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Research Article

Keywords: Fiscal Rules, Climate Policy, Public Debt, Present Bias, Golden Rule of Fiscal Policy, Social Cost of Carbon

Posted Date: September 29th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10820254/v1>

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Additional Declarations: No competing interests reported.

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Abstract

Climate policy imposes costs now for benefits that accrue largely to future generations, and public debt can align the two over time. Fiscal rules, adopted to restrain present-biased governments from over-borrowing, foreclose this alignment — and are criticized more broadly for reducing investment in dynamic public goods. The standard remedy, the golden rule of public finance, exempts public investment from the deficit limit but founders operationally: what counts as investment cannot be sharply observed, leaving it open to creative accounting. We propose a green–golden rule that changes the privileged asset: it ties the admissible deficit not to public investment in general but to the reduction in greenhouse-gas emissions — a change in the *atmospheric* capital stock, valued at the social cost of carbon (SCC). Because the quantity is sharply measurable, the rule leaves no room for creative accounting; because it is homogeneous, its depreciation rate and return are readily quantifiable, unlike the asset-specific schedules the classical golden rule requires; and because the rule conditions borrowing on the *return* to abatement rather than its *cost*, it is output- rather than input-based, giving the government an incentive to undertake only abatement that passes a cost–benefit test. We embed the rule in a welfare-theoretic model, in which it reconciles fiscal discipline with efficient climate policy. In quantity- and price-based versions, a carbon price on building and transport emissions of

200 Euro — our assumed SCC — would justify a deficit of about 72 billion Euro per year for the European Union.

Keywords: Fiscal Rules, Climate Policy, Public Debt, Present Bias, Golden Rule of Fiscal Policy, Social Cost of Carbon

JEL Classification: E62 , H54 , H62 , H63 , Q54 , Q58

1 Introduction

A defining feature of climate policy is that it imposes costs now while the bulk of its benefits accrues in the distant future. Public debt can align these costs and benefits over time — a genuine synergy: by shifting part of the financing burden onto the future generations who reap the benefits, debt-financed climate policy can be made intertemporally equitable and, in overlapping-generations settings, even Pareto-improving (Bovenberg and Heijdra 1998, 2002; Sachs 2014; Andersen et al. 2020; Kotlikoff et al. 2021).

Governments, however, are largely prevented from exploiting this synergy. Rising government debt ratios have led many countries to adopt fiscal rules that contain deficits. The usual rationale is a political-economy distortion, of which an important class is *present bias* — governments giving excessive weight to the present and so over-borrowing at the expense of future generations (see Yared 2019, for an overview). Yet by restraining deficits indiscriminately, the same rules also foreclose the intertemporal alignment of costs and benefits that debt-financed climate policy could achieve.

The damage may run deeper still: fiscal rules are sometimes criticized for containing deficits at the expense of public investment more broadly. The empirical evidence is design-dependent: two recent reviews find no conclusive relationship on average (Potrafke 2025; Blesse et al. 2026), but rigid rules — those without escape clauses or special treatment of investment expenditure — are associated with lower public investment (Poterba 1995; Venturini 2020; Ardanaz et al. 2021), whereas rules that exempt investment are not (Gregori 2018; Burret and Feld 2018). The design of the rule is therefore decisive.

Of the designs proposed to protect investment — escape clauses, expenditure rules, carve-outs for specific spending categories — the most prominent is the *golden rule of public finance*, which exempts public investment as a whole from the deficit limit. Its justification is threefold: under the benefit or “pay-as-you-use” principle, those who enjoy the services of long-lived public capital should share in its cost (Musgrave 1939); a golden rule offsets the under-provision of durable public goods that arises when current voters disregard benefits accruing to future generations (Bassetto and Sargent 2006); and, because public investment raises output, debt-financed investment need not raise the debt-to-GDP ratio (Abiad et al. 2016; Ciaffi et al. 2024). Each of these arguments, however, presupposes that the spending so privileged genuinely is investment — and precisely that has proven contestable in practice, leaving the rule open to circumvention by “creative accounting.”

The green-golden rule.

A convincing reform would therefore do two things at once: prevent the abuse the classical golden rule allows, and put to work the synergy between public debt and climate policy with which we opened. In this article we propose such a reform — the *green-golden rule*.¹ Its central idea is to change the asset to which the golden rule applies. Classically, the relevant asset is the physical capital stock, and net investment is its change over time. More recent proposals focus on a “green” subset of the capital stock, e.g. wind parks, grids, charging infrastructure. We instead tie the admissible deficit to a change in the *atmospheric* capital stock — the reduction in greenhouse-gas emissions, measured in tons of CO₂ equivalents — which we term *climate investment*. Under the proposed rule, the admissible deficit increases proportionally to the realised emission reductions by a factor equal to the social cost of carbon (SCC). The rethinking of the underlying asset is one of the central conceptual contributions we make and provides a link to the *genuine wealth* literature (Arrow et al. 2004).

Two key characteristics of climate investments defined as emission reductions are worth highlighting: they are sharply measurable and they are perfectly homogeneous. Three improvements follow: because emission reductions are sharply measurable, the rule leaves no room for creative accounting; because emission reductions are homogeneous, the depreciation rate is readily quantifiable; and because it conditions borrowing on the *return* to abatement rather than its *cost*, it is output- rather than input-based, giving the government an incentive to undertake only abatement that passes a cost-benefit test. We now briefly elaborate on the two characteristics and the resulting improvements in turn.

Measurability and creative accounting.

The golden rule is widely regarded as theoretically attractive (Bassetto and Sargent 2006; Bom 2019); its difficulty is not conceptual but operational. Distinguishing investment from consumptive expenditure is hard, and any government whose spending priorities are distorted toward consumption by political-economy frictions has an incentive to exploit the resulting ambiguity by relabelling current spending as investment. This is the “creative accounting” critique (Milesi-Ferretti 2003; von Hagen and Wolff 2006; Burret and Feld 2018), which has led to the assessment that, despite its intuitive appeal, the golden rule does not appear to be an appropriate solution (Balassone and Franco 2000). It is this operational wall, rather than any flaw in the underlying logic, that the golden rule has never cleared.

A range of more recent proposals refine the golden rule but run into the same wall. Blanchard and Giavazzi (2004) would exclude net public investment from the deficit measure, an approach echoed by Truger (2016). Closest to our own setting are the climate-specific variants: Darvas and Wolff (2023) propose a “green fiscal pact,” and Caselli et al. discuss a “green fiscal rule” in the same spirit, both shielding climate-related expenditure from deficit limits and treating investment as a change

¹We are not the first to use the term *green-golden rule*. Darvas and Wolff (2023) propose a rule where qualifying green investment is defined by a categorization that must be verified case by case. The admissible deficit is tied to the cost of the investment. We share its name and motivation with this contribution but not the construction. Chichilnisky et al. (1995), by contrast, use “golden rule” in the sense of neoclassical growth theory — the consumption-maximizing savings rate — rather than the golden rule of fiscal policy.

in a stock of green capital. All, however, remain exposed to the creative-accounting critique. Some seek to contain it through case-by-case classification and verification. For instance, [Darvas and Wolff \(2023\)](#) propose a European Council-defined priority list whose compliance is assessed by the European Commission, national fiscal councils, and audit offices. However, these micro-level assessments are resource intensive at best; at worst they leave space for political interference at a lower level because the privileged category remains a heterogeneous, hard-to-value quantity (net investment broadly or mitigation and adaptation outlays).

The green-golden rule clears this wall by construction — the first of its three improvements. It does so due to a property of the atmospheric stock that physical capital lacks: *measurability*. The emission reduction is quantified at the macro level under inventory conventions established by the Intergovernmental Panel on Climate Change (IPCC), without project-by-project assessment. This removes any dispute over what counts as investment and over how much of it has taken place, and with it the government’s scope for creative accounting. There is no heterogeneous, hard-to-value capital stock left to reclassify or revalue, and so no margin on which the qualifying quantity can be inflated.

Homogeneity, depreciation, and returns.

The second property of the atmospheric capital stock that distinguishes it from the physical capital counterpart is *homogeneity*. Because one ton of CO₂ equivalent is identical to any other, the entire stock is characterized by a *single* depreciation rate and a *single* rate of return, rather than by the asset-specific schedules that a heterogeneous capital stock would require. Both, moreover, are quantifiable: First, the depreciation rate of climate investment — the atmospheric decay rate of carbon — is a near-zero physical constant. It thereby disposes of a standard objection to the classical golden rule: that the depreciation (or *amortisation*) of public capital is hard and administratively costly to assess ([Balassone and Franco 2000](#)).

Second, the return is the social cost of carbon (SCC). At this point, it becomes apparent that the green-golden rule does not abolish discretion, but the homogeneity of the underlying investment concentrates it into two macro-level judgments, the first being the SCC just introduced. That judgment is a real one — the SCC embeds a normative choice, above all of the social discount rate — but it is a single parameter that experts and society can debate and settle once, in the open, and that then applies uniformly to every ton, rather than a multitude of case decisions each open to quiet capture.² The second is a counterfactual, business-as-usual scenario, which we specify when operationalizing the rule.

²It is worth noting that the SCC is a quantity with an established pedigree. A large academic literature is devoted to its computation ([Nordhaus 2014](#); [Rennert et al. 2022](#); [Tol 2023](#)), and it has been used to guide policy in practice — most notably for more than fifteen years by the US Environmental Protection Agency ([Environmental Protection Agency](#)). The benefits of climate investment can therefore be computed with established methods, and have already been used in past policy applications.

Output- versus input-based rules.

As described above, homogeneity allows us to quantify the return on the emission reductions — the SCC. This makes it possible to transition from an *input*-oriented rule to an *output*-oriented rule.

The improvement is a sharper break than it may at first appear. The classical golden rule conditions deficits on the *cost* of investment, not on its return, and the proposals that refine it inherit this orientation: net-investment exclusions (Blanchard and Giavazzi 2004; Truger 2016) and the green variants (Darvas and Wolff 2023; Caselli et al.) alike condition on the cost of qualifying expenditure.³ One may conjecture that this reliance on the input side is itself a response to the difficulty of measuring the returns to public investment — when returns cannot be observed, conditioning on observable costs becomes the natural fallback.

It is precisely this fallback that the climate case escapes, because the SCC provides a credible monetized return. Our rule is accordingly *output*-oriented: the admissible deficit is tied to the *return* to abatement. What the government may finance through debt is governed by the benefit it has generated, not by what it has spent.⁴

This third improvement, output-orientation, has in turn three consequences that we regard as further substantive payoffs of the rule and that set it apart from its input-oriented counterparts. First, because the rule rewards realized abatement rather than expenditure, it gives the government an incentive to abate where it is cheapest — to maximize emission reductions per euro — rather than merely to spend on qualifying categories. Second, and relatedly, the rule gives the government an incentive to undertake only investments that pass a cost–benefit test. Because the deficit it permits is bounded by the monetized benefit of the abatement achieved rather than by its cost, projects that fail this test reduce the government’s effective fiscal space. The classical golden rule offers no such discipline.⁵ Third, the deficit room the rule grants is unconditional. Because the rule conditions on the benefit already generated — the realized abatement, valued at the SCC — rather than on a designated qualifying outlay, the government has fulfilled its side of the rule’s bargain once the emissions are reduced; the funds it may then borrow carry no restriction on their use and may be directed to any spending category, be it further climate-related measures, education, social compensation, or defense. This is a sharp departure from input-based rules, under which the admissible deficit is, by construction, tethered to the specific expenditure that justifies it.

³The point reaches beyond golden-rule carve-outs: the future ratio (Zukunftsquote) of Bohne et al. is not a golden rule but an informational indicator scoring spending by its presumed future orientation — innovative in reach, yet disregarding the return on the tracked expenditure items.

⁴In conditioning fiscal treatment on a realized policy outcome, the rule is related to recent proposals for performance-based transfers and bonds to governments, conditional on a predefined policy variable; see Harstad and Storesletten (2023) on forest conservation and Kalkuhl and Stern (2024) on raising fossil-fuel prices to curb fossil-fuel demand. A recent EU-level proposal in the same vein is the European climate bond of Monasterolo et al. (2025), whose disbursement is conditional on members’ delivery of climate-related investments.

⁵Exceptionally discussing this point explicitly, Bohne et al. (2024) acknowledge that a high rating by their input-based indicator of future orientation does not certify a favorable cost–benefit relation for the rated expenditure item.

Scope.

The two properties of measurability and homogeneity are what make a rule of this kind feasible, and in doing so they delimit its scope. Whether other dynamic public goods — improvements in health, biodiversity protection, or adaptation to climate change such as investment in resilient infrastructure — admit an analogous reconceptualization, with a comparably sharp and priced output, is a question of each sector’s economics that we are not positioned to settle. We therefore advance the rule for climate policy without claiming that climate is the only domain to which the underlying principle could apply: it is tied to, but not confined to, climate policy.

The model.

It is for climate policy, however, that we make the rule precise. We embed it in a stylized welfare-theoretic model of how fiscal rules shape the provision of dynamic public goods, in which a present-biased government finances climate abatement whose benefits accrue mainly to future generations. The model reproduces results familiar from related work:⁶ a present-biased government runs excessive deficits that redistribute toward the current generation, and a rigid deficit limit — as in the EU’s Stability and Growth Pact (SGP) or the German debt brake — curbs these deficits only at the cost of lower climate investment. If, instead, the admissible deficit is linked to the level of emission reductions, both the efficient deficit and the efficient level of emission reductions are implemented. Notably, in our model this holds regardless of the degree of present bias, so that fiscal discipline and climate-policy efficiency are reconciled rather than traded off. We then operationalize the rule in a quantity version and a price version — where the deficit is linked not to emissions but to the level of the effective carbon price — and flag the practical caveats. Finally, we quantify the relevant magnitudes for the EU’s upcoming ETS2 and Germany: at a carbon price of 200 Euro/tCO₂ — our assumed SCC — the rule would justify a deficit of about 72 billion Euro per year for the European Union.

The remainder of the paper is organized as follows. Section 2 presents the stylized model, derives the effects of a present-biased government, of a rigid deficit rule, and of the green-golden rule, and discusses the rule’s properties and robustness. Section 3 provides the exemplary computations, and Section 4 concludes.

2 Model

Consider a two-period model with one generation living in each period $t = 1, 2$.⁷ A period here represents a generation: its length is set by the horizon over which climate damages materialize, on the order of decades. The preferences of both generations are defined solely over their consumption c_t and are represented by a utility function $u(c_t)$, $t = 1, 2$. The function $u(c)$ has the usual properties: $u'(c) > 0$ and $u''(c) < 0$. The economy under consideration is a small open economy with access to a perfect

⁶Cf. in particular Peletier et al. (1999), Bassetto and Sargent (2006), and Bergmann and Moretti (2026).

⁷An extension of the basic model considered here to include infinitely many periods is provided in Section 2.5.

international capital market.⁸ Additionally, climate policy, along with its costs and consequences, is integrated into this simple model framework by assuming that the government can reduce emissions in $t = 1$ compared to a business-as-usual (BAU) scenario. This reduction is denoted by $\Delta e \geq 0$. It incurs convex costs $\gamma(\Delta e) \geq 0$ with $\gamma'(\Delta e) > 0$, $\gamma''(\Delta e) > 0$, and $\gamma(0) = 0$. The benefits of emission reductions materialize in the form of reduced climate damage $s\Delta e$ in $t = 2$.⁹ We incorporate these benefits into the budget constraint instead of including emission reductions into the objective function of the government, because we will equate the benefits from the reductions to the SCC. The latter are the monetized sum of damages caused by additional carbon emissions and thus commensurable with the other variables in the budget constraint. Here s is the marginal climate damage borne by the country's own future generation: the rule conditions on the benefit a nation (or the EU) internalizes, not on the global social cost of carbon. That domestic abatement also benefits other countries is a separate matter of international cooperation, which the rule neither addresses nor needs to — it removes the distortion a deficit rule imposes on whatever abatement the domestic decision-maker values (the territorial-versus-global magnitude of s is discussed in Section 3).¹⁰

We can now be more specific concerning the BAU scenario. We define it as the counterfactual scenario, in which the marginal benefits from emission reductions are nil, that is, $s = 0$. Hence, our BAU scenario features zero emission reductions in excess of the exogenous emissions trend. We can abstract from the trend in the analytical two-period model but will specify it in the calibrated version in Section 3.

The following intertemporal budget constraint of the government must hold when deciding on emission reductions:

$$c_1 + \gamma(\Delta e) + \frac{c_2}{1+r} = y + \frac{y + s\Delta e}{1+r},$$

where r denotes the exogenous interest rate. We assume identical income in both periods under the BAU scenario, meaning that business-as-usual has no negative consequences. This assumption was initially made for simplicity and can, as shown in Section 2.4, be modified to include future income losses as well as income growth in the BAU scenario. In this framework, the SCC is given by $s/(1+r)$. Moreover, let

⁸In a closed economy, an increase in public debt would crowd out private capital and lead to an increase in the real interest rate. This, in turn, would decrease optimal emission reductions and increase the cost of debt redemption in the future. However, the effect sizes in the exemplary calculations are small enough to justify abstracting from this. As shown later, a carbon price of 200 Euro/tCO₂ would allow for a cumulative additional deficit of approximately 4% of the EU's GDP over a period of 10 years. Blanchard et al. (2021) use a rule of thumb that a 1 percentage point increase in the public debt over GDP ratio entails a 2 – 4 basis point increase in the real interest rate, explicitly expecting the effect to be smaller for the EU, due to its integration in international capital markets. This implies an increase in the real interest rate of at most 16 basis points over 10 years (compared to a baseline real interest rate of 1.5% per year) as well as an additional cost of climate policy through debt-financing of at most 4%. For the sake of our exemplary calculations, this seems negligible.

⁹In this two-period model, we cannot differentiate between emission reduction policies that act over different time horizons. Measures that induce behavioral changes have an instantaneous effect and can be reversed at no cost. Measures that target fossil capital stocks act over longer time horizons and are costly to reverse. This distinction is important for the dynamic incentives of governments' subject to the rule proposed in this article. Nevertheless, we abstract from it to keep the framework simple and focus on the core mechanism, the substitutability between emission reductions and public debt.

¹⁰Including benefits from emission reductions into the objective function complicates the graphical exposition of the model but does not change our key results (see Appendix A).

β denote the social discount factor. Then, the welfare-maximizing allocation can be derived by solving the following optimization problem:

$$\begin{aligned} \max_{c_1, c_2, \Delta e} \quad & W(c_1, c_2, \Delta e) = u(c_1) + \beta u(c_2) \\ \text{s. t.} \quad & c_1 + \gamma(\Delta e) + \frac{c_2}{1+r} = y + \frac{y + s \Delta e}{1+r}. \end{aligned} \quad (\text{P-1})$$

To abstract from tax smoothing motives for taking public debt, we now assume that the interest rate corresponds to the social time preference rate, that is $1+r = 1/\beta$ holds.¹¹ Based on this assumption, the welfare-maximizing allocation $(c_1^*, c_2^*, \Delta e^*)$ can be characterized as follows:

$$c_1^* = c_2^* = y + \frac{s \beta \Delta e^* - \gamma(\Delta e^*)}{1 + \beta} \quad (1)$$

where Δe^* results from the optimality condition $\gamma'(\Delta e^*) = s/(1+r) = s\beta$.

2.1 Present-biased government and public deficits

With the welfare-maximizing allocation as a starting point, we now examine the decisions made by a present-biased government that gives excessive weight to the generation living in the first period. Such present bias can arise through several channels (see [Yared 2019](#), for an overview). The literature points to political competition, under which an incumbent facing a high probability of electoral defeat takes on more debt (e.g. [Persson and Svensson 1989](#); [Tabellini and Alesina 1990](#); [Wissenschaftlicher Beirat beim BMWK](#)); a tragedy-of-the-commons dynamic, in which uncoordinated government departments internalize only part of the financing cost of the projects they champion ([Weingast et al. 1981](#); [Velasco 2000](#)); and the political aggregation of heterogeneous time preferences, such as the greater weight given to older cohorts in an aging society (see e.g. [Jackson and Yariv 2015](#); [Wissenschaftlicher Beirat beim BMWK](#)).

In the following, this present bias is captured by the parameter $0 \leq \delta \leq 1$, which reduces the weight given to the generation living in the second period by the present government. We treat δ as a reduced form: rather than model the within-period political process, we represent its net effect by this single parameter. Among these channels, only electoral competition operates at a markedly sub-generational frequency; the others are structural or themselves generational. In no case does the friction set the length of a period, which is fixed by the climate-damage horizon. The literature robustly motivates the direction of the distortion, $\delta < 1$. The policy implemented in the first

¹¹The assumption ensures that a non-zero deficit is only efficient in this model because in $t = 1$ there is the possibility of producing a dynamic public good that increases the available resources in $t = 2$. Without this possibility, the welfare-maximizing allocation according to (1) would be characterized by $c_1 = c_2 = y$ and the efficient deficit would result accordingly as $b^* = 0$. In other words, we abstract from tax smoothing motives in the style of [Barro \(1979\)](#) as a motive to take on debt for the government. Such a motive could easily be added to our model (and the later derived green-golden rule) but would increase notational complexity without giving new insights.

period is then a solution to the optimization problem:

$$\begin{aligned} \max_{c_1, c_2, \Delta e} \quad & W^\delta(c_1, c_2, \Delta e) = u(c_1) + \delta \beta u(c_2) \\ \text{s. t.} \quad & c_1 + \gamma(\Delta e) + \frac{c_2}{1+r} = y + \frac{y + s \Delta e}{1+r}. \end{aligned} \quad (\text{P-2})$$

If the solutions for c_1 , c_2 and Δe of the optimization problem (P-2) are expressed as functions of the parameter δ , a comparative-static analysis can be used to show that $c'_1(\delta) < 0$ and $c'_2(\delta) > 0$ (see Appendix B). Compared to the welfare-maximizing allocation, a stronger present bias (a lower δ) means that the consumption of the generation living in the first period increases at the expense of the consumption of the future generation. This reallocation in favor of the current generation is made possible by increasing the public deficit compared to the welfare-maximizing allocation: The deficit b in the first period corresponds to $b = c_1 + \gamma(\Delta e) - y$ and can therefore also be represented as a function of the parameter δ . The comparative-static analysis then yields $b'(\delta) < 0$ — a stronger present bias results in a public deficit that is too high compared to the welfare-maximizing solution, $b^\delta > b^*$. Note that this allocation is not inefficient in the Pareto sense: it lies on the same frontier as the welfare-maximizing benchmark and differs from it only in the weight the government attaches to the future generation, so the objection to it is distributional — it reduces welfare relative to the socially desirable discount factor β — and not one of allocative efficiency.

However, the government's present bias has no influence on emission reductions Δe . These still fulfill the optimality condition $\gamma'(\Delta e^*) = s/(1+r) = s\beta$. Intuitively, emission reductions enter the government's problem only through the budget constraint, as the monetized benefit $s\Delta e$, and not through its objective. The decision therefore separates into two stages: the government first chooses Δe to maximize the resources available for distribution across the two periods — which pins down the efficient level $\gamma'(\Delta e^*) = s\beta$ irrespective of δ — and only then allocates those resources between present and future consumption according to its preferences. Present bias bears on the second stage alone and leaves abatement untouched. The neutrality is thus specific to this budget-based formulation: were emission reductions to enter the objective directly, a present-biased government would under-provide them, as we show in Appendix A. In this model, it is not the present bias *per se* that is responsible for inefficiently high emissions; only the government deficit is undesirably high. However, as will be shown next, measures intended to limit excessive deficits can lead to inefficiently high emissions.¹²

2.2 Effects of a deficit rule

An excessive deficit run by a present-biased government can be countered by a deficit rule that limits public deficits.

It is worth addressing why a present-biased government would be bound by such a rule at all. A present-biased government would not constrain its own choices; but

¹²Including the benefits from emission reductions in the government's objective rather than the budget constraint (Appendix A) does not overturn this; in that variant, a binding deficit rule reduces emission reductions further still, so the motivation for the alternative rule developed below carries over.

the dynamic inconsistency underlying its bias makes it want its successor to be more ambitious — to run lower deficits — than it is itself. Deficit rules thus operate as commitment devices imposed on successors and entrenched at a higher, constitutional layer, as the prevalence of national and supranational fiscal rules attests (Yared 2019). Piguiem and Riboni (2021) make this precise in an Tabellini and Alesina (1990)-style setting: when fiscal institutions are chosen before the incumbent’s identity is known, the optimal rule arises endogenously in equilibrium, as an incumbent uncertain of re-election imposes it on its successor and, where it commands a constitutional majority, the successor is effectively bound. We therefore take the existence of a binding deficit rule as given and study how it should be designed.

With $\bar{b} \geq 0$ denoting such a deficit limit and assuming that it is actually binding (i.e. it is smaller than the excessive deficit derived above, $\bar{b} < b^\delta$), the allocation implemented by a present-biased government results as a solution to the optimization problem:

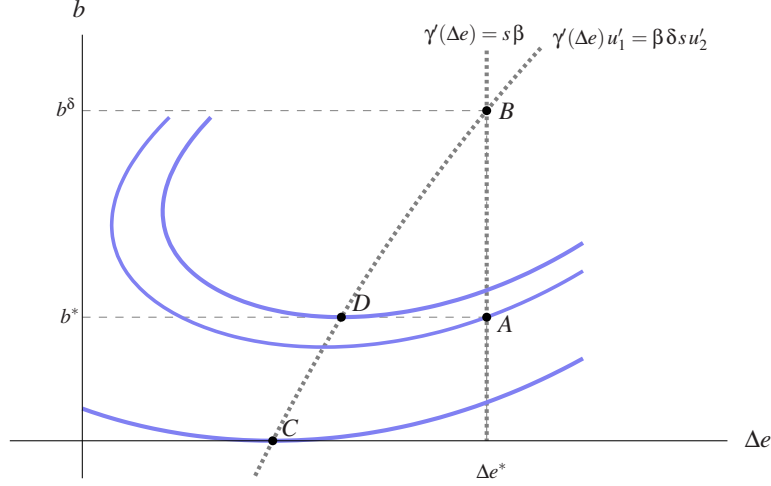
$$\begin{aligned} \max_{c_1, c_2, \Delta e} \quad & W^\delta(c_1, c_2, \Delta e) = u(c_1) + \delta \beta u(c_2) \\ \text{s. t.} \quad & c_1 + \gamma(\Delta e) = y + \bar{b} \\ & c_2 = y + s \Delta e - \bar{b}/\beta \end{aligned} \tag{P-3}$$

If the solutions of (P-3) for c_1 , c_2 and Δe are expressed as functions of $\bar{b}$, the result is $c'_1(\bar{b}) > 0$ and $\Delta e'(\bar{b}) > 0$. The effect on consumption in the second period, on the other hand, is not clear a priori, $c'_2(\bar{b}) \leq 0$ (see Appendix C). Therefore, a binding deficit limit is associated with a lower reduction in emissions than the case with no deficit rule and, thus, also compared to welfare-maximizing policies. While a deficit limit addresses the problem of excessive public deficits and leads to a reduction in consumption by the current generation, this is at the expense of the provision of the dynamic public good, that is, at the expense of the emission reductions induced by climate policy.¹³

Figure 1 illustrates these considerations. It shows the allocations resulting from the model as a function of government deficit and emission reductions. Point *A* represents the welfare maximum — the solution of (P-1) — with the optimal emission reductions Δe^* , for which $\gamma'(\Delta e) = s\beta$ applies, and the optimal deficit b^* . Point *B* represents the allocation resulting from a present-biased government’s actions. At this point, the optimal emission reduction level Δe^* is reached. However, it is accompanied by a higher deficit, b^δ , which serves to redistribute resources intertemporally in favor of the first generation. It should be noted that all allocations on the vertical line characterized by the optimal emission reduction level Δe^* , which runs through points *A* and *B*, are Pareto-efficient. These differ only according to the weight given to the second generation via the discount factor. We assume here that the socially desirable discounting factor is β , whereas a present-biased government would discount more heavily with discount factor $\beta \delta < \beta$.

¹³In an extension of this two-period model of a present-biased government to an infinite time horizon, as described in Section 2.5.3, the current government would attempt to bind *future* governments to fiscal rules and ambitious climate policy targets. At the same time, it would act in a time-inconsistent manner and abandon climate targets and fiscal rules — if within its power — as soon as their costs occur.

Fig. 1 Consequences of a deficit limit



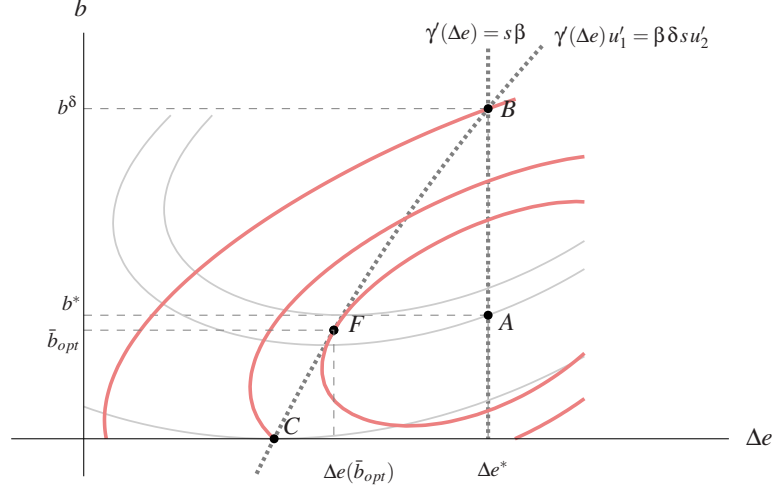
The blue curves represent indifference curves of the function W^δ maximized by a present-biased government in the $b/\Delta e$ plane. Pareto-efficient allocations are located on the straight line passing through points A and B , where A is the welfare maximum and B is the allocation that is implemented by a present-biased government. For exogenously given deficit limits, a present-biased government chooses allocations along the curve running through points C and B .

The figure also shows indifference curves of the function W^δ , which is maximized by a present-biased government, in the $b/\Delta e$ -plane (shown in blue). These indifference curves can be used to illustrate the consequences of deficit limit: Given a binding deficit limit $\bar{b}$, a present-biased government chooses an allocation that maximizes W^δ according to (P-2), which is the case when the highest indifference curve achievable under the deficit limit has a slope of zero. This is the case whenever $\beta \delta s u'_2 = \gamma'(\Delta e) u'_1$ holds. In the figure, the curve running through points C , D and B shows all combinations of Δe and b for which this is given. Point C represents the allocation that occurs when a balanced budget rule ($\bar{b} = 0$) is introduced, point D the allocation that results when the optimal deficit b^* is fixed by means of a deficit limit.

Overall, the previously described result becomes evident: while any binding deficit limit reduces the public deficit compared to the solution implemented by a government with present bias and no fiscal rule (point B), it also results in an inefficiently low level of emission reduction. It also becomes clear that a binding deficit limit $\bar{b} < b^\delta$ cannot implement a Pareto-efficient allocation: Pareto-efficient allocations are characterized by the efficient emission reduction level Δe^* (see the vertical line through points A and B).

However, this does not imply that the introduction of a binding deficit limit could not lead to an increase in welfare compared with an unrestricted present-biased government. In fact, there is an optimal deficit limit $0 < \bar{b}_{opt} < b^\delta$ that maximizes social welfare W and generates higher welfare compared to an unconstrained present-biased government (see Appendix D). However, this optimal deficit limit is only a second-best

Fig. 2 Optimal deficit limit



Red curves represent indifference curves of the social welfare function W in the $b/\Delta e$ plane, whereas gray curves represent indifference curves of the function W^δ . Confronted with a deficit limit $\bar{b} < b^\delta$, a present-biased government chooses an allocation along the curve running through points C and B . The welfare-maximizing deficit limit is the one for which the maximum social welfare level is reached along this curve, which is the case at point F .

solution, as it does not implement the welfare-maximizing allocation. The fact that the welfare-maximizing deficit limit $\bar{b}_{opt}$ is strictly positive in the present model is due to the existence of the dynamic public good yielding benefits for the second generation, which is provided by the first generation (Peletier et al. (1999) already describe this effect, Bergmann and Moretti (2026) characterize the optimal deficit limit in more detail). Without this, the only welfare-reducing effect of a present-biased policy would be to redistribute resources from the second generation in favor of the first generation by means of debt, which could be prevented by implementing a balanced-budget rule.

Figure 2 illustrates the properties of an optimal (in the sense of a second-best solution) deficit limit. The figure shows some indifference curves of the social welfare function W according to (P-1) (in red). For comparability with Figure 1, some indifference curves of the function W^δ are also shown (in grey). For a given deficit limit $\bar{b} < b^\delta$, a present-biased government always chooses an allocation on the curve running through points C , F and B , where the slope of the indifference curves of the function W^δ is zero. Consequently, the optimal deficit limit is the one at which the highest social indifference curve is reached along this curve. This is the case at point F with the associated deficit limit $\bar{b}_{opt}$.

For the scenario depicted in Figure 2 it follows that $\bar{b}_{opt} < b^*$. On the one hand, this is not an inevitable result: While it can be shown that there is always an optimal deficit limit (in the sense of a second-best solution), it is not possible to determine its properties more precisely without further assumptions (see Appendix D). On the

other hand, [Bergmann and Moretti \(2026\)](#) show that the aforementioned result holds under very general assumptions in a closely related framework.

2.3 Effects of a green–golden rule

As shown above, a deficit limit can solve the problem of excessive public deficits, which can arise due to a government’s present bias. However, this also leads to inefficiently high emissions. Therefore, it is reasonable to assume that a fiscal rule in the vein of the golden rule is a better solution and enables welfare gains compared to a rigid deficit limit. To show that this is indeed the case, a modified golden rule is considered below, which links the maximum debt to the level of emission reductions according to the rule $b = \psi \Delta e + k$ with $\psi > 0$. The allocation implemented by a present-biased government is then the solution to the optimization problem:

$$\begin{aligned} \max_{c_1, c_2, \Delta e} \quad & W^\delta(c_1, c_2, \Delta e) = u(c_1) + \delta \beta u(c_2) \\ \text{s. t.} \quad & c_1 + \gamma(\Delta e) = y + \psi \Delta e + k \\ & c_2 = y + s\Delta e - \frac{\psi \Delta e + k}{\beta} \end{aligned} \tag{P-4}$$

Any rule that rewards emission reductions Δe by allowing deficits in proportion to the emission reductions and the SCC $s\beta$ induces the efficient level of emission reductions. More precisely, if we set $\psi = s\beta$ it follows that $\Delta e = \Delta e^*$, regardless of the choice of k (see [Appendix E](#)).¹⁴ Since the efficient emission reductions Δe^* maximizes the government’s intertemporal budget, the resulting intertemporal allocation is always Pareto-optimal. The affine-linear parameter k determines the resulting consumption levels for the first and second generation. A direct consequence is that for every deficit limit $\bar{b}$, there exists an affine-linear rule that constitutes a Pareto improvement.¹⁵

Furthermore, it can be shown that the specific affine-linear rule $b = s\beta \Delta e + k^*$ with $k^* = (\gamma(\Delta e^*) - s\beta \Delta e^*)\beta/(1 + \beta) < 0$ maximizes social welfare W despite the government’s present bias (see [Appendix E](#)). This specific rule is referred to as the green–golden rule and can be characterized as follows:

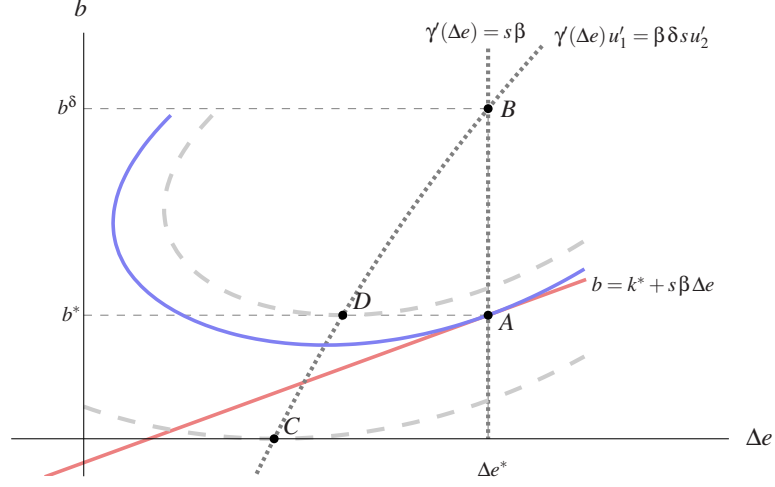
$$\begin{aligned} b &= k^* + s\beta \Delta e \\ k^* &= \frac{\beta}{1 + \beta} (\gamma(\Delta e^*) - s\beta \Delta e^*) \end{aligned} \tag{GGR}$$

[Figure 3](#) graphically illustrates the relationships underlying the green–golden rule. The green–golden rule induces a present-biased government to implement the

¹⁴A rule that links admissible deficits to the cost of emission reductions $b = \gamma(\Delta e) + k$ also implements the efficient emission reductions for each k and can, in the present model, achieve the welfare optimum by appropriately choosing k . In this study, we do not consider this formulation, as it differs in the incentives for a government when implemented in practice. While the focus on realized emissions Δe favors the government’s choice of the most efficient technology to reduce emissions, the efficiency of the technology could become secondary if the rule is formulated as a function of the costs of emissions reductions.

¹⁵More precisely, for every $\bar{b} < b^\delta$ there exists an interval $[k_{min}, k_{max}]$, so that a rule of the form $b = k + s\beta \Delta e$ for all k from this interval represents a Pareto improvement. See also [Figure 4](#) and [appendix F](#) for a constructive proof with a “surplus abatement rule”.

Fig. 3 Green–golden debt rule



Blue and dashed gray curves represent indifference curves of the function W^δ . Under the restriction formulated by the green–golden rule (the red straight line), a present-biased government chooses the point along this straight line that maximizes W^δ . The solution is therefore the welfare-maximizing allocation represented by point A.

welfare-maximizing allocation indicated by point A. This is achieved by allowing the government to take on debt only in accordance with emission reductions Δe according to the rule $b = k + s\beta \Delta e$. Because the slope parameter $s\beta$ of this rule corresponds to the gradient of the indifference curves of W^δ at the point Δe^* , this ensures that the optimal emission reductions Δe^* are achieved. The optimal deficit b^* and thus the optimal intertemporal consumption allocation c_1^*, c_2^* can also be implemented by a suitable choice of intercept k . Under the corresponding restriction (depicted by the red line in Figure 3), the present-biased government chooses b and Δe such that its objective function W^δ is maximized, which is the case at point A, the welfare maximum.

Whether the transition from an existing binding deficit limit to the green–golden rule represents a Pareto improvement depends on the level of the underlying deficit limit. There is an interval $[\bar{b}_{min}, \bar{b}_{max}] \in [0, b^\delta]$ of deficit limits for which this is the case (see Figure 4). For deficit limits outside this interval, a Pareto-improving affine-linear rule with gradient $s\beta$ can be constructed (see Appendix F for a ”surplus abatement rule”).

2.4 Properties of the green–golden rule

This section provides more details on two aspects of the green–golden rule derived above. Firstly, this section addresses how to determine the efficient deficit level b^* associated with the efficient emission reduction level Δe^* . Secondly, we explain why the green–golden rule is independent of the government’s present bias.

determine b^* . For this purpose, Equation (2b) is reformulated as follows:

$$b^* = \frac{\beta}{1+\beta} s \Delta e^* \left(\frac{\gamma(\Delta e^*)}{s \Delta e^*} + 1 \right)$$

At the optimum, $\gamma'(\Delta e^*) = s\beta$ and therefore $s \Delta e^* = \Delta e^* \gamma'(\Delta e^*)/\beta$. Plugging this into the equation above gives:

$$b^* = \frac{\beta}{1+\beta} s \Delta e^* \left(\beta \frac{\gamma(\Delta e^*)}{\gamma'(\Delta e^*) \Delta e^*} + 1 \right)$$

The term $\frac{\gamma'(\Delta e^*) \Delta e^*}{\gamma(\Delta e^*)}$ represents the elasticity of the costs associated with emission reductions (at the point Δe^*). If this elasticity is assumed to be constant and denoted by η , it follows that:

$$b^* = \frac{\beta}{1+\beta} s \Delta e^* \left(\frac{\beta}{\eta} + 1 \right)$$

Consequently, knowledge of s , β , η , and Δe^* is required to determine the efficient deficit.

We can now compare the admissible deficit b^* with the cost of emission reductions $\gamma(\Delta e^*)$. Dividing b^* from (2b) by $\gamma(\Delta e^*)$, we obtain:

$$\frac{b^*}{\gamma(\Delta e^*)} = \frac{\beta}{1+\beta} \left(1 + \frac{s \Delta e^*}{\gamma(\Delta e^*)} \right) = \frac{\beta}{1+\beta} \left(1 + \frac{\eta}{\beta} \right) = \frac{\beta + \eta}{1+\beta}$$

It follows that the admissible deficit exceeds the cost of abatement:

$$\frac{\gamma(\Delta e^*)}{b^*} = \frac{1+\beta}{\beta + \eta} < 1.$$

This inequality always holds, since the assumptions of a constant elasticity η and convex cost of abatement $\gamma(\cdot)$ with $\gamma(0) = 0$ imply $\eta > 1$.¹⁶ In contrast to the classical golden rule of fiscal policy, which conditions the admissible deficit on the *cost* of investment, the green-golden rule permits a deficit that *exceeds* the cost of abatement, $b^* > \gamma(\Delta e^*)$. At the same time, the deficit falls short of the present value of the abatement benefit, $b^* < s \beta \Delta e^*$. The efficient deficit therefore lies between the cost of abatement and the present value of its benefit,

$$\gamma(\Delta e^*) < b^* < s \beta \Delta e^*. \quad (3)$$

Another appealing property of the green-golden rule is its independence from the level of present bias of the government, a parameter that is difficult to measure in practice. This further distinguishes the green-golden rule from the optimal deficit limit mentioned above, which decreases with the level of present bias (Bergmann and Moretti 2026). The intuition behind this independence is as follows. The affine-linear

¹⁶The assumptions of a constant elasticity η and convex cost of abatement $\gamma(\cdot)$ with $\gamma(0) = 0$ imply that the cost of abatement has the functional form $\gamma(x) = \kappa x^\eta$. This function is convex if and only if $\eta > 1$

rule with an intercept equal to the SCC equates second-period marginal benefits (from reduced emissions) and second-period marginal cost (from increased debt service) *for any level* of emission reductions Δe . This eliminates the intertemporal trade-off that characterizes climate policy and transforms the problem into a static optimization problem, thus eliminating the distorting effect of the present bias. The result holds for any degree of present bias, including the limiting case $\delta = 0$, in which the government attaches no weight whatsoever to the second generation. Even such a government implements the efficient emission reductions Δe^* : under the rule, second-period consumption no longer varies with Δe , so the abatement decision reduces to maximizing first-period resources, and each unit of abatement is rewarded with admissible deficit $s\beta$ in excess of its marginal cost up to Δe^* . Efficient abatement is therefore in the present generation's own interest, however little it values the future.

Both this independence and the neutrality of emission reductions to present bias noted above hold exactly under the assumption of a constant interest rate. If instead the rate rose with the deficit—as it would were public debt to affect the country's financing conditions—the relevant price of first-period resources would be the marginal cost of funds, which exceeds the interest rate for a net borrower. A more present-biased government would then borrow more, face a higher marginal cost, and reduce emissions by somewhat less; and the slope of the rule that exactly restores efficient abatement would itself come to depend on the bias. Both properties are therefore the limiting case, as the responsiveness of the rate to the deficit vanishes, of a more general relationship. This deviation is of first order in that responsiveness and, at the magnitudes relevant for the present application, negligible.

2.5 Model extensions

In this section we introduce three extensions of the basic model. The first is a reformulation of the model resulting in a price version of the green–golden rule. Here, the admissible deficit is a function of the observed carbon price in the economy instead of the observed emission reductions. The second extension introduces economic growth and, more generally, differing period endowments y_1 and y_2 in the BAU scenario and shows that results are unaffected. The third extension consists of an infinite-horizon model. We show how it can be mapped into our previous two-period model.

2.5.1 A price rule

The first extension of the previous model framework is an alternative formulation of the green–golden rule as a price rule. Instead of formulating it as a function of emission reductions Δe , which depend not only on the government's efforts but also on long-term trends and business cycle fluctuations, the green–golden rule can also be formulated as a function of the observed price level of fossil fuels *before* a carbon price increase p_0 , the observed price level of fossil fuels *after* a carbon price increase p and the new carbon price τ , the SCC, $s\beta$, as well as the price elasticity of emissions $\epsilon(p)$ (see Appendix G):

$$\begin{aligned}
b &= b^* - s \beta \epsilon(p) \frac{e(p)}{p} (s \beta - \tau) \\
b^* &= \frac{1}{1 + \beta} \epsilon(p_0) \frac{e(p_0)}{p_0} \left(\frac{\beta}{\eta} + 1 \right) (s \beta)^2
\end{aligned} \tag{GGR.2}$$

The price rule in (GGR.2) relies on a first-order approximation of the current- and optimal emissions using the price elasticity of emissions. Instead of sanctioning deviations from the efficient emission reductions as in the quantity formulation in (2b), the price rule reduces the admissible deficit in proportion to deviations from the efficient carbon tax level $s \beta$ (the SCC). The efficient deficit level b^* maintains its interpretation as the deficit level prevailing in the social optimum but is now computed relying on the price elasticity of emissions and the SCC, instead of the efficient emission reduction level Δe^* .

A formulation of the green-golden rule as a price rule has both advantages and disadvantages compared to the quantity rule, particularly regarding its practical implementation. One major advantage is the presence of a natural reference level for climate policy efforts induced by a carbon tax: its absence. In contrast, the quantity rule requires determining the counterfactual emissions level e_{BAU} to evaluate the benefits of emission reductions Δe . Because computing e_{BAU} is far from trivial, this constitutes a significant practical advantage for implementing the price rule. However, a notable limitation of the price rule is that it accounts only for emission reductions directly induced by an increase in the carbon price. It disregards the effects of other climate policy instruments such as standards, subsidies, or regulatory interventions, which are widely used and can have substantial impacts in practice. Although this may be seen as a disadvantage, it also has a conceptual upside. By tying the admissible deficit to observed emissions, the quantity rule may inadvertently distort incentives for present-biased governments, steering them away from long-term mitigation strategies such as investments in non-fossil capital that yield delayed emission reductions. The price rule avoids this problem: When the emissions elasticity ϵ is chosen to reflect long-run responses to changes in the price level, it rewards governments for future emission reductions triggered by current price-induced investment, even if the effects materialize after the government's term ends. From an investor's perspective, the price rule stabilizes expectations that future governments will find it in their interest to set a carbon price close to the SCC.

The appropriate choice of price elasticity should also account for potential rebound effects, especially when carbon pricing revenues are redistributed in ways that stimulate demand for carbon-intensive goods. Incorporating these effects is essential to ensure accurate estimation of emissions reductions under a price-based framework.

2.5.2 Economic growth

A limitation of the model examined so far is the absence of economic growth. The second model extension shows that it is straightforward to consider growth and climate

damages in the BAU scenario in this setting. Doing this does not affect the results discussed thus far.

Assume that the income y_2 of the second generation differs from the income y_1 of the first generation because of economic growth and climate damages occurring in the BAU scenario. Denote the net growth effect attributable to these two components by ϕ . Then $y_2 = (1 + \phi) y_1$.¹⁷ Furthermore, we assume CRRA-utility $u(c) = c^{1-\rho}/(1-\rho)$. If we continue abstracting from tax smoothing motives to take on deficits, that is, if we assume that the relationship between the real interest factor R , the discount factor β and the growth factor $1 + \phi$ satisfies $1 = u'^{-1}(\beta R) (1 + \phi)$,¹⁸ the green-golden rule $b = k^* + s \beta \Delta e$ still implements the welfare-maximizing allocation despite the present bias of the government. The relationship $1 = u'^{-1}(\beta R) (1 + \phi)$ ensures that the deficit at the welfare maximum only serves to distribute the burdens and the benefits arising from the intertemporal provision of the dynamic public good. It is not used to appropriate the resources of the second generation, which have changed due to the growth effect, by the first-period government.

2.5.3 The green-golden rule with infinite time horizon

Finally, we extend the two-period model to a model with an infinite time horizon to show that the conclusions drawn so far are valid in a more general setting. The starting point is an optimization problem whose solution is the social optimum, which can be formulated as follows for an infinite time horizon:

$$\begin{aligned} \max_{\Delta e, c_1, c_2, \dots} \quad & W = u(c_1) + \rho u(c_2) + \rho^2 u(c_3) + \dots = u(c_1) + \rho \sum_{t=2}^{\infty} \rho^{t-2} u(c_t) \quad (\text{P-5}) \\ \text{s. t.} \quad & c_1 + \frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{c_t}{R_\rho^{t-2}} + \gamma(\Delta e) = y + \frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{y}{R_\rho^{t-2}} + \frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{s \Delta e}{R_\rho^{t-2}}, \end{aligned}$$

where ρ denotes the discount factor for future generations' utility and R_ρ denotes the exogenous interest rate factor. The term $\frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{s \Delta e}{R_\rho^{t-2}}$ denotes the SCC — the present value of all damage avoided through emission reductions. If, as in the previous analysis, we assume that $\rho = 1/R_\rho$ holds, it follows from (P-5), that $c_t = c_2$ for all $t > 2$ and (P-5) can be formulated as follows with $R = R_\rho - 1$ (see Appendix H):

$$\begin{aligned} \max_{\Delta e, c_1, c_2} \quad & W = u(c_1) + \frac{\rho}{1-\rho} u(c_2) \quad (\text{P-6}) \\ \text{s. t.} \quad & c_1 + \frac{c_2}{R} + \gamma(\Delta e) = y + \frac{y}{R} + \frac{s \Delta e}{R} \end{aligned}$$

With $\beta = \frac{\rho}{1-\rho}$ this optimization problem is formally equivalent to the problem in (P-1). Accordingly, a present-biased government solves the corresponding optimization

¹⁷With $y_2 = (1 + \phi) y_1 = (1 + \mu) (1 - \psi) y_1$, μ stands for exogenous economic growth and ψ for the loss that occurs if emissions remain at the BAU level.

¹⁸This is a generalization of the assumption $1 + r = 1/\beta$ made in the main model specification.

problem:

$$\begin{aligned} \max_{\Delta e, c_1, c_2, \dots} \quad & W^\delta = u(c_1) + \delta \rho \sum_{t=2}^{\infty} \rho^{t-2} u(c_t) \\ \text{s. t.} \quad & c_1 + \frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{c_t}{R_\rho^{t-2}} + \gamma(\Delta e) = y + \frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{y}{R_\rho^{t-2}} + \frac{1}{R_\rho} \sum_{t=2}^{\infty} \frac{s \Delta e}{R_\rho^{t-2}} \end{aligned} \quad (\text{P-7})$$

Again, $\rho = 1/R_\rho$ implies that $c_t = c_2$ for all $t > 2$ and (P-7) becomes:

$$\begin{aligned} \max_{\Delta e, c_1, c_2} \quad & W^\delta = u(c_1) + \delta \frac{\rho}{1-\rho} u(c_2) \\ \text{s. t.} \quad & c_1 + \frac{c_2}{R} + \gamma(\Delta e) = y + \frac{y}{R} + \frac{s \Delta e}{R} \end{aligned} \quad (\text{P-8})$$

With $\beta = \frac{\rho}{1-\rho}$ this optimization problem is formally equivalent to (P-2). Therefore, an extension of the two-period model considered above to the case of an infinite number of periods does not alter the properties of the green-golden rule. As before, its slope $s\beta$ is determined by the SCC. However, there are changes when determining or interpreting the model parameters β and R . The interest rate factor R_ρ and the discount factor ρ introduced above refer to generations and therefore depend on the assumed period length of one generation. The assumptions made about these variables then determine the parameters β and R in the original formulation of the green-golden rule.

3 Exemplary calculations and illustration

In this section, we provide exemplary calculations based on the formulation of the infinite-horizon model from Section 2.5 to illustrate the implied deficit levels of the proposed green-golden rule for the EU and Germany.¹⁹ For the EU, we apply the price rule (GGR.2) to the sectors encompassed by the EU's effort sharing regulation (ESR) as they are planned to be covered by a new emissions trading scheme from 2027 onward, the EU-ETS 2. We currently observe increasing political opposition to the introduction of the EU-ETS 2 and the associated (potentially high) carbon prices. The green-golden rule could increase acceptability of high prices by generating additional resources for member states. This complements recent proposals for jointly issued, allowance-funded EU climate bonds (Monasterolo et al. 2025): where such proposals develop the common-issuance architecture, the green-golden rule offers a principled key for allocating the resulting resources across member states, sizing each entitlement by the monetized return to its abatement rather than by the cost or delivery of designated projects. For Germany, we compute figures based on both the price rule and the quantity rule (GGR) inspired by recent discussion about the necessity and size of debt-financed funds to achieve Germany's national climate targets.

¹⁹A spreadsheet with the illustrative calculations is available at <https://doi.org/10.5281/zenodo.17314477>.

The following parameters were used for all numerical calculations. We consider a SCC $s\beta$ of 200 Euro/tCO₂, in the same ballpark as the latest estimates for the global SCC by the [Environmental Protection Agency](#). Since the green-golden rule we propose is a concept best suited for the national context or a supranational entity like the EU, one might argue that the global SCC does not capture the extent to which future generations in a country profit from national climate policy. Computing the "territorial SCC", that is, taking into account climate damages occurring on the country's territory only, would decrease the figure computed by the EPA.²⁰ While carbon leakage may further reduce the territorial SCC, policy spillovers ([Linsenmeier et al. 2023](#)), reciprocal design of international agreements ([Kornek and Edenhofer 2020](#); [Beaufils et al.](#)) or technological change induced by national climate policy with cross-country spillovers may crowd in mitigation by other governments, implying higher territorial SCC. In addition, a recent study finds a much larger global SCC than the one used by the EPA, around 1200 USD/tCO₂ ([Bilal and Känzig 2026](#)), implying values around 250 USD/tCO₂ for the territorial SCC of the EU ([Bilal and Känzig 2025](#)), broadly in line with the 200 Euro/tCO₂ we adopt. In Appendix I, we additionally compute a lower bound for the territorial SCC of 12 Euro/tCO₂ that accounts for carbon leakage and only EU-wide territorial damages, assuming that EU's territorial damages scale with EU's GDP share. We show that the results for the price rule are quantitatively much smaller than the results shown in this section. These considerations highlight the importance of international cooperation and mechanisms like the CBAM to link national climate policy to effective global emission reductions. Without an effective international climate policy architecture, the admissible deficit for national climate policy would therefore be very small.

We assume a period length of 30 years (a generation) and a yearly interest rate of 1.5%, implying a period discount factor $\rho = 0.64$ for the infinite horizon model from Section 2.5.3. This has been shown to be equivalent to a two-period-model with a weight attached to the second period of $\beta = \rho/(1 - \rho) = 1.78$ in the equivalent two-period model. We now turn to the calibration of the parameters specific to the three examples.

3.1 A price rule for the EU

We start by analyzing a price rule, tying admissible deficits to the level of carbon prices in the transport and building sectors. We use 2024 as the base year and compute the current EU27 wide average price of energy $p_0 = p_{BAU} + \tau_0$ of 585 Euro/tCO₂ (including the current taxes, levies and subsidies) using data from Eurostat on energy consumption shares, electricity and natural gas prices as well as price level data to convert everything into 2024 prices. We take oil prices from the EU Commission's weekly oil bulletin. The emission intensity of electricity in the EU is obtained from the European Environment Agency. For all other energy sources, we use the emission intensities and prices from [Hänsel et al. \(2022\)](#).²¹ The initial 2024 carbon price τ_0 is

²⁰Note that there is no established concept to calculate territorial SCC. Moreover, entrenching a general norm to consider territorial SCC only would be disadvantageous to a country ([Environmental Protection Agency](#)).

²¹When it comes to the energy intensity of heat, this means that we apply Germany's emission intensity for district heat production to the EU as a whole. This simplification is due to data restrictions. It should

set equal to 28 Euro/tCO₂ and is calculated from data on the national carbon prices in non-EU-ETS 1 sectors in vigor as of 2024 in EU-ETS 1 member states. We obtain this data from the World Bank’s carbon pricing dashboard and aggregate it weighting each national price by the share of fossil energy supply over all EU-ETS 2 member states, obtained from Eurostat’s complete energy balances dataset.

For EU27 carbon emissions, we consider those emissions covered by the EU’s ESR, which constitute 60% of total EU emissions. According to the EU Commission’s emission database EDGAR, total EU emissions in 2023 amounted to 3,222 megatons of CO₂ equivalents. Thus, our initial emissions $e(p_0)$ value is $1,933 \text{ MtCO}_2 = 0.6 \times 3,222 \text{ MtCO}_2$. We focus on these emissions because they largely coincide with those covered by the announced EU-ETS 2, mainly encompassing the heating and transportation sectors. An increasing number of member states are calling for a price cap in the EU-ETS 2, fearing the consequences of high carbon prices in the building and transport sectors. In this situation, admissible deficits could help alleviate negative consequences of high carbon prices without compromising the price signals from the emissions trading scheme.²²

We compute admissible deficits for three values of price elasticity, ranging between -0.5 and -1.1. This is consistent with estimates of long-term price elasticities for the transportation, heating, and electricity sectors. We find estimates for gasoline of -0.84 in a meta-study by Brons et al. (2008), a range of -0.6 to -1.1 for Diesel in Europe by Zimmer and Koch (2017), ranges of -0.34 to -0.58 and -0.65 to -0.97 for the German transport sector by Pothén and Tovar Reaños (2018) and Beznoska. For the heating sector in Germany, Nikodinoska and Schröder (2016) find values ranging from -0.56 to -0.68 and Pothén and Tovar Reaños (2018) from -0.48 to -0.67. More recent studies find much larger values for residential electricity as well as electric vehicle demand in California of -2.4 (Buchsbaum 2022) and -2.1 (Muehlegger and Rapson 2022), respectively.

Furthermore, we assume the abatement cost to be quadratic, i.e. $\eta = 2$. This simplifying choice makes it possible to assume a constant price elasticity ϵ (see Appendix G), which further simplifies the price rule (GGR.2). This is a common simplifying choice in the literature (Vogt-Schilb et al. 2018; Gollier 2024).

Table 1 displays values for the admissible deficit per year for different values of a hypothetical EU-wide carbon price that affects all emissions considered in the ESR in a plausible range for the permit price of the EU-ETS 2 (Günther et al. 2025, columns) and different values of the price elasticity of emissions ϵ (rows).

Our computations show, that an EU-wide carbon price of 75 Euro/tCO₂, i.e. in the same ballpark as the current permit price in the EU-ETS 1, would already allow for a positive deficit for all considered price elasticities. For the median elasticity value of $\epsilon = -0.8$, the GGR would grant an additional deficit of 14.7 billion Euro per year for the EU as a whole. For a carbon price of 100 Euro/tCO₂, the median elasticity value would allow for a deficit of almost 30 billion Euro per year. Raising the carbon price to the assumed SCC of 200 Euro/tCO₂ would grant an additional fiscal space of almost 72 billion Euro per year, amounting to roughly 0.4% of EU 2024 GDP. Note that this

only have minor effects on the results, due to the low energy consumption share of district heat for the EU (5% after excluding all sources contributing less than 2% to final energy consumption).

²²The ESR emissions also include emissions from the even more controversial agricultural sector.

Admissible annual deficit (billions of Euro)							
	Carbon price (Euro/tCO ₂ -eq.)						
ϵ	0	50	75	100	150	200	250
-0.5	-26.1	-1.9	8.2	17.3	32.7	44.9	54.6
-0.8	-43.4	-2.2	14.7	29.5	53.7	71.9	85.3
-1.1	-61.9	-1.9	22.2	42.9	75.7	98.9	114.2

Table 1 Annual admissible deficit at EU27-level according to the green-golden price rule for different values of the carbon price on ESR-relevant emissions and price elasticities of emissions ϵ .

deficit would be admissible in the year of the carbon price increase as well as in every subsequent year the carbon price stays at that same level.²³ It is worth emphasizing again that this additional fiscal space would come with no strings attached. Therefore, it could be used for compensation programs, subsidies for renewable energy, healthcare, military spending, or any other type of government expenditure. Intergenerational equity is ensured by reduced climate damage resulting from an increase in the carbon price and subsequent emission reductions.

3.2 A price rule for the case of Germany

For the price rule, we use 2024 as base year and compute the current price of energy $p_0 = p_{BAU} + \tau_0$ of 588 Euro/tCO₂ (including a carbon price τ_0 of 45 Euro/tCO₂ in vigor in 2024) based on Hänsel et al. (2022), updating their value for January 2024 using the consumer price index for Germany. For German carbon emissions, we take an estimate from Agora Energiewende for 2024 of 656 megatons of CO₂ equivalents which acts as initial emissions $e(p_0)$. Unlike the EU calculation above, which is restricted to the ESR sectors in anticipation of the EU-ETS 2, the German illustration assumes an economy-wide carbon price. Table 2 displays values for the admissible deficit per year for different values of the German carbon price after a potential reform (columns) and the price elasticity of emissions ϵ (rows). In the previous section, we explained our choice of the parameter space and why we set $\eta = 2$.

Our computations show that a carbon price of 50 Euro/tCO₂, in the same ballpark as the 55 Euro/tCO₂ that came into force in Germany as of January 1, 2025, if applied to the economy as a whole, would not be sufficient to allow for an additional deficit according to our green-golden rule. A carbon price of 75 (100) Euro/tCO₂ would allow for additional deficits of 3.9 (9.2) billion Euro per year for the median price elasticity value of emissions of $\epsilon = -0.8$. Raising the carbon price to the assumed SCC of 200 Euro/tCO₂ would grant an additional fiscal space of 24.3 billion Euro per year, amounting to roughly 0.56% of German GDP.

²³Note that a decreasing observed emissions trajectory $e_t(p)$ would lead to a gradual decline of the admissible deficit until net-zero is reached (see Equation (GGR.2)).

Admissible annual deficit (billions of Euro)							
ϵ	Carbon price (Euro/tCO ₂ -eq.)						
	0	50	75	100	150	200	250
-0.5	-9.9	-1.3	2.2	5.5	10.9	15.2	18.6
-0.8	-16.7	-2.1	3.9	9.2	17.8	24.3	29.1
-1.1	-24.2	-2.8	5.8	13.3	25.0	33.4	39.0

Table 2 Annual admissible deficit for Germany according to the green-golden price rule for different values of the carbon price and different price elasticities of emissions ϵ .

3.3 A quantity rule for the case of Germany

To compute the optimal deficit b^* and admissible deficit b according to the quantity formulation of the GGR in Equations (2a) and (2b), we need to specify the counterfactual emission path $e_{BAU,t}$, the optimal emission path e_t^* , the weight attached to the future period β , as well as SCC $SCC = s\beta$. We decide to use the yearly emission goals specified in the German Federal Climate Action Act (KSG) as our measure for optimal emissions e_t^* . The KSG was passed in 2019, enacted in 2020 and affected — when enacted — mainly future governments (the next federal election in Germany was in 2021). In other words, the law was conceived to bind future governments. Hence, we believe that it is plausible that the targets were not affected by the potential present bias of the government that enacted the law. Because the KSG specifies emission reduction targets starting in 2020, we choose it as our base year.

Next, we estimate the exogenous trend component of emissions and the impact of business cycles using the following model:

$$\ln e_t = \alpha_0 + g_e \times t + \omega \times \text{gap}_t,$$

where e_t represents emissions in Germany (in million tons of CO₂), and gap_t denotes the output gap (in percent) in period t . The output gap is estimated by applying the HP filter to Germany's real GDP time series.²⁴ Using data from 1991 to 2019, we estimate $g_e = 0.01227$ and $\omega = 0.00232$. The estimated growth rate g_e is then used to construct the business-as-usual emissions $e_{BAU,t}$, where emissions decline each period by the factor $1 - g_e$, starting from a pre-specified emissions level corresponding to the 2020 emissions limit under the KSG. To account for business cycle effects, actual emissions e_t in each period are adjusted by subtracting $\omega \times \text{gap}_t$ from $\ln e_t$. The intuition for this is that governments should neither be punished nor rewarded for business-cycle-related emission changes but only for changes caused by active climate policy.

Table 3 displays the results of our computations for German emissions from 2020-2023 while Figure 5 illustrates three scenarios for future emission pathways: (1) BAU

²⁴Emissions data is sourced from the German Federal Office for the Environment (Umweltbundesamt, Nationale Treibhausgas- & Luftschadstoff-Inventare 1990 bis 2022, as of March 2024). Real GDP data (GDP at constant prices) is obtained from the AMECO database of the European Commission.

Year	2020	2021	2022	2023	...	2030
Counterfactual emissions, $e_{BAU,t}$ (Mt CO ₂)	813	803	793.2	783.4	...	718.6
e_t^* (Mt CO ₂)	813	786	756	720	...	438
Optimal emission reductions, Δe_t^* (Mt CO ₂)	0	17	37.2	63.4	...	280.6
Optimal deficit, b^* (Bn. Euro)	0	2.3	5.1	8.6	...	32.18
Optimal deficit, cumulative (Bn. Euro)	0	2.3	7.4	16.0	...	190.7
Observed emissions (Mt CO ₂)	731.8	759.6	750	674	...	
Adjusted [†] emissions e_t (Mt CO ₂)	736.9	760.2	749.8	675.6	...	
Adjusted [†] emission reductions, Δe_t (Mt CO ₂)	76.1	42.8	43.4	107.8	...	
Admissible deficit, b_t (Bn. Euro)	15.2	7.5	6.3	17.5	...	
Admissible deficit, cumulative (Bn. Euro)	15.2	22.7	29.0	46.5	...	

Table 3 The quantity formulation of the green-golden rule: Optimal and admissible deficits based on optimal emissions from the German Federal Climate Action Act.

[†] Observed emissions adjusted for the business-cycle component.

starting in 2024, (2) optimal emission reductions, and (3) an intermediate scenario. According to the quantity rule, a government that reduces emissions in accordance with the KSG targets could incur a cumulative additional deficit of 191 billion Euro in the period 2020-2030. This roughly corresponds to the cumulative admissible deficit over ten years according to the price rule for an elasticity of $-\epsilon$ that is slightly higher than 0.5 and a carbon price equal to the SCC (see Table 2). In the scenario where the government keeps the efforts constant from 2024 on and emissions only decline with the same rate as BAU-emissions, the cumulative admissible deficit still amounts to 108 billion Euro.²⁵

4 Conclusion

Public debt can align the costs and benefits of climate policy over time — costs that fall now, benefits that accrue largely to future generations. Deficit rules, adopted to restrain present-biased governments from over-borrowing, foreclose this synergy, and with it the broader provision of dynamic public goods that debt finance could support. The classical remedy, the golden rule of public finance, exempts public investment from the deficit limit, but it founders on an operational problem: what counts as investment cannot be sharply observed, which leaves the rule open to creative accounting. Our main contribution is a reconception of the golden rule that, in the case of climate policy, escapes this problem.

The single departure from the classical golden rule is to change the asset to which the rule applies: rather than tying the admissible deficit to a change in the physical

²⁵Note that the cost of emission reductions $\gamma(\Delta e_t)$ in this scenario is still positive, since the government's efforts are constant and not decreasing.

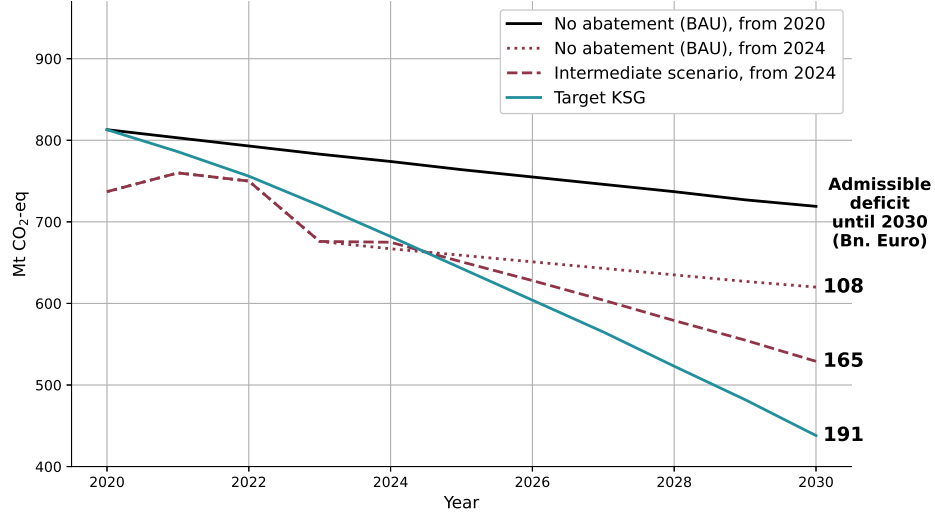


Fig. 5 Three emission scenarios and their corresponding cumulative admissible deficit until 2030

capital stock, we tie it to a change in the *atmospheric* capital stock — the reduction in greenhouse-gas emissions, measured in tons of CO₂ equivalents.

Three properties follow from this single move and together set the rule apart from a mere relabeling of the classical golden rule of fiscal policy. First, because the privileged quantity is sharply measurable at the macro level, there is no discretion over what counts as investment — and no case-by-case classification through which such discretion could re-enter — so there is no scope for the “creative accounting” to which the classical golden rule is exposed. Second, because the quantity is homogeneous, its depreciation rate and its return are readily quantifiable rather than estimated asset by asset, so the rule disposes of the critique that assessing the depreciation rate of a heterogeneous capital stock is hard and administratively costly. Third, because the return is observable, the admissible deficit can be conditioned on the monetized benefit of the abatement achieved rather than on its cost — the rule is output-based rather than input-based. This output-orientation gives the government two incentives the classical golden rule cannot — to abate where it is cheapest, maximizing emission reductions per euro, and to undertake only abatement that passes a cost–benefit test, since projects that fail it reduce its effective fiscal space — and it makes the resulting deficit room unconditional: once emissions have been reduced, no restriction attaches to how the borrowed funds are spent. We show in the model that a rule of exactly this form — with slope equal to the SCC and an appropriately chosen intercept — restores the welfare-maximizing allocation, so that both the efficient deficit and the efficient level of emission reductions are implemented.

The green-golden rule can be formulated as both a quantity and a price rule. The key advantage of the quantity rule is that it grants full flexibility to the government in terms of the choice of policy instruments. The downside is that it necessitates a convincing computation of the counterfactual emission path in absence of climate

policy. Using a SCC of 200 Euro/t CO₂, computing counterfactual emissions based on the emission trend of the past 30 years and assuming that the targets from the German Climate Protection Act (KSG) represent the efficient amount of emissions, we compute an admissible cumulated deficit of 191 billion Euro for the period from 2020-2030 for full compliance with the KSG.

The price rule’s disadvantage is that it ties the admissible deficit to the level of the carbon price only, thus restricting the government’s instrument choice for climate policy. However, it has the key advantage of not relying on the estimation of counterfactual emission values. According to our computations, a carbon price of 200 Euro/t CO₂ in conjunction with a medium estimate for the price elasticity of emissions ($\epsilon = -0.8$) grants a yearly permissible deficit of almost 72 billion Euro for the EU, if applied to the EU-ETS2 sectors (24 billion Euro for Germany as a whole) from 2024 on, corresponding to 0.4% of the EU’s GDP (roughly 0.56% of German GDP) as of 2024. If carbon leakage is big or the EU (Germany) acts unilaterally when reducing emissions, the admissible deficit is smaller. This highlights the importance of international cooperation and mechanisms like the CBAM for the green-golden rule, too.

Our findings are particularly relevant for countries where limited political support and fiscal constraints impede climate policy implementation; the green-golden rule could substantially ease these constraints, as the quantitative magnitudes presented here suggest. Its implementation, however, requires complementary institutional measures. An independent commission should determine the SCC — possibly from a domestic perspective that accounts for the leakage and spillover effects of national mitigation — specify the elasticity for the price rule, and develop a method to aggregate carbon prices across sectors when fossil-fuel taxes or carbon prices are heterogeneous. Under the quantity rule, multi-year compliance periods could align fiscal incentives with longer-term mitigation outcomes, allowing governments to be rewarded for delayed emission reductions through annual interim disbursements based on updated projections.

More broadly, the principle behind the rule is to define the privileged investment as a sharp, measurable, homogeneous quantity — closing the door on creative accounting — and, because such a quantity carries an observable return, to condition borrowing on what is achieved rather than on what is spent. Climate policy is the natural first application, because emission reductions supply precisely such a quantity, with a homogeneous, priced output. Whether other public investment admits a comparable reconceptualization, with a comparably sharp and priced output, is a question of each sector’s economics that we do not settle here. The green-golden rule is thus tied to, but not confined to, climate policy: by linking permissible deficits to measurable outcomes, it offers a way to reconcile fiscal responsibility with the provision of dynamic public goods, even where political support or fiscal space is scarce.

Acknowledgements. We thank Désirée I. Christofzik, Lennart Stern, Marco Runkel and the participants of the committee for macroeconomics of the *Verein für Socialpolitik* in June 2024 at the University of Potsdam as well as the participants of the ZEW Public Finance Conference in Mannheim in May 2025 for helpful comments. This work was supported by the German Federal Ministry of Research, Technology

and Space (BMFTR) as part of the ARIADNE project (grant references: 03SFK5J0 and 03SFK5P0-2).

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Competing Interests and Funding

This work was supported by the German Federal Ministry of Research, Technology and Space (BMFTR) as part of the ARIADNE project (grant references: 03SFK5J0 and 03SFK5P0-2).

Appendix A Emission reductions in utility

Instead of including the benefits from emission reductions Δe directly in the budget constraint, as we do in the welfare maximization problem (P-1) and the present-biased government's problem (P-2), it is possible to include Δe as additional argument in the utility function. Then, the respective objective functions for problems (P-1) and (P-2) are

$$\begin{aligned} W(c_1, c_2, \Delta e) &= u(c_1) + \beta v(c_2, \Delta e) \\ W^\delta(c_1, c_2, \Delta e) &= u(c_1) + \beta \delta v(c_2, \Delta e) \end{aligned}$$

with $v(c_2, \Delta e)$ increasing in both of its arguments at decreasing rate. The budget constraint reads

$$c_1 + \gamma(\Delta e) + \frac{c_2}{1+r} = y + \frac{y}{1+r}$$

Let v_j denote the partial derivative of v with respect to argument j , $\partial v / \partial j$, $j = c_2, \Delta e$. For $R = 1/\beta$, the welfare maximizing allocation implies $u'(c_1^*) = v_c(c_2^*, \Delta e^*)$ and $\beta v_{\Delta e}(c_2^*, \Delta e^*) = u'(c_1^*) \gamma'(\Delta e^*)$. By the same token, the present-biased government's unconstrained solution is characterized by $u'(c_1^*) = \delta v_c(c_2^*, \Delta e^*)$ and $\beta \delta v_{\Delta e}(c_2^*, \Delta e^*) = u'(c_1^*) \gamma'(\Delta e^*)$. Combining the two conditions yields $\gamma'(\Delta e^*) = \beta v_{\Delta e} / v_c$, so present bias bears on abatement only through the marginal rate of substitution $v_{\Delta e} / v_c$, which a lower δ shifts via c_2 .

If we assume a constant marginal rate of substitution between c_2 and Δe , $\frac{v_{\Delta e}}{v_c} = s$ (e.g. for a utility function $v(c_2, \Delta e) = v(c_2 + s \Delta e)$), the result is equal to the one in the main text where climate benefits are part of the budget constraint.

The more general case with a varying marginal rate of substitution between c_2 and Δe implies some changes. For instance, the vertical line through points A and B in Figure 1 becomes a curve whose slope, under plausible assumptions, is negative.

Since a stronger present bias raises the deficit and thus moves the allocation from A toward B , the present-biased government then also chooses lower abatement — unlike in the main model, and in line with [Janeba \(2025\)](#), who includes the benefits of public investment in utility directly. The curve running through points B , C , and D maintains a positive slope, so the results derived on the effect of a deficit rule (see maximization problem (P-3)) remain unaffected.

However, these differences have *no effect* on the resulting green–golden rule. Since the latter aims at implementing the welfare optimal allocation, it must hold that

$$\frac{db}{d\Delta e} = \gamma'(\Delta e^*) = \beta \frac{v_{\Delta e}^*}{v_c^*} \quad (\text{A1})$$

$$\Leftrightarrow \quad b = k + \beta \underbrace{\frac{v_{\Delta e}^*}{v_c^*}}_{\equiv s} \Delta e. \quad (\text{A2})$$

Here, s is a constant that denotes the marginal rate of substitution *at the optimum*. Its present discounted value is equal to the SCC.

Hence, the key arguments of this study are preserved in a model version, where emission reductions enter utility directly instead of entering the budget constraint. These differences mainly affect the graphical representation of the results presented in the main text.

Appendix B Present-biased government

In the case of a present-biased government, maximizing subject to the intertemporal budget constraint also implies that the chosen emission reduction, Δe^δ , satisfies the optimality condition $\gamma'(\Delta e^\delta) = s\beta$, which implies that $\Delta e^\delta = \Delta e^*$. The solutions for c_1 and c_2 from (P-2) solve the system of equations:

$$u'(c_1) = \delta u'(c_2) \quad (\text{B3a})$$

$$c_1 + \beta c_2 = y(1 + \beta) - \gamma(\Delta e^*) + \beta s \Delta e^* \quad (\text{B3b})$$

The derivative with respect to δ yields

$$\begin{pmatrix} u''(c_1) & -u''(c_2) \\ 1 & \beta \end{pmatrix} \begin{pmatrix} \frac{dc_1}{d\delta} \\ \frac{dc_2}{d\delta} \end{pmatrix} = \begin{pmatrix} u'(c_2) \\ 0 \end{pmatrix} \quad (\text{B4})$$

Here $\mathcal{D} < 0$ denotes the determinant of the 2×2 matrix (Hessian matrix) on the left-hand side of the system of equations (B4). Using the first-order conditions (B3a) and (B3b), the following solutions are obtained:

$$\begin{aligned} \begin{pmatrix} \frac{dc_1}{d\delta} \\ \frac{dc_2}{d\delta} \end{pmatrix} &= \frac{1}{\mathcal{D}} \begin{pmatrix} \beta & u''(c_2) \\ -1 & u''(c_1) \end{pmatrix} \begin{pmatrix} u'(c_2) \\ 0 \end{pmatrix} \\ &= \frac{1}{\mathcal{D}} \begin{pmatrix} \beta u'(c_2) \\ -u'(c_2) \end{pmatrix} \end{aligned} \quad (\text{B5})$$

Since $\mathcal{D} < 0$ it follows that $dc_1/d\delta < 0$ and $dc_2/d\delta > 0$. Hence, the debt b^δ is given by $b^\delta = c_1 + \gamma(\Delta e^\delta) - y = c_1 + \gamma(\Delta e^*) - y$. In combination with (B5) this yields

$$\frac{db^\delta}{d\delta} = \frac{dc_1}{d\delta} < 0$$

Appendix C Deficit limit

Given a binding deficit limit $\bar{b}$, the solutions for c_1 , c_2 , and Δe from the system (P-3) are given by

$$u'(c_1)\gamma'(\Delta e) = \delta\beta s u'(c_2) \quad (\text{C6a})$$

$$c_1 + \gamma(\Delta e) = y + \bar{b} \quad (\text{C6b})$$

$$c_2 - s\Delta e = y - \bar{b}/\beta \quad (\text{C6c})$$

The derivative of $c_1(\bar{b})$, $c_2(\bar{b})$ and $\Delta e(\bar{b})$ based on (C6a) - (C6c) yield the following system of equations:

$$\begin{pmatrix} u''(c_1)\gamma'(\Delta e) & -\delta\beta s u''(c_2) & u'(c_1)\gamma''(\Delta e) \\ 1 & 0 & \gamma'(\Delta e) \\ 0 & 1 & -s \end{pmatrix} \begin{pmatrix} \frac{dc_1}{d\bar{b}} \\ \frac{dc_2}{d\bar{b}} \\ \frac{d\Delta e}{d\bar{b}} \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ -1/\beta \end{pmatrix} \quad (\text{C7})$$

Again, $\mathcal{D} = -u''(c_1)\gamma'(\Delta e)^2 - \delta\beta s^2 u''(c_2) + u'(c_1)\gamma''(\Delta e) > 0$ denotes the determinant of the 3×3 Hessian matrix on the left-hand side of the system (C7). The solution is given by

$$\begin{pmatrix} \frac{dc_1}{d\bar{b}} \\ \frac{dc_2}{d\bar{b}} \\ \frac{d\Delta e}{d\bar{b}} \end{pmatrix} = \frac{1}{\mathcal{D}} \begin{pmatrix} u''(c_2)s\delta(\gamma'(\Delta e) - s\beta) + \gamma''(\Delta e)u'(c_1) \\ \frac{1}{\beta}(u''(c_1)\gamma'(\Delta e)(\gamma'(\Delta e) - s\beta) - u'(c_1)\gamma''(\Delta e)) \\ -\gamma'(\Delta e)u''(c_1) - s\delta u''(c_2) \end{pmatrix} \quad (\text{C8})$$

For debt limits $\bar{b} \leq b^\delta$ it holds that $\gamma'(\Delta e) \leq s\beta$. Hence, from (C8) it follows that

$$c'_1(\bar{b}) > 0, \quad c'_2(\bar{b}) \leq 0, \quad \Delta e'(\bar{b}) > 0 \quad (\text{C9})$$

Thus the sign of $c'_2(\bar{b})$ is not unique.

Appendix D Optimal deficit limits

Plugging in the solution $\Delta e(\bar{b})$ from (P-3) into the social welfare function and taking differences from $\bar{b}$ yields

$$\frac{dW}{d\bar{b}} = u'(c_1(\bar{b})) (1 - \gamma'(\Delta e(\bar{b})) \Delta e'(\bar{b}) + \beta u'(c_2(\bar{b})) (s \Delta e'(\bar{b}) - 1/\beta) \quad (\text{D10})$$

Whenever the debt limit binds, (C6a) is fulfilled and (D10) becomes

$$\frac{dW}{d\bar{b}} = u'(c_1(\bar{b})) - u'(c_2(\bar{b})) + \Delta e'(\bar{b}) u'(c_2(\bar{b})) \beta s (1 - \delta) \quad (\text{D11})$$

It can be shown that welfare increases if $\bar{b}$ is increased starting from $\bar{b} = 0$ or decreased starting from $\bar{b} = b^\delta$

- (i) if $\bar{b} = 0$ holds, $u'(c_1(\bar{b})) - u'(c_2(\bar{b})) = u'(y - \gamma(\Delta e(\bar{b}))) - u'(y + s \Delta e(\bar{b})) > 0$ holds. Therefore, $\Delta e'(\bar{b}) > 0$ results from (D11):

$$\frac{dW}{d\bar{b}} \big|_{\bar{b}=0} > 0$$

- (ii) If $\bar{b} = b^\delta$ holds, from (B3a), it follows that $u'(c_1(\bar{b})) - u'(c_2(\bar{b})) = (\delta - 1) u'(c_2(\bar{b})) < 0$. If $\bar{b} = b^\delta$, however, $\gamma'(\Delta e) = s \beta$ applies and it follows:

$$\frac{dW}{d\bar{b}} \big|_{\bar{b}=b^\delta} = u'(c_2(\bar{b})) (1 - \delta) (\Delta e'(\bar{b}) \beta s - 1) < 0, \quad (\text{D12})$$

The sign (D12) follows from the results derived in (C8) for $\Delta e'(\bar{b})$, which at the point b^δ implies, that $\Delta e'(\bar{b}) < \frac{1}{s\beta}$ holds: Then from (C8) it follows for $\Delta e'(\bar{b})$:

$$\Delta e'(\bar{b}) = \frac{-\gamma'(\Delta e) u''(c_1) - s \delta u''(c_2)}{u'(c_1) \gamma''(\Delta e) - \gamma'(\Delta e)^2 u''(c_1) - s^2 \beta \delta u''(c_2)} \quad (\text{D13})$$

For $\bar{b} = b^\delta$ it holds that $\gamma'(\Delta e) = s \beta$ and from (D13) it follows:

$$\Delta e'(b^\delta) = \frac{\gamma'(\Delta e) u''(c_1) + s \delta u''(c_2)}{s \beta [\gamma'(\Delta e) u''(c_1) + s \delta u''(c_2)] - u'(c_1) \gamma''(\Delta e)} \quad (\text{D14})$$

From (D14) it follows that $\Delta e'(b^\delta) < \frac{1}{s\beta}$ and thus the sign listed in (D12) for $\frac{dW}{d\bar{b}} \big|_{\bar{b}=b^\delta}$.

Since $W(c_1(\bar{b}), c_2(\bar{b}), g(\bar{b}))$ is a continuous function of $\bar{b}$, it follows that there exists a $\bar{b}_{opt} \in (0, b^\delta)$ that maximizes welfare.

However, the optimal deficit limit $\bar{b}_{opt}$ is only a second-best solution, as $\bar{b}_{opt}$ does not implement the welfare-maximizing allocation. The latter requires that $u'(c_1) = u'(c_2)$, which is only the case if $\bar{b} = \frac{\beta}{1+\beta} (s \Delta e + \gamma(\Delta e))$. However, according to (C6a), it holds that $\gamma'(\Delta e) = \delta \beta s < \beta s$. Therefore, the second necessary condition for a welfare-maximizing allocation, which requires $\gamma'(\Delta e) = \beta s$, is not fulfilled.

Appendix E Optimal affine-linear rule

For a general affine-linear rule $b = \psi \Delta e + k$, the solutions for c_1, c_2 and Δe of (P-4) solve the system of equations:

$$\begin{aligned}
u'(c_1)(\gamma'(\Delta e) - \psi) &= \delta \beta (s - \psi/\beta) u'(c_2) \\
c_1 + \gamma(\Delta e) &= y + \psi \Delta e + k \\
c_2 + \frac{\psi \Delta e + k}{\beta} &= y + s \Delta e
\end{aligned} \tag{E15a}$$

Denote the solutions of (E15a) depending on the affine-linear rule as $c_1(\psi, k)$, $c_2(\psi, k)$ and $\Delta e(\psi, k)$. For $\psi = s\beta = s/(1+r)$, $\gamma'(\Delta e(s\beta, k)) = s\beta$ holds for any k . The emission reductions $\Delta e(s\beta, k) = \Delta e^*$ are therefore efficient for any k and thus the resulting allocation between c_1 and c_2 is Pareto-optimal. By carefully choosing k , the welfare optimum can also be induced, which implies $c_1 = c_2$. This is the case if:

$$k = k^* := -\frac{\beta}{1+\beta}(s\beta\Delta e^* - \gamma(\Delta e^*)) < 0 \tag{E16}$$

Appendix F Pareto improving affine-linear rule

Let $\Delta e(\bar{b})$ and $\bar{c}_t(\bar{b})$, $t = 1, 2$ denote the emission reductions and consumption in both periods, depending on the current binding deficit limit $\bar{b}$. To see that the introduction of a *surplus abatement rule* $b = \beta s(\Delta e - \Delta e(\bar{b}))$ is a Pareto improvement and induces a Pareto-optimal outcome, we first note that the surplus abatement rule is an affine-linear rule:

$$\begin{aligned}
b &= \beta s(\Delta e - \Delta e(\bar{b})) \\
&= \beta s \Delta e + \kappa,
\end{aligned} \tag{F17}$$

where $\kappa = -\beta s \Delta e(\bar{b})$. Because the slope of this rule corresponds to the SCC βs , it induces a Pareto optimum (see Appendix E) and the efficient emission reductions $\Delta e = \Delta e^*$. Moreover, consumption after the introduction of the rule in the first period $c_{1,z}$ is

$$\begin{aligned}
c_{1,z} &= y - \gamma(\Delta e^*) + s\beta(\Delta e^* - \bar{\Delta}e) \\
&= y - \gamma(\Delta e^*) + \gamma'(\Delta e^*)(\Delta e^* - \bar{\Delta}e) \\
&\geq y - \gamma(\bar{\Delta}e) = \bar{c}_1,
\end{aligned} \tag{F18}$$

where the second line uses $s\beta = \gamma'(\Delta e^*)$ and the inequality in the third line follows from the convexity of $\gamma(\cdot)$. Therefore, the first generation is not worse off due to the introduction of the surplus abatement rule. For strictly convex costs $\gamma(\cdot)$, it is strictly better off. For the consumption in the second period after the introduction of the rule $c_{2,z}$, we obtain

$$c_{2,z} = y + s \Delta e^* - \frac{s\beta(\Delta e^* - \bar{\Delta}e)}{\beta} \tag{F19}$$

$$=y + s \Delta e = \bar{c}_2$$

The introduction of the surplus abatement rule does not affect the consumption of the second generation. Therefore, the rule represents a Pareto improvement over the deficit limit $\bar{b}$.

Appendix G Optimal price rule

In this section, we reformulate the optimal affine-linear rule from Equation (2b) as a function of the price of fossil fuels. For this purpose, it is assumed that there is an inverse relationship between emissions e and the price of fossil fuels p , which is characterized by the price elasticity $\epsilon(p)$:

$$e = e(p), \quad \text{with:} \quad \frac{e'(p)p}{e(p)} = -\epsilon(p).$$

Let us denote the price in the BAU scenario ($\Delta e = 0$) as p_{BAU} . The emissions in the BAU scenario can be approximated as follows:

$$e(p_{BAU}) = e(p) + \epsilon(p) \frac{e(p)}{p} (p - p_{BAU})$$

Denoting the difference in prices as $\Delta p = p - p_{BAU}$, the reduction in emissions $\Delta e(p)$ induced by the price of fossil fuels p is:

$$\Delta e(p) = e(p_{BAU}) - e(p) = \epsilon(p) \frac{e(p)}{p} \Delta p$$

By the same token, for $\Delta p^* = p^* - p_{BAU}$ and since for any price p' we obtain

$$\begin{aligned} \Delta e^* &= \Delta e(p^*) = e(p_{BAU}) - e(p') - (e(p^*) - e(p')) \\ &= \epsilon(p') \frac{e(p')}{p'} (p' - p_{BAU}) - \epsilon(p') \frac{e(p')}{p'} (p' - p^*) \end{aligned}$$

we obtain that optimal emission reductions can be approximated by $\Delta e^* = \epsilon(p) \frac{e(p)}{p} \Delta p^*$. (2a) can thus be written as:

$$b = b^* + s \beta \epsilon(p) \frac{e(p)}{p} (p - p^*) \quad (\text{G20})$$

Note that we can also approximate the optimal emission reductions $\Delta e^* = \epsilon(p_0) \frac{e(p_0)}{p_0} \Delta p^*$, where p_0 is the initially observed price, for example implemented by a present-biased government. For b^* from (2b), we then obtain

$$b^* = s \beta \epsilon(p_0) \frac{1}{1 + \beta} \frac{e(p_0)}{p_0} \left(\frac{\beta}{\eta} + 1 \right) \Delta p^* \quad (\text{G21})$$

Denote the current carbon price with τ and assume that $p = p_{BAU} + \tau$, that is, p_{BAU} is the fossil energy price for a carbon price of zero and that $p^* = p_{BAU} + s\beta$, that is, the optimal price is the BAU price plus the SCC. In that case, we can reformulate Equations (G20) and (G21) as:

$$b = b^* + s\beta \epsilon(p) \frac{e(p)}{p} (\tau - s\beta) \quad (\text{G22})$$

$$b^* = \epsilon(p_0) \frac{1}{1+\beta} \frac{e(p_0)}{p_0} \left(\frac{\beta}{\eta} + 1 \right) (s\beta)^2 \quad (\text{G23})$$

In the last step, we note that the abatement cost elasticity η from the abatement cost function $\gamma(\Delta e) := \kappa \Delta e^\eta$ and the price elasticity of emissions ϵ cannot be calibrated independently and show, how the choice of quadratic abatement cost $\eta = 2$ (and only this choice) simplifies the analysis by allowing both elasticities to be constant.

To see this, note that the price elasticity of emissions is defined as

$$\epsilon := - \frac{e'(p)p}{e(p)}$$

and that, since $\Delta e(p) := e(p_{BAU}) - e(p)$, we have

$$\frac{\partial \Delta e(p)}{\partial p} \frac{p}{\Delta e(p)} = \epsilon \frac{e(p)}{e(p_{BAU}) - e(p)}. \quad (\text{G24})$$

Furthermore, throughout our analysis we assume that the carbon price equals marginal abatement cost, $p - p_{BAU} = \tau \stackrel{!}{=} \gamma'(\Delta e(p)) = \kappa \eta \Delta e^{\eta-1}$. Therefore

$$\frac{\partial \Delta e(p)}{\partial p} \frac{p}{\Delta e(p)} = \frac{1}{\eta - 1} \frac{p}{p - p_{BAU}}. \quad (\text{G25})$$

Combining (G24) and (G25), we obtain

$$\epsilon = \frac{1}{\eta - 1} \frac{e(p)}{e(p_{BAU}) - e(p)} \frac{p}{p - p_{BAU}}. \quad (\text{G26})$$

(G26) implies that if the percentage reduction in emissions $\Delta e(p)/e(p)$ brought about by a price of fossil energy $p = p_{BAU} + \tau$ approximately corresponds to the ratio of the carbon tax over the price of fossil energy τ/p , then $\eta = (1 + \epsilon/\epsilon)$.

Moreover, assuming constant price elasticity ϵ , we obtain $\frac{e(p_{BAU}) - e(p)}{p - p_{BAU}} \approx \epsilon \frac{e(p)}{p}$ for all prices of fossil energy p . Plugging this into (G26), we obtain $\epsilon = \frac{1}{1-\eta} \epsilon$. This can only hold for $\eta = 2$ or $\epsilon = 0$, where the last case is not of interest.

Appendix H Infinite time horizon

With $\frac{1}{R} = \frac{1}{R_\rho - 1}$ the budget constraint from (P-5) becomes $c_t = c_2$ for all $t > 2$:

$$\begin{aligned} c_1 + \frac{1}{R_\rho} \frac{R_\rho}{R_\rho - 1} c_2 + \gamma(\Delta e) &= y + \frac{1}{R_\rho} \frac{R_\rho}{R_\rho - 1} y + \frac{1}{R_\rho} \frac{R_\rho}{R_\rho - 1} s \Delta e \\ \Leftrightarrow c_1 + \frac{c_2}{R} + \gamma(\Delta e) &= y + \frac{y}{R} y + \frac{1}{R} s \Delta e \end{aligned} \quad (\text{H27})$$

Correspondingly, $\sum_{t=2}^{\infty} \rho^{t-2} = \frac{1}{1-\rho}$ implies that:

$$\rho \sum_{t=1}^{\infty} \rho^{t-2} u(c_2) = \frac{\rho}{1-\rho} u(c_2) \quad (\text{H28})$$

From (H27) and (H28) then follows the equivalence between (P-6) and (P-5). The corresponding procedure in the case of a present-biased government results in the equivalence between (P-7) and (P-8).

Appendix I A price rule for the EU - A lower bound

We recompute the computation from Section 3.1 using a lower bound for the SCC of 11 Euro/tCO₂. We compute this value based on a value of direct climate benefits from the reduction of one ton of CO₂ for the EU of 33 Euro from Edenhofer et al. which follows from assuming that climate damages on the EU's territory scale with its GDP. Therefore, the EU's SCC are the global SCC weighed by its share in global GDP. The calculated territorial SCC constitutes a naive estimate ignoring potential carbon leakage that would offset domestic emission reductions to some extent. We therefore account for energy source specific carbon leakage rates as provided in Edenhofer et al.. We aggregate the global reduction in carbon emission (EU reduction net of leakage rate), using the share of energy sources in EU carbon emissions for 2023 from the International Energy Agency (IEA) and the weights between thermal and coking coal for 2023 from the European Commission's Coal Production and Consumption statistics. This gives an effective EU SCC (accounting for leakage and territorial benefits only) of 12 Euro.

Table I1 illustrates the results. The admissible deficit is now positive for lower values of the carbon price. However, the lower bound of admissible deficit for a carbon price of 200 Euro/tCO₂ and the median elasticity value of -0.8 is approximately 3.8 billion Euro per year. This is a significant reduction in the admissible deficit compared to a value of almost 72 billion Euro per year in our preferred specification. It highlights the value of cooperation and instruments like a CBAM to reduce carbon leakage. The green-golden rule thus aligns the incentives for a government to maximize its fiscal space and to efficiently reduce global carbon emissions.

Admissible annual deficit (billions of Euro)							
ϵ	Carbon price (Euro/tCO ₂ -eq.)						
	0	50	75	100	150	200	250
-0.5	-0.09	0.87	1.27	1.62	2.19	2.62	2.93
-0.8	-0.16	1.39	1.99	2.50	3.28	3.78	4.07
-1.1	-0.22	1.89	2.67	3.31	4.19	4.64	4.74

Table I1 Annual admissible deficit for different values of the carbon price and price elasticities of emissions ϵ .

References

- Andersen, T.M., Bhattacharya, J., Liu, P.: Resolving intergenerational conflict over the environment under the pareto criterion. *Journal of Environmental Economics and Management* **100**, 1–27 (2020) <https://doi.org/10.1016/j.jeem.2019.102290>
- Ardanaz, M., Cavallo, E., Izquierdo, A., Puig, J.: Growth-friendly fiscal rules? safeguarding public investment from budget cuts through fiscal rule design. *Journal of International Money and Finance* **111**, 102319 (2021) <https://doi.org/10.1016/j.jimonfin.2020.102319>
- Arrow, K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S., Mäler, K.-G., Schneider, S., Starrett, D., Walker, B.: Are we consuming too much? *The Journal of Economic Perspectives* **18**(3), 147–172 (2004) <https://doi.org/10.1257/0895330042162377>
- Abiad, A., Furceri, D., Topalova, P.: The macroeconomic effects of public investment: Evidence from advanced economies. *Journal of Macroeconomics* **50**, 224–240 (2016) <https://doi.org/10.1016/j.jmacro.2016.07.005>
- Agora Energiewende: Die Energiewende in Deutschland: Stand der Dinge 2024. Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2025. <https://www.agora-energiewende.de/publikationen/die-energiewende-in-deutschland-stand-der-dinge-2024> Accessed 2025-01-31
- Barro, R.J.: On the determination of the public debt. *Journal of Political Economy* **87**(5), 940–971 (1979) <https://doi.org/10.1086/260807>
- Blesse, S., Dörr, L., Dorn, F., Lay, M.: Do fiscal rules undermine public investments? a review of empirical evidence. *European Journal of Political Economy* **91**, 102775 (2026) <https://doi.org/10.1016/j.ejpoleco.2025.102775>
- Beznoska, M.: Estimating a consumer demand system of energy, mobility and leisure: A microdata approach for Germany. Deutsches Institut für Wirtschaftsforschung Berlin. <https://doi.org/10.2139/ssrn.2433025>

- Balassone, F., Franco, D.: Public investment, the stability pact and the ‘golden rule’. *Fiscal Studies* **21**(2), 207–229 (2000) <https://doi.org/10.1111/j.1475-5890.2000.tb00023.x>
- Burret, H.T., Feld, L.P.: (un-)intended effects of fiscal rules. *European Journal of Political Economy* **52**, 166–191 (2018) <https://doi.org/10.1016/j.ejpoleco.2017.06.002>
- Blanchard, O., Giavazzi, F.: Improving the sgp through a proper accounting of public investment. CEPR Discussion Papers 4220, C.E.P.R. Discussion Papers (February 2004)
- Bovenberg, A.L., Heijdra, B.J.: Environmental tax policy and intergenerational distribution. *Journal of Public Economics* **67**(1), 1–24 (1998) [https://doi.org/10.1016/S0047-2727\(97\)00064-9](https://doi.org/10.1016/S0047-2727(97)00064-9)
- Bovenberg, A.L., Heijdra, B.J.: Environmental abatement and intergenerational distribution. *Environmental and Resource Economics* **23**(1), 45–84 (2002)
- Bohne, A., Heinemann, F., Heinzel, C.: The future ratio: A new metric for forward-looking fiscal policy in Europe. Mannheim: ZEW-Leibniz Centre for European Economic Research. https://www.zew.de/fileadmin/FTP/gutachten/FutureRatio_Report_ZEW.pdf
- Bohne, A., Heinemann, F., Niebel, T., Thöne, M.: Die zukunftsquote: ein neuer kompass für den bundeshaushalt. *Perspektiven der Wirtschaftspolitik* **25**(2), 113–129 (2024) <https://doi.org/10.1515/pwp-2024-0008>
- Bilal, A., Känzig, D.R.: Does unilateral decarbonization pay for itself? *AEA Papers and Proceedings* **115**, 369–373 (2025) <https://doi.org/10.1257/pandp.20251035>
- Bilal, A., Känzig, D.R.: The macroeconomic impact of climate change: Global versus local temperature. *Quarterly Journal of Economics* **141**(2), 889–944 (2026) <https://doi.org/10.1093/qje/qjag011>
- Blanchard, O., Leandro, A., Zettelmeyer, J.: Redesigning eu fiscal rules: From rules to standards. *Economic policy* **36**(106), 195–236 (2021)
- Bergmann, T., Moretti, N.: Trading budget deficits for public investment: Optimal deficit rules for present-biased governments. *European Journal of Political Economy* **93**, 102852 (2026) <https://doi.org/10.1016/j.ejpoleco.2026.102852>
- Brons, M., Nijkamp, P., Pels, E., Rietveld, P.: A meta-analysis of the price elasticity of gasoline demand. a sur approach. *Energy Economics* **30**(5), 2105–2122 (2008) <https://doi.org/10.1016/j.eneco.2007.08.004>
- Bom, P.R.D.: Fiscal rules and the intergenerational welfare effects of public investment.

- Economic Modelling **81**, 455–470 (2019) <https://doi.org/10.1016/j.econmod.2018.02.002>
- Bassetto, M., Sargent, T.J.: Politics and efficiency of separating capital and ordinary government budgets. *Quarterly Journal of Economics* **121**(4), 1167–1210 (2006) <https://doi.org/10.1093/qje/121.4.1167>
- Buchsbaum, J.: Long-run price elasticities and mechanisms: Empirical evidence from residential electricity consumers. *Energy Institute Working Paper* **331** (2022)
- Beaufils, T., Wanner, J., Wenz, L.: The potential of carbon border adjustments to foster climate cooperation. *Journal of the Association of Environmental and Resource Economists* (forthcoming) <https://doi.org/10.1086/742163>
- Ciaffi, G., Deleidi, M., Di Domenico, L.: Fiscal policy and public debt: Government investment is most effective to promote sustainability. *Journal of Policy Modeling* **46**(6), 1186–1209 (2024) <https://doi.org/10.1016/j.jpolmod.2024.07.002>
- Chichilnisky, G., Heal, G., Beltratti, A.: The green golden rule. *Economics Letters* **49**(2), 175–179 (1995) [https://doi.org/10.1016/0165-1765\(95\)00662-Y](https://doi.org/10.1016/0165-1765(95)00662-Y)
- Caselli, F., Lagerborg, A., Medas, P.A.: Green Fiscal Rules? Challenges and Policy Alternatives: IMF Working Paper. <https://doi.org/10.5089/9798400280726.001>
- Darvas, Z., Wolff, G.B.: A green fiscal pact for the eu: increasing climate investments while consolidating budgets. *Climate Policy* **23**(4), 409–417 (2023) <https://doi.org/10.1080/14693062.2022.2147893>
- Edenhofer, O., Kalkuhl, M., Stern, L.: How to scale up effective international climate finance by the EU? Tax coalitions and jurisdictional reward funds for the case of fossil fuel. Kiel Institute for the World Economy. https://www.kielinstitut.de/fileadmin/Dateiverwaltung/IfW-Publications/fis-import/82955e96-dd0f-4bb5-8b2e-ee4a311a987b-KWP_2296.pdf
- Environmental Protection Agency: Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances, Washington DC. https://www.epa.gov/system/files/documents/2023-12/epa_scghg.2023_report_final.pdf Accessed 2025-01-29
- Gollier, C.: The cost-efficiency carbon pricing puzzle. *Journal of Environmental Economics and Management* **128**, 103062 (2024) <https://doi.org/10.1016/j.jeem.2024.103062>
- Günther, C., Pahle, M., Govorukha, K., Osorio, S., Fotiou, T.: Carbon prices on the rise? shedding light on the emerging second eu emissions trading system (eu ets 2). *Climate Policy*, 1–12 (2025) <https://doi.org/10.1080/14693062.2025.2485196>

- Gregori, W.D.: To what extent do fiscal spending rules affect budget composition? *Public Sector Economics* **42**(3), 325–345 (2018) <https://doi.org/10.3326/pse.42.3.5>
- Hänsel, M.C., Franks, M., Kalkuhl, M., Edenhofer, O.: Optimal carbon taxation and horizontal equity: A welfare-theoretic approach with application to german household data. *Journal of Environmental Economics and Management* **116** (2022) <https://doi.org/10.1016/j.jeem.2022.102730>
- Harstad, B., Storesletten, K.: Conservation by lending. Technical report, CESifo Working Paper No. 10533 (2023)
- Janeba, E.: The effect of fiscal rules on public investment: Theory and application to the German Debt Brake. Mimeo (2025)
- Jackson, M.O., Yariv, L.: Collective dynamic choice: The necessity of time inconsistency. *American Economic Journal: Microeconomics* **7**(4), 150–178 (2015) <https://doi.org/10.1257/mic.20140161>
- Kornek, U., Edenhofer, O.: The strategic dimension of financing global public goods. *European Economic Review* **127**, 103423 (2020) <https://doi.org/10.1016/j.euroecorev.2020.103423>
- Kotlikoff, L., Kubler, F., Polbin, A., Sachs, J., Scheidegger, S.: Making carbon taxation a generational win win. *International Economic Review* **62**(1), 3–46 (2021) <https://doi.org/10.1111/iere.12483>
- Kalkuhl, M., Stern, L.: Rewarding countries for taxing fossil fuel combustion: optimal mechanisms under exogenous budgets. Technical report, SSRN (2024). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5076373
- Linsenmeier, M., Mohommad, A., Schwerhoff, G.: Global benefits of the international diffusion of carbon pricing policies. *Nature Climate Change* **13**(7), 679–684 (2023) <https://doi.org/10.1038/s41558-023-01710-8>
- Milesi-Ferretti, G.M.: Good, bad or ugly? on the effects of fiscal rules with creative accounting. *Journal of Public Economics* **88**(1-2), 377–394 (2003) [https://doi.org/10.1016/S0047-2727\(02\)00076-2](https://doi.org/10.1016/S0047-2727(02)00076-2)
- Monasterolo, I., Pacelli, A., Pagano, M., Russo, C.: A european climate bond. *Economic policy* **40**(122), 307–339 (2025) <https://doi.org/10.1093/epolic/eiae065>
- Muehlegger, E., Rapson, D.S.: Subsidizing low- and middle-income adoption of electric vehicles: Quasi-experimental evidence from california. *Journal of Public Economics* **216**, 104752 (2022) <https://doi.org/10.1016/j.jpubeco.2022.104752>
- Musgrave, R.A.: The nature of budgetary balance and the case for the capital budget. *The American Economic Review*, 260–271 (1939)

- Nordhaus, W.: Estimates of the social cost of carbon: Concepts and results from the dice-2013r model and alternative approaches. *Journal of the Association of Environmental and Resource Economists* **1**, 273–312 (2014) <https://doi.org/10.1086/676035>
- Nikodinoska, D., Schröder, C.: On the emissions–inequality and emissions–welfare trade-offs in energy taxation: Evidence on the german car fuels tax. *Resource and Energy Economics* **44**, 206–233 (2016) <https://doi.org/10.1016/j.reseneeco.2016.03.001>
- Peletier, B.D., Dur, R.A.J., Swank, O.H.: Voting on the budget deficit: Comment. *The American Economic Review* **89**(5), 1377–1381 (1999) <https://doi.org/10.1257/aer.89.5.1377>
- Poterba, J.M.: Capital budgets, borrowing rules, and state capital spending. *Journal of Public Economics* **56**(2), 165–187 (1995) [https://doi.org/10.1016/0047-2727\(94\)01431-M](https://doi.org/10.1016/0047-2727(94)01431-M)
- Potrafke, N.: The economic consequences of fiscal rules. *Journal of International Money and Finance* **153**, 103286 (2025) <https://doi.org/10.1016/j.jimonfin.2025.103286>
- Piguillem, F., Riboni, A.: Fiscal rules as bargaining chips. *The Review of Economic Studies* **88**(5), 2439–2478 (2021) <https://doi.org/10.1093/restud/rdaa080>
- Persson, T., Svensson, L.E.O.: Why a stubborn conservative would run a deficit: Policy with time- inconsistent preferences. *The Quarterly Journal of Economics* **104**(2), 325 (1989) <https://doi.org/10.2307/2937850>
- Pothen, F., Tovar Reaños, M.A.: The distribution of material footprints in germany. *Ecological Economics* **153**, 237–251 (2018) <https://doi.org/10.1016/j.ecolecon.2018.06.001>
- Rennert, K., Errickson, F., Prest, B.C., Rennels, L., Newell, R.G., Pizer, W., Kingdon, C., Wingenroth, J., Cooke, R., Parthum, B., Smith, D., Cromar, K., Diaz, D., Moore, F.C., Müller, U.K., Plevin, R.J., Raftery, A.E., Ševčíková, H., Sheets, H., Stock, J.H., Tan, T., Watson, M., Wong, T.E., Anthoff, D.: Comprehensive evidence implies a higher social cost of co2. *Nature* **610**(7933), 687–692 (2022) <https://doi.org/10.1038/s41586-022-05224-9>
- Sachs, J.D.: Climate change and intergenerational well-being. *The Oxford handbook of the macroeconomics of global warming*, 248–259 (2014)
- Tabellini, G., Alesina, A.: Voting on the budget deficit. *The American Economic Review* **80**(1), 37–49 (1990)
- Tol, R.S.J.: Social cost of carbon estimates have increased over time. *Nature Climate Change* **13**(6), 532–536 (2023) <https://doi.org/10.1038/s41558-023-01680-x>

- Truger, A.: Reviving fiscal policy in europe: towards an implementation of the golden rule of public investment*. *European Journal of Economics and Economic Policies: Intervention* **13**(1), 57–71 (2016) <https://doi.org/10.4337/ejeep.2016.01.06>
- Velasco, A.: Debts and deficits with fragmented fiscal policymaking. *Journal of Public Economics* **76**(1), 105–125 (2000) [https://doi.org/10.1016/S0047-2727\(99\)00054-7](https://doi.org/10.1016/S0047-2727(99)00054-7)
- Venturini, F.: The unintended composition effect of the subnational government fiscal rules: The case of italian municipalities. *European Journal of Political Economy* **63**, 101874 (2020) <https://doi.org/10.1016/j.ejpoleco.2020.101874>
- Hagen, J., Wolff, G.B.: What do deficits tell us about debt? empirical evidence on creative accounting with fiscal rules in the eu. *Journal of Banking & Finance* **30**(12), 3259–3279 (2006) <https://doi.org/10.1016/j.jbankfin.2006.05.011>
- Vogt-Schilb, A., Meunier, G., Hallegatte, S.: When starting with the most expensive option makes sense: Optimal timing, cost and sectoral allocation of abatement investment. *Journal of Environmental Economics and Management* **88**, 210–233 (2018) <https://doi.org/10.1016/j.jeem.2017.12.001>
- Wissenschaftlicher Beirat beim BMWK: Finanzierung von Staatsaufgaben: Herausforderungen und Empfehlungen für eine nachhaltige Finanzpolitik: Gutachten des Wissenschaftlichen Beirats beim Bundesministerium für Wirtschaft und Klimaschutz (BMWK). <https://logistic-natives.com/wp-content/uploads/2023/12/gutachten-wissenschaftlicher-beirat-finanzierung-von-staatsaufgaben.pdf> Accessed 2024-11-06
- Weingast, B.R., Shepsle, K.A., Johnsen, C.: The political economy of benefits and costs: A neoclassical approach to distributive politics. *Journal of Political Economy* **89**(4), 642–664 (1981)
- Yared, P.: Rising government debt: Causes and solutions for a decades-old trend. *The Journal of Economic Perspectives* **33**(2), 115–140 (2019) <https://doi.org/10.1257/jep.33.2.115>
- Zimmer, A., Koch, N.: Fuel consumption dynamics in europe: Tax reform implications for air pollution and carbon emissions. *Transportation Research Part A: Policy and Practice* **106**, 22–50 (2017) <https://doi.org/10.1016/j.tra.2017.08.006>