrium path, the First Order Conditions (FOC) imply:

$$\begin{aligned} (1+\mathbb{E}[\pi_{t+1}])U_c\left(c_{t+1}, E_{t+1}\right) &= \gamma U_E\left(c_{t+1}, E_{t+1}\right) \\ E_{t+1} &= \gamma c_{t+1}\left(1+\mathbb{E}[\pi_{t+1}]\right) \end{aligned} \tag{16}$$

which establishes the optimal correspondence between the environment, consumption, and inflation. The marginal utilities U_c and U_E are equal, weighted by inflation and the marginal response of E to green activities.

From the concavity of the objective function concerning n, Eq. (16) allow us to obtain the optimal internal solution as:

$$n_t = \frac{1}{2}\left[w_t - \frac{(1-d)E_t + \beta c_t}{\gamma}\right] \tag{17}$$

Given that agents get utility from consumption but also value environmental quality, there is a trade-off between resources dedicated to conservation efforts and c. The relationship between them in the equilibrium path is intermediated by β/γ. This ratio captures the relative importance of both elements to E in $t+1$, see Eq. (13).

3.4 Inflation and monetary policy

We refer to Gordon's (1977) triangle model, which proposes a Phillips curve depending on inertia, demand, and supply factors. The first element includes wage and price contracts previously determined. The second captures demand-side-driven inflation sources in terms of the output gap. Among the supply factors, we include *climateflation*. The accumulation of climate-related physical and transition risks is interpreted as a supply shock that affects agents' expectations about inflation ($\mathbb{E}[\cdot]$). Assuming a separable equation, we write:

$$\pi_t = P(\pi_{t-1}, z_t - y_t) + \mathbb{E}[\pi_{t+1}]$$

where

$$\mathbb{E}[\pi_{t+1}] = \rho D(E_t) + \epsilon_t$$

such that

$$\epsilon_t \sim N(0, \sigma)$$

Function $P(\cdot)$ groups inertia and demand effects, z stands for per capita aggregate demand, and $\rho > 0$ intermediates the response of inflation to supply shocks related to global warming. Stochastic shocks ϵ are i.i.d. with σ corresponding to the standard error. They capture the fundamental uncertainty surrounding the formation of expectations, especially regarding climate-related inflationary pressures.

The study of the macroeconomic effects of supply disruptions, such as energy price shocks or the pandemic emergency, has gained momentum in the profession (e.g. Gordon, 2013; Fornaro and Wolf, 2023). In the present paper, we are specifically interested in price variations related to the environmental crisis, thus motivating our choice to take them as a function of $D(\cdot)$. Moreover, precisely because the role of inflation inertia goes beyond the scope of our main narrative, and we are assuming $z = y$ for all t, we silence that channel and simplify the expression above to:

$$\pi_t = \mathbb{E}[\pi_{t+1}] = \rho D(E_t) + \epsilon_t \tag{18}$$

such that an improvement in EPI reduces the pressure on π. Considering the functional specification proposed in Eq. (3) and that $E \in [0, 100]$, an index close to the upper boundary means inflation fluctuates around a zero mean.

The monetary authority has its primary role in maintaining price stability, defined by a specific level of inflation. A common framework to describe the behaviour of Central Banks is Taylor's (1993) rule. It describes that interest rates should respond to divergences of actual from target inflation and the output gap:

$$i_t = R(\mathbb{E}[\pi_{t+1}] - \bar{\pi}, z_t - y_t)$$

where $R(\cdot)$ is an increasing function in both arguments and $\bar{\pi}$ corresponds to the inflation target. As before, we recall that our model does not account for an output gap. Thus, we assume the Central Bank commits to a sequence of nominal interest rates which only react to deviations of expected inflation from the target rate:

$$i_t = \bar{r} + \phi(\mathbb{E}[\pi_{t+1}] - \bar{\pi}) \tag{19}$$

where $\bar{r}$ describes the "neutral" real interest rate while $\phi > 0$ is a policy reaction parameter. The nominal rate will equal $\bar{r}$ conditional to actual inflation matching $\bar{\pi}$. In this case, monetary policy is neither accommodative nor restrictive.

Substituting Eq. (18) into (19), the nominal interest rate becomes endogenous to environmental conditions:

$$i_t = \bar{r} + \phi\left[\rho D(E_t) - \bar{\pi}\right] + \phi\epsilon_t \tag{20}$$

By leading to a deterioration of the environment, higher CO2 emissions are ceteris paribus related to higher inflation and, consequently, to a more stringent monetary policy. The possible consequences of such a policy framework will be studied in what follows under different scenarios.

3.5 Dynamic system

The basic structure of the dynamic system comes from the government's budget constraint (9), our representative agent portfolio constraint (11) provided that the budget constraint (12) is also satisfied, and the dynamics of EPI in Eq. (13). After some rearrangements, we obtain:

$$\begin{aligned} b_{t+1} &= \theta\left[1 - D\left(E_t\right)\right] A k_t^{\alpha} + \left(\frac{i_t}{1 + \mathbb{E}[\pi_{t+1}]}\right) b_t \\ k_{t+1} &= \frac{w_t - n_t}{1 + \mathbb{E}[\pi_{t+1}]} - \theta\left[1 - D\left(E_t\right)\right] A k_t^{\alpha} - \left(\frac{i_t}{1 + \mathbb{E}[\pi_{t+1}]}\right) b_t \\ E_{t+1} &= \left(1 - d\right) E_t - \beta c_t + \gamma n_t \end{aligned} \tag{21}$$

Substituting Eqs. (5), (14), (17), (18), and (20) into the system (21), while abstracting from the stochastic component to focus on the deterministic skeleton of the model, our 3-dimension nonlinear map is defined and given by:

$$\begin{aligned} b_{t+1} &= \theta\left[1 - D\left(E_t\right)\right] A k_t^{\alpha} + \left\{\frac{\bar{r} + \phi\left[\rho D(E_t) - \bar{\pi}\right]}{1 + \rho D\left(E_t\right)}\right\} b_t \\ k_{t+1} &= \left(\frac{1-\alpha}{2}\right) \frac{\left[1 - D\left(E_t\right)\right] A k_t^{\alpha}}{1 + \rho D\left(E_t\right)} + \left(\frac{1}{2\gamma}\right)\left[\frac{\left(1 - d\right) E_t + \beta\left(k_t + b_t\right)}{1 + \rho D\left(E_t\right)}\right] \\ &\quad - \theta\left[1 - D\left(E_t\right)\right] A k_t^{\alpha} - \left\{\frac{\bar{r} + \phi\left[\rho D(E_t) - \bar{\pi}\right]}{1 + \rho D\left(E_t\right)}\right\} b_t \\ E_{t+1} &= \left(\frac{1-d}{2}\right) E_t - \frac{3\beta}{2}\left(k_t + b_t\right) + \gamma\left(\frac{1-\alpha}{2}\right)\left[1 - D\left(E_t\right)\right] A k_t^{\alpha} \end{aligned} \tag{22}$$

where the functional form of the damage function is defined in Eq. (3).

In steady state, $b_t = b_{t+1} = b^*$, $k_t = k_{t+1} = k^*$, and $E_t = E_{t+1} = E^*$. Thus, the equilibrium conditions are defined and given by:

$$\begin{aligned} b^* - \theta\left(1 - \frac{1}{1 + \eta E^*}\right) A k^{*\alpha} - \left[\frac{\bar{r} + \phi\left(\frac{\rho}{1+\eta E^*} - \bar{\pi}\right)}{1 + \frac{\rho}{1+\eta E^*}}\right] b^* &= 0 \\ \left(\frac{1-\alpha}{2}\right)\left(\frac{1 - \frac{1}{1+\eta E^*}}{1 + \frac{\rho}{1+\eta E^*}}\right) A k^{*\alpha} + \frac{1}{2\gamma}\left[\frac{\left(1 - d\right) E^* + \beta\left(k^* + b^*\right)}{1 + \frac{\rho}{1+\eta E^*}}\right] - b^* - k^* &= 0 \\ \left(\frac{1-d}{2}\right) E^* - \frac{3\beta}{2}\left(k^* + b^*\right) + \gamma\left(\frac{1-\alpha}{2}\right)\left(1 - \frac{1}{1 + \eta E^*}\right) A k^{*\alpha} - E^* &= 0 \end{aligned}$$

Table 1: Calibration strategy

Parameter	Value	Source
θ	0.05	Consistent with a government deficit to GDP of 5%
η	7.5	Consistent with a $D(E) \in (0.005, 0.01)$
A	20.75	Consistent with $y^* \approx 100$
α	0.4	Consistent with a labour income to GDP of 60%
ϕ	1.5	Hamilton et al. (2011) & Carvalho et al. (2021)
$\bar{r}$	0.025	Laubach and Williams (2003) & Holston et al. (2017)
$\bar{\pi}$	0.02	Consistent with a 2% inflation target
γ	2.5	Caravaggio and Sodini (2022; 2023)
d	0.1	Consistent with a natural recovery rate of 10%
β	1.5	Caravaggio and Sodini (2022; 2023)
ρ	4.5	Consistent with climateflation $\in (0.005, 0.02)$
ϵ	0.01	Conrad et al. (2022) & Falck et al. (2021)

Unfortunately, we cannot find a closed-form equilibrium solution for the system (21). Therefore, we rely on numerical experiments to study the existence of equilibrium and some of its dynamic properties, with a special emphasis on policy insights.

4 Numerical experiments

To provide a more concrete view of the main transmission mechanisms of the model, we present a numerical exercise based on a broad choice of parameters for our dynamic system. We do not aim to represent a specific country or region but rather to assess the forces that might be at play in our environmental OLG setup. Table 1 reports our calibration strategy. Some values, for example, those related to the Taylor rule and estimates of the natural interest rate, were chosen following the conventional macro literature (e.g. Laubach and Williams, 2003; Hamilton et al., 2011; Holston et al., 2017; Carvalho et al., 2021). Others, such as the government deficit and the production function technical coefficient, were selected to match general macroeconomic stylised facts. Finally, we adopt a conservative approach for parameters related to *climateflation* and the damage function, allowing for relatively small effects.

Using the parameter values in Table 1, the deterministic part of our system admits a unique stable equilibrium:

$$P_1 = (b^*, k^*, E^*) = (5.1, 40, 46)$$

which is consistent with a level of output per young agent ≈ 100. Still, we would like to rule out more confidently, at least numerically, the existence of other stable solutions. Thus, we plot in Fig. 4 the basin of attraction of P_1 in the interval:

$$b \in [-100, 100], \quad k \in [0, 100], \quad E \in [0, 100]$$

While most likely $b > 0$, we consider initial conditions for which the government is a lender instead of a net borrower. Moreover, we are treating output as an index that fluctuates around 100. Thus, we allow the capital stock to vary in a similar interval. Finally, by definition, the environmental quality indicator lies between zero and 100. The red region in Fig. 4 indicates all initial conditions converging to P_1 while, in black, we show those diverging from it. Notice that you need very low levels of environmental quality and capital

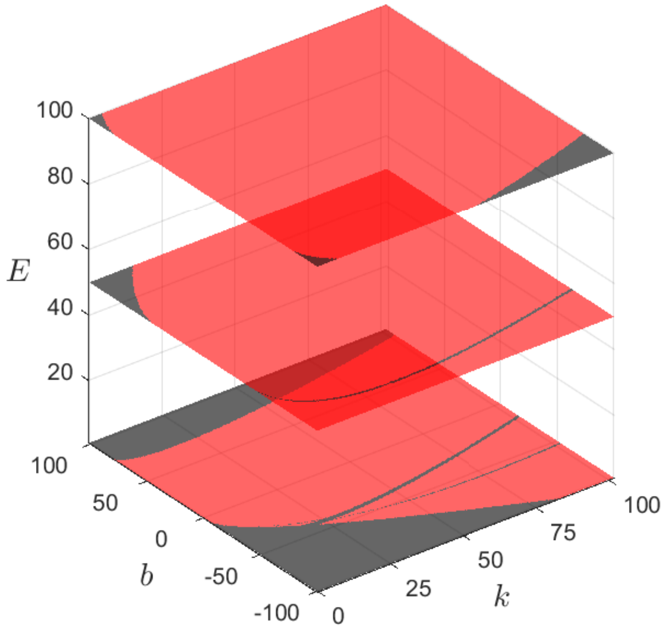

Figure 4: Basins of attraction of the numerically obtained unique stable equilibrium point P_1. The red region indicates initial conditions converging to P_1 while, in black, we have those diverging from it.

stock combined with high debt to escape the attracting region around P_1. Alternatively, the government would have to be a large creditor, $b < 0$, which seems unrealistic. Therefore, we feel comfortable treating P_1 as the system's unique stable (relevant) equilibrium point.

We proceed by performing a series of experiments for the stochastic version of the system. Exogenous shocks from inflation expectations interact with monetary policy, further reverberating in the rest of the economy. We assume $\epsilon = 0.01$ following evidence discussed by Falck et al. (2021) and Conrad et al. (2022). The model was run 1000 times in each scenario to report the average with the respective confidence interval. We study four scenarios, three regarding monetary policy and the last referring to a more expansive fiscal policy.

4.1 Monetary policy

We evaluate the response of the model to changes in three crucial parameters. First, we study what happens when there is an increase in the expectations response to *climateflation*. We doubled the value of ρ from 4.5 to 9, equivalent to raising expected climate-related inflation from $\approx 1.25\%$ to 2.5%. In a second scenario, we explore the implications of an increase in the central bank's response to inflation. Such a case is analogous to saying the monetary authority becomes more inflation-averse. To illustrate it, we doubled the respective coefficient from 1.5 to 3. A last experiment involving monetary policy consists in raising the inflation target. One could read this setting as a recognition that climate change-related physical and transition risks are somehow part of the new reality that should be incorporated into the targets adopted to pursue price stability.

Fig. 5 reports, in blue, our baseline scenario and, in orange, the model's response to increasing ρ. The first result that emerges is an apparent trade-off between economic activity and environmental quality. As agents strongly incorporate climate change into their inflation expectations, there is an increase in inflationary pressures, to which the monetary authority responds by adopting a contractionary monetary policy, i.e. higher i. Its motivation lies in the need to keep expectations anchored. However, this move raises the share of public debt and reduces capital accumulation. A reduction in production and consumption of the old brings the environmental pressure down, allowing an improvement in E. Still, the last effect is not strong enough to reduce $\mathbb{E}[\pi_{t+1}]$, leaving inflation above the baseline scenario.

Using similar colours, we depict in Fig. 6 the system's response to a central bank that is more responsive to deviations of inflation from the target. The trade-off between y and E is still there, though with a different flavour. Inflationary pressures from environmental degradation exist but are stable, explaining the almost constant π. That is because expectations depend more on the shape of the function $D(\cdot)$ than on ϕ. As agents have utility from E, they reduce savings to maintain a certain level of conservation activities. This change results in a contraction of wealth, slightly stronger from the side of b rather than k. Thus, contrary to the previous case, there is no switch in the wealth composition. The share of productive assets increases somewhat relative to public debt holdings. Still, the stochastic component of $\mathbb{E}[\cdot]$ makes that b/k remain the same for practical purposes.

Our third experiment consists of investigating the consequences of increasing the inflation target. There is at least one good reason the monetary authority might pursue such a strategy. When expected inflation equals $\bar{\pi}$, the Taylor rule indicates the nominal interest rate equals the "neutral" one. If climate change implies a sequence of cumulative supply shocks associated with physical and transition risks that are part of the new reality, policymakers might want to accommodate monetary policy accordingly. Fig. 7 shows the system's response to doubling $\bar{\pi}$ to 4%. Notice that the six diagrams in Figs. 6 and 7 are quite similar. The trade-off between y and E is still there. Agents prefer physical assets, reducing the b/k ratio. Moreover, the reduction in economic activity favours a certain recovery of environmental quality through two main channels. First, there are fewer resources to consume. Second, as some resources are still used for environmental conservation activities, they slightly improve E.

A natural question arises: What inflation target and EPI deliver a nominal interest equal to the real neutral rate? Fig. 8 provides some insights into that direction, taking Denmark, South Africa, and the United States as reference points. In blue and orange, the panel on the left reports the curves corresponding to $\rho = 4.5$ and 9, respectively. In both cases, we have a negative relationship between $\bar{\pi}$ and E, reflecting the intrinsic nature of *climateflation*. Improving environmental conditions is associated with reduced emissions that limit climate-related supply shocks. Thus, the inflation target compatible with $i = \bar{r}$ decreases. A higher ρ means inflationary expectations respond strongly to the damage function, explaining why the orange curve lies above the blue one. The panel on the right refers to a similar situation, but we now change the shape of the $D(\cdot)$ function. Again, the higher the damage related to a lower E, the higher $\bar{\pi}$ would have to be. For example, in the case of the USA – which has an EPI score close to 50 – the hypothetical inflation target is between 1%, see the orange line in the right diagram, and 7.5%, as depicted by the orange line in the left panel.[3]

This environmental OLG model suggests that monetary policy has non-neglectable economic and environmental performance implications. The main transmission channel lies in conventional monetary policy having real effects because it determines the composition of the public's portfolio between productive capital and government bonds. *Climateflation* generates inflationary pressures, and the central bank's response leads to the emergence of

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[3] As indicated the first time we referred to the EPI, it ranks 180 countries on climate change performance. most of them are in the interval [20,80]. The choice of plotting DNK, ZAF and the USA was mainly motivated to provide a visualisation of the spectrum where developed and developing countries lie according to this indicator. Moreover, it allows us somehow to compare the environmental performance of a leading European country with the United States.

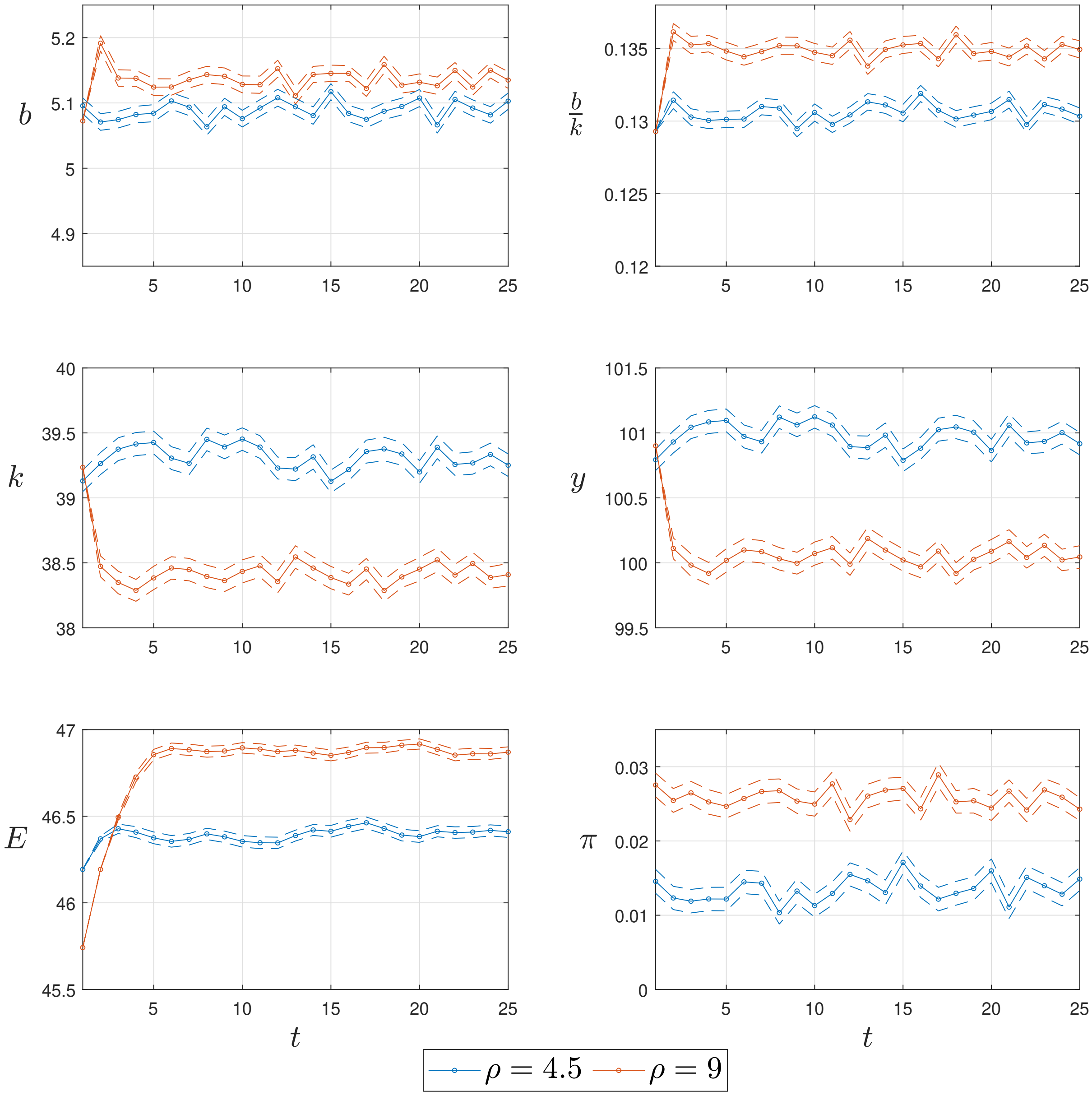

Figure 5: Response to a negative shock under different scenarios of climate-change-related inflation. The dotted lines mark the 95% confidence interval. For comparability reasons, we use the same scale for the respective diagrams in Figs 5 to 7.

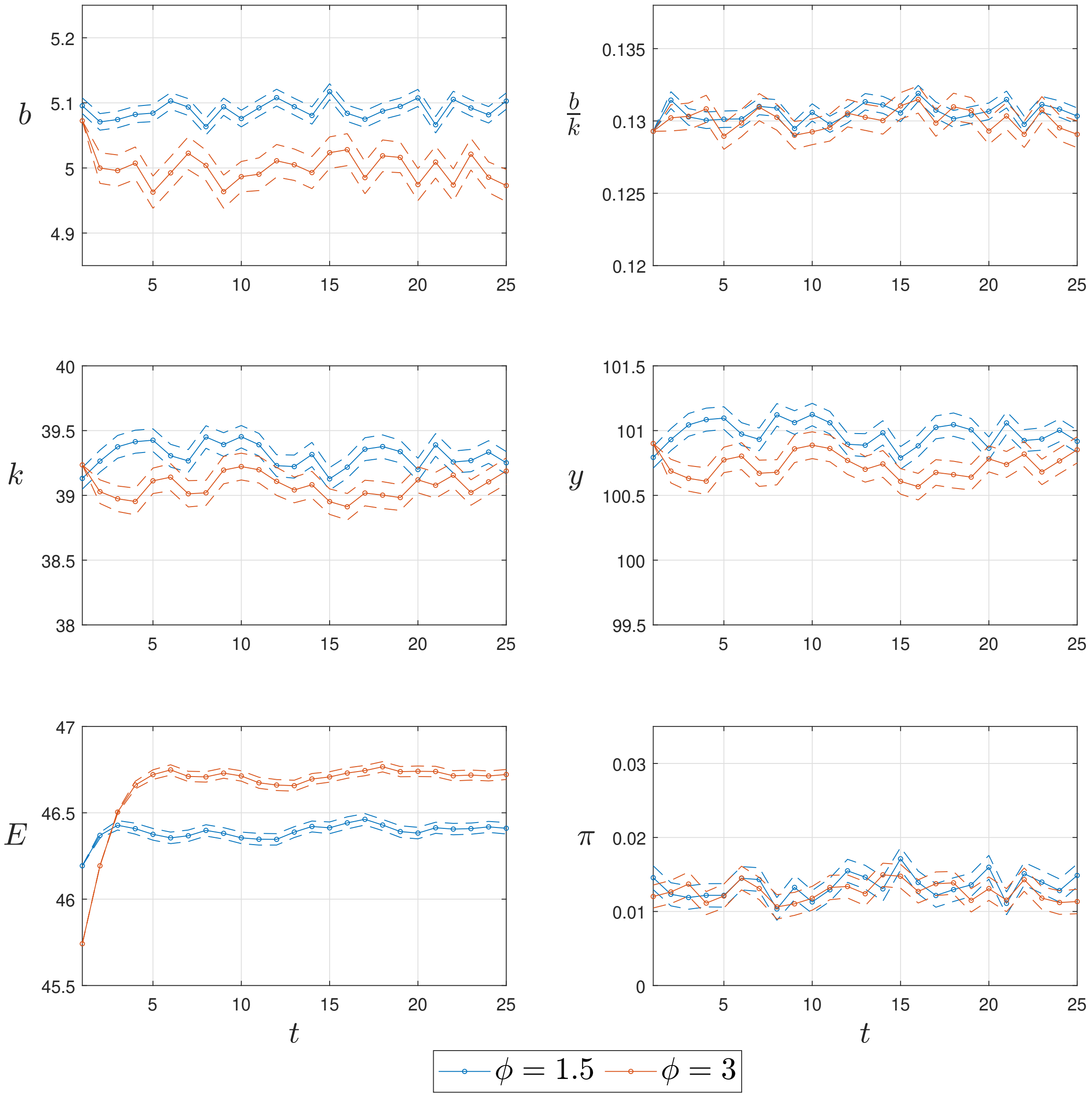

Figure 6: Response to a negative shock under different scenarios of inflation aversion by the Central Bank. The dotted lines mark the 95% confidence interval. For comparability reasons, we use the same scale for the respective diagrams in Figs 5 to 7.

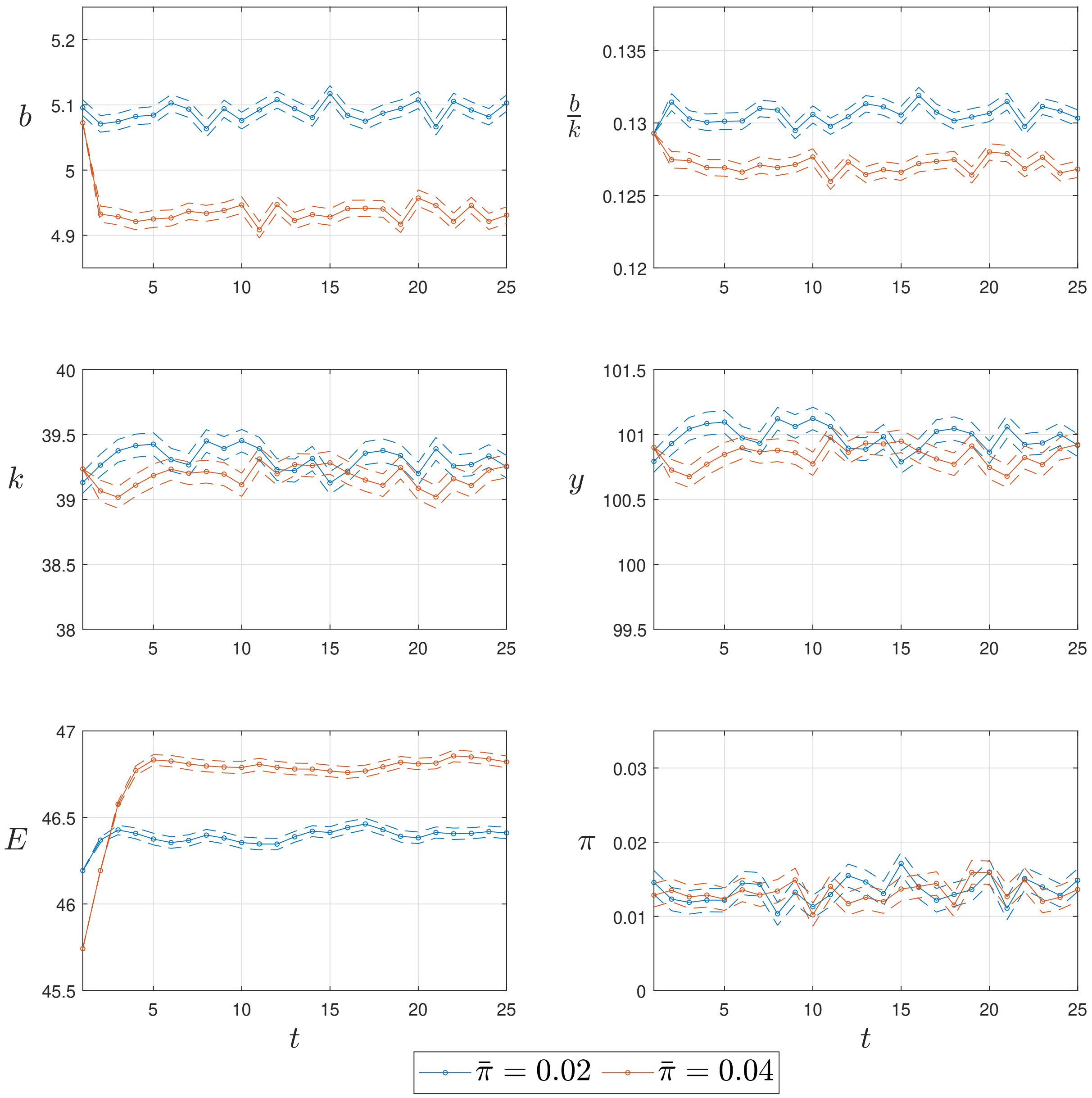

Figure 7: Response to a negative shock under different inflation targets. The dotted lines mark the 95% confidence interval. For comparability reasons, we use the same scale for the respective diagrams in Figs 5 to 7.

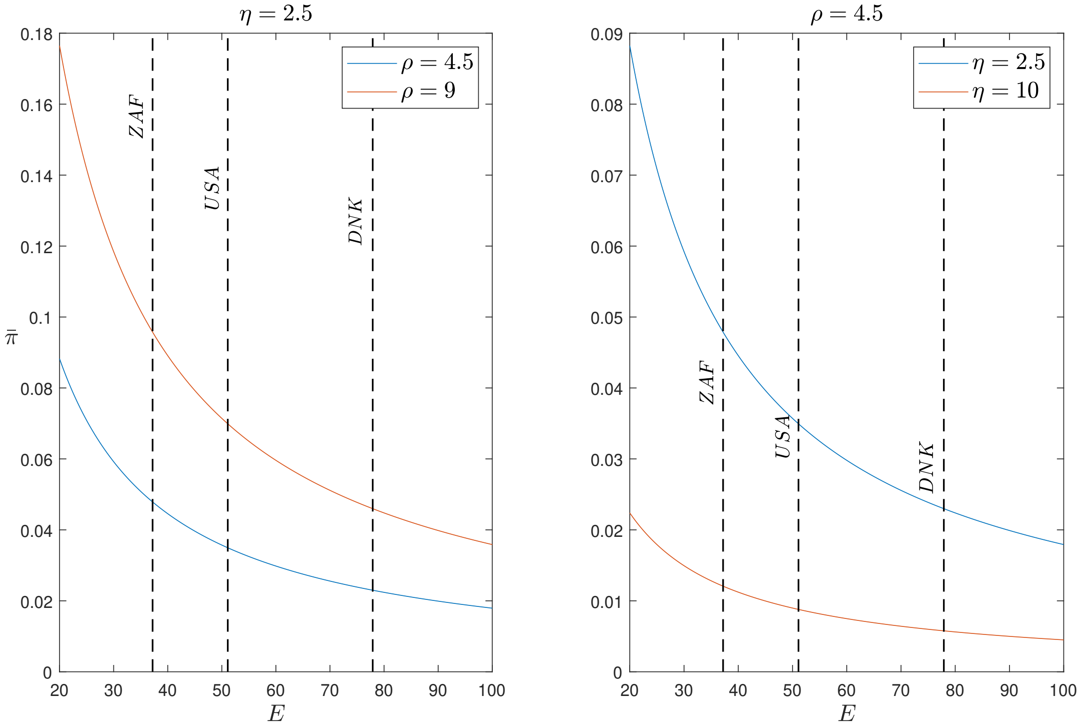

Figure 8: Inflation target and EPI combination delivering a nominal interest rate equal to the real neutral rate.

the trade-off between output and environmental quality. A contractionary monetary policy allows for some improvement in E at the cost of a reduction in y. The monetary authority can reduce the costs of such a trade-off but only to some extent by increasing its inflation target.

4.2 Fiscal policy

Our last experiment regards the adoption of a more lenient fiscal policy. This last set of findings should be taken with a pinch of salt. In the model, the government has a passive role regarding climate change. It does not actively engage in improving environmental quality nor implement any sort of carbon taxes. While future research on the topic will be encouraged, Fig. 9 has an important message. If fiscal policy does not take seriously global warming, raising θ is dangerous. Monetary policy guarantees a positive rate of return to government debt. Therefore, an expansionary fiscal policy leads to a strong switch towards that asset, significantly reducing capital accumulation. Per capita output depends on physical capital; thus, economic activity is also reduced. Moreover, as such a contraction is the strongest reported in our simulations, the pool of resources available for conservation purposes is harmed. The trade-off between economic activity and the environment disappears, with y and E going down.

An expansive fiscal policy has strong negative implications for economic activity. However, that might be the case only when the government does not engage in conservation activities. We slightly modified Eq. (13) to test this alternative, assuming all the deficit is used to improve environmental quality. We could think about this scenario as the government keeping a balanced budget and incurring debt only to promote a green-transition

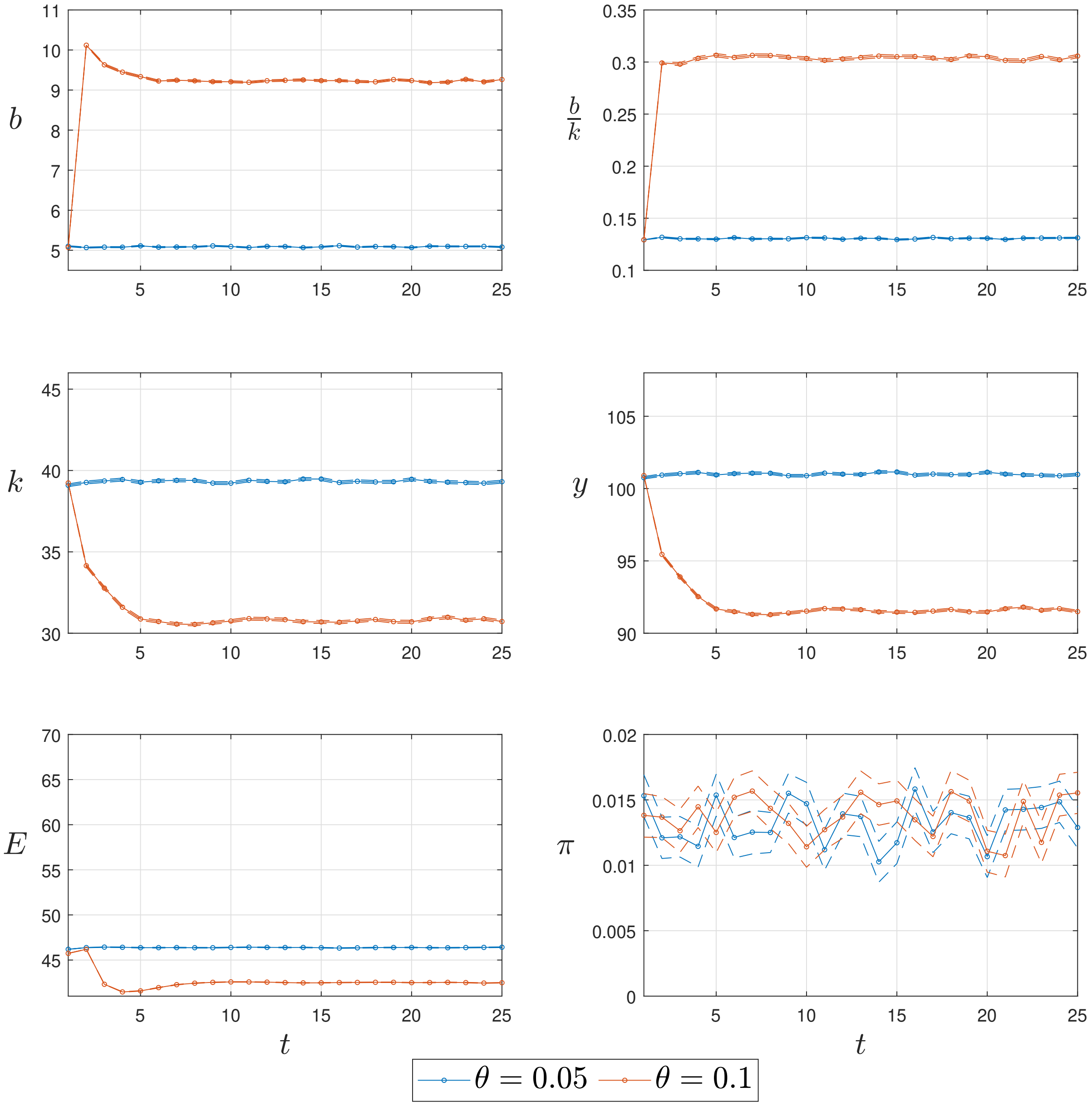

Figure 9: Response to a negative shock under different deficits. The dotted lines mark the 95% confidence interval. For comparability reasons, we use the same scale as in Fig. 10.

agenda:

$$E_{t+1} = (1-d)E_t - \beta c_t + \gamma(n_t + \theta y_t) \tag{23}$$

where θ is the target deficit embodied in the fiscal rule, see Eq. (8), lead by one period. Eq. (23) implies that private and public action have the same impact on E, intermediated by parameter γ.

The modified 3-dimension deterministic skeleton of our nonlinear map is defined and given by:

$$\begin{aligned}
b_{t+1} &= \theta \left[1 - D\left(E_t\right)\right] A k_t^{\alpha} + \left\{ \frac{\bar{r} + \phi\left[\rho D(E_t) - \bar{\pi}\right]}{1 + \rho D\left(E_t\right)} \right\} b_t \\
k_{t+1} &= \left(\frac{1-\alpha}{2}\right) \frac{\left[1 - D\left(E_t\right)\right] A k_t^{\alpha}}{1 + \rho D\left(E_t\right)} + \left(\frac{1}{2\gamma}\right) \left[\frac{(1-d)\, E_t + \beta\left(k_t + b_t\right)}{1 + \rho D\left(E_t\right)} \right] \\
&\quad - \theta\left[1 - D\left(E_t\right)\right] A k_t^{\alpha} - \left\{ \frac{\bar{r} + \phi\left[\rho D(E_t) - \bar{\pi}\right]}{1 + \rho D\left(E_t\right)} \right\} b_t \\
E_{t+1} &= \left(\frac{1-d}{2}\right) E_t - \frac{3\beta}{2}\left(k_t + b_t\right) + \gamma \left(\frac{1-\alpha}{2} + \theta\right) \left[1 - D\left(E_t\right)\right] A k_t^{\alpha}
\end{aligned} \tag{24}$$

where the main difference with the baseline model is that θ also appears in the last dynamic relation, reflecting the positive impact of the government on environmental quality.

Fig. 10 plots, in blue, time series under the standard calibration used in Table 1. We refer to it as a zero-green government deficit because public debt is used to finance activities unrelated to climate change or sustainability. In orange, we report the opposite situation: All deficit is directed to the environment. The bottom left diagram shows a strong improvement in the EPI. An immediate implication is a reduction in inflation, as the government lowers inflationary expectations by mitigating climate-related risks. We document a certain increase in public debt, but the strong reduction in the negative externality from the damage function guarantees agents prefer physical assets. These two effects together are related to higher production. The environment-production trade-off is broken again, with both variables improving together. We conclude that expansive fiscal policy should be avoided unless the government engages – directly or indirectly – green activities. Such a result is in line with the recent literature highlighting the importance of the public sector in tackling climate change among more conventional approaches (Brock and Taylor, 2010; Nordhaus, 2019), including OLG models (Jaimes, 2023), but also behavioural macroeconomics (e.g. Sordi and Davila-Fernandez, 2023; Campiglio et al., 2023).

5 Final considerations

The so-called "independence" hypothesis lies at the core of the current macroeconomics paradigm and is at the basis of the inflation-targeting framework. Still, recent empirical evidence challenges the view that productive capacity is independent of monetary policy. This is happening in a context in which central banks are increasingly realising that climate change can potentially impact prices, and they should do something about it. The present paper aims to contribute to the intersection of these two major themes. We studied the interplay between conventional monetary policy and the environment in a context where money is not neutral in the long run.

Using an environmental OLG model treating government debt as net wealth, we innovate by linking the environment to inflation through inflationary expectations in a modified Phillips curve. Central banks set the nominal interest rate using a generalised Taylor rule.

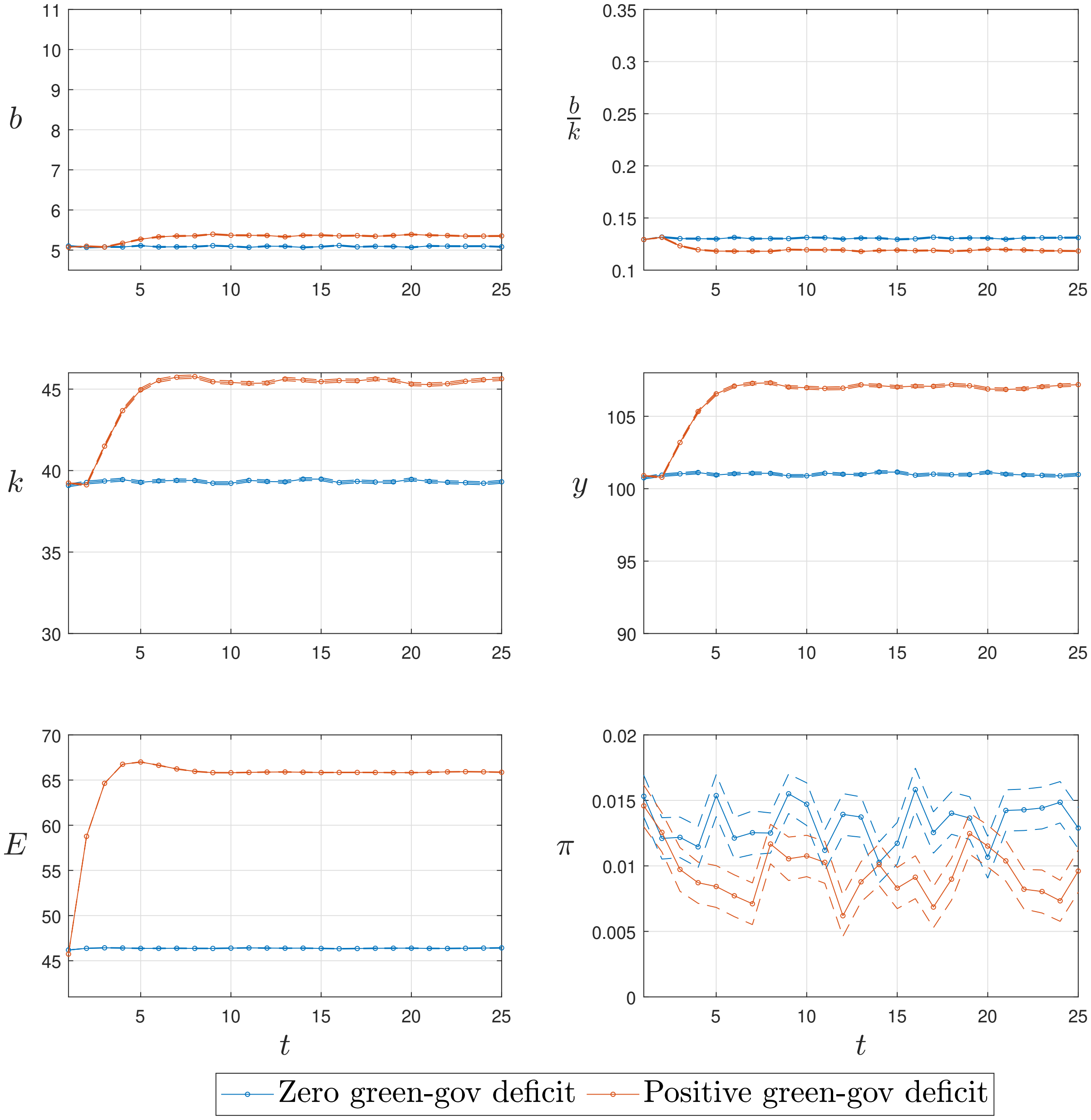

Figure 10: Response to a negative shock when the government finances environmental conservation. Zero green-gov deficit indicates $\theta > 0$, but fiscal policy is not used to improve environmental quality. A positive green-gov deficit corresponds to the alternative case. The dotted lines mark the 95% confidence interval. For comparability reasons, we use the same scale as in Fig. 9.

They affect wealth composition via the individual lifetime choice problem. Numerical experiments allow us to assess the robustness of the trade-off between environmental quality and economic activity when (i) expectations are more responsive to *climateflation*, (ii) the monetary authority is more inflation-averse, (iii) the central bank increases the inflation target, and (iv) fiscal policy is less stringent.

In the first three scenarios, a more stringent monetary policy in response to *climateflation* leads to lower output and a certain improvement of environmental conditions. The main transmission channel was the composition of the public's portfolio between government bonds and other assets, recently highlighted in a different context by Hu et al. (2023). Finally, we showed that expansive fiscal policies might be counterproductive if the government does not improve environmental conditions. This could be done through its direct or indirect involvement in financing the development of green technologies. Without such actions, increases in the public deficit divert wealth accumulation from physical assets to pure government debt. As a main consequence, production and environmental quality are reduced, breaking the previously mentioned trade-off.

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