Democratic Climate Policies with Overlapping Generations

Arnaud Goussebaïle*

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Abstract

An extensive climate policy literature provides various recommendations for mitigating climate change, but these recommendations are not supported democratically, since the models employed consider either infinitely-lived individuals or normative social objectives (or both). In contrast, the present paper provides policy recommendations capable of incorporating democratic processes. I develop an overlapping generation model with political process micro-foundations and show how democratic climate policies are interconnected with other democratic policies. Time inconsistent social objectives combined with commitment issues lead to an inefficient tax on capital accumulation and a climate policy below the efficient level; while suppressing the tax on capital accumulation generates a climate policy even further below the efficient level. I derive a novel politico-economic Keynes-Ramsey rule for the market interest rate, which is useful for calculating the climate policy level. I show that individual pure time preference, individual altruism toward descendants, and young generation political power are key determinants of democratic climate policy ambition.

Keywords: Climate change; Discounting; Externality; Overlapping generations; Political economy.

JEL codes: D6; D7; E6; Q5.

*ETHZ, Scheuchzerstrasse 7, 8092 Zürich, Switzerland, agoussebaile@ethz.ch, +41446338686.

1 Introduction

Climate change mitigation raises fundamental coordination issues: coordination between States (see, e.g., Batabyal (2017) for a literature review) and between generations. In the long term, greenhouse gas (GHG) emissions generate economic damage through climate change. The Intergovernmental Panel on Climate Change (2021) shows that the various scenarios for future GHG emissions differ significantly in terms of their climate change impacts, particularly after 2050. Yet, the literature largely ignores the intergenerational coordination issue: policy prescriptions are based on normative approaches to climate change mitigation that make strong assumptions about present generations' altruistic objectives or commitment capacities (or both) (e.g., Barrage (2018); Harstad (2020); Kotlikoff et al. (2021); Nordhaus (1993); Schneider et al. (2012)). By questioning these strong assumptions, the present paper aims to move the debate to policies that would be democratically acceptable. This is necessary in order to create a common ground where economists and present generations can discuss climate policy choices.

The paper's contributions are threefold. First, I develop a tractable overlapping generations (OLG) model with political micro-foundations in order to study the determinants of democratic climate policy choices. Individuals live for two periods and have an intertemporal additive utility function with a time preference discount factor. They may also demonstrate some pure altruism toward their direct descendants.[1] The capital used to produce the consumption good can accumulate over time and the production process generates a long-term pollution externality representing climate change. I focus my attention on the intergenerational coordination issue and exclude the international coordination issue by considering one global government in each period. Policies are determined in each period by a social welfare function. If the altruism of the old living generation dominates the political power of the young living generation, the social welfare function corresponds to the preferences of the old generation, which I call the "paternalist" mode. If the political power of the young living generation dominates the altruism of the old

[1]Altruism toward a descendant is said to be pure if it concerns the total utility of the descendant (Galperti and Strulovici 2017). In other words, with pure altruism toward direct descendants, individuals are indirectly altruistic toward their indirect descendants.

living generation, the weight of the young generation in the social welfare function is equal to its political power, which I call the "political" mode. This mode can be micro-founded with probabilistic voting models.[2]

Second, I highlight how democratic climate policy choices are interconnected with other intergenerational policy choices. The paternalist mode leads to standard Pareto optimal policies: an efficient pollution emission tax (i.e., equal to the marginal emission damage discounted at the market interest rate), plus intratemporal lump-sum transfers across generations. Conversely, the political mode leads to inefficient policies because the democratic social objective is time inconsistent and governments cannot commit to future policies.[3] I demonstrate that if a capital investment tax is allowed, the policies will comprise an inefficient capital investment tax, an inefficient pollution emission tax, and intratemporal lump-sum transfers across generations. The emission tax is equal to the marginal emission damage discounted at the market interest rate, but in this case, it is below the efficient level since the investment tax leads to an interest rate above the efficient level. I then show how the emission tax and the intratemporal lump-sum transfers are modified if an investment tax is not allowed. The interest rate used to discount the marginal emission damage for the emission tax computation is no longer equal to the market interest rate. Compared to the case with investment tax, the market interest rate is lower and the interest rate used to discount the marginal emission damage is higher, which corresponds to a lower emission tax. In this case, the government is less willing to abate pollution emissions because there is more capital investment. This result highlights the value of implementing taxes on capital investment to make society more willing to implement climate policies.

Third, I emphasize how the political power of young generations and the altruism toward descendants affect democratic climate policy choices. I choose a model parametrization where pure time preference and altruism toward descendants are entangled, and where the annual market interest rate is around 4.6% in the paternal-

[2]See Coughlin and Nitzan (1981); Lindbeck and Weibull (1987) for micro-foundations with probabilistic voting models. The relative political power between two living generations may reflect their relative size and relative ideological strength.

[3]See Millner and Heal (2018); Strotz (1955) for details on social welfare functions and the inconsistency of objectives between successive governments.

ist mode. I show how the market interest rate and the interest rate used to discount the marginal emission damage move away from this value when the model moves away from the paternalist mode and when pure time preference and altruism toward descendants are disentangled. Although the latter two characteristics play a similar role in the paternalist mode, it is interesting to disentangle them as they theoretically have different levels.[4] For instance, interest rates are around 5.1% instead of 4.6% if the altruism toward descendants is divided by two and the pure time preference is not modified. While young generation political power does not play any role in the paternalist mode, it plays a significant role in the political mode. It has two opposite effects on interest rates since it gives more weight to young relative to old generations within each period, but it also creates time inconsistency. With or without an investment tax, I show that the market interest rate and the interest rate used to discount the marginal emission damage decrease with young generation political power, which means that the first effect dominates the second effect. In the political mode, without altruism and with an investment tax, interest rates are around 5.5% when young people have half the political power of old people and 5.2% when young people have the same political power as old people. Thus, the higher the young generation political power, the higher the emission tax. This result is in line with the rise of a youth movement supporting the implementation of climate policies.[5] These interest rate levels (i.e., 5.5% and 5.2%) are higher than the interest rates noted above (i.e., 5.1% and 4.6%) and the difference between them is lower (i.e., 0.3% versus 0.5%). This emphasizes the fact that young generation political power is less efficient at promoting an emission tax in the political mode than old generation altruism toward descendants in the paternalist mode. Essentially, the political mode creates inefficiencies, while the paternalistic mode does not. Finally, altruism toward descendants also plays a significant role in the political mode in terms of supporting the emission tax level, since it eases the inconsistency of ob-

[4] The empirical literature stresses that individual altruism toward descendants is quite low (Hurd 1989; Kopczuk and Lupton 2007; Laitner and Juster 1996; Wilhelm 1996). This actually suggests that democracies lean more toward the political mode than the paternalist mode.

[5] See for instance https://globalclimatestrike.net and https://fridaysforfuture.org regarding the rise of a youth movement supporting climate policies. Surveys have also shown that younger generations are more concerned by climate change than older generations and are more willing to accept climate policies (e.g., Douenne and Fabre (2020); Whitmarsh (2011)).

jectives between successive governments. With equal political power for old and young people and with an investment tax, interest rates are around 5.2% without altruism and 4.6% when altruism is entangled with pure time preference.

The present paper contributes to the extensive literature on climate policies. One branch of the literature develops infinitely-lived agent (ILA) models. The most standard ILA model comprises one representative individual who has an intertemporal additive utility function with a constant discount factor and a social welfare function identical to the utility function of the representative individual (e.g., Acemoglu et al. (2012); Dietz et al. (2018); Golosov et al. (2014); Nordhaus (2013)). The standard ILA model can be seen as a specific case of my model in which individuals care as much about the consumption of their direct descendants as about their own consumption when they are old, and where young generations have low political power (i.e., paternalist mode).[6] The explicit formula I provide for the market interest rate corresponds in this case to the Keynes-Ramsey rule of the standard ILA model. I contribute to this branch of the literature by disentangling individual altruism toward descendants from individual pure time preference and by studying the role played by young generation political power, which generates inefficiencies.

Some papers in the ILA branch deviate from the standard ILA model by considering a non-constant discount factor (e.g., Gerlagh and Liski (2018); Harstad (2020); Iverson and Karp (2021)). This deviation generates inconsistent objectives and strategic behavior between successive selves at the individual and government levels. A key result of these papers is that when capital and climate change have different longevity and when the discount rate is decreasing, the interest rate used to discount very long-term climate damage is lower than the market interest rate. The assumption of a decreasing discount rate is mainly motivated by empirical studies of individuals' behavior.[7] My paper differs significantly from these papers as individual and government objectives differ from each other in my model. Individuals are heterogeneous, with old and young people in each period, and each type has time consistent preferences. However, the social welfare function is time incon-

[6] See also Barro (1974); Kotlikoff et al. (2021); Schneider et al. (2012) on why ILA models are only good stylized representations of overlapping generations in specific cases.

[7] See Angeletos et al. (2001); Frederick et al. (2002) for surveys of empirical studies of individuals' behavior and decreasing discount rates.

sistent with an increasing discount rate because of the combination of generational overlapping and democratic processes. The young living generation is more highly valued than the following unborn generation in the present compared to the future, as the unborn generation can vote in the future but not in the present. The increasing discount rate means that the government discounts future climate damages at a rate above the market interest rate in the case where an investment tax is not allowed. Moreover, this result is obtained without considering any longevity difference between capital and climate change since my model features only two periods.

Other papers in the ILA branch deviate from the standard ILA model by considering a discount factor in the social welfare function that differs from the discount factor in the individual utility function (e.g., Barrage (2018); Belfiori (2017); van der Ploeg and Rezai (2019)). This deviation generates additional strategic behavior between governments and individuals compared with the standard ILA model. Since the assumed difference corresponds to a discount rate in the social welfare function that is lower than the discount rate in the individual utility function, it leads to subsidies on capital accumulation and climate policies above standard efficient levels. The assumption that the social discount rate is lower than the individual discount rate is based on a normative approach to intergenerational social objectives.[8] By contrast, my democratic approach to intergenerational social objectives leads to taxes on capital accumulation and climate policies below standard efficient levels. Moreover, in the normative approach considered in this branch of the literature, suppressing policies related to capital accumulation leads to even higher climate policies, while in my democratic approach, it leads to even lower climate policies.

The present paper also complements the branch of climate policy literature that develops OLG models. In this branch, some papers assume a normative welfare criterion for the social objective, which involves maximizing a social welfare function including all generations (e.g., Howarth and Norgaard (1992); Marini and Scaramozzino (1995); Schneider et al. (2012)). Other papers assume a normative Pareto criterion, which involves targeting a Pareto improvement including all gener-

[8]See Bernheim (1989); Farhi and Werning (2007) on why a normative approach to social objectives with overlapping generations favors a lower discount rate in the social welfare function.

ations (e.g., Andersen et al. (2020); Bovenberg and Heijdra (1998); Kotlikoff et al. (2021)). In line with these papers, I show that normative criteria lead to a Pareto optimal allocation when a sufficiently rich set of public policies is considered. Since public debt plays a neutral role in the presence of lump-sum transfers, it is sufficient to consider a climate policy and lump-sum transfers, as I do in my model.[9] Unlike the normative criteria, the democratic approach I consider below takes into account the fact that policies are chosen in each period by living generations without the possibility of committing to future policies.

To the best of my knowledge, in the branch of literature on climate policies with OLG models, only Karp (2017) and Karp and Rezai (2014) consider a democratic approach. The former paper ignores capital markets and focuses on the interactions between international and intergenerational coordination issues relating to climate change. The latter paper is closer to my approach as it models capital markets and focuses on climate policies without considering the international coordination issue. In this latter paper, individuals are selfish, climate policies are studied independently from other intergenerational policies, and the democratic approach is solved numerically. In contrast, I consider individual altruism toward descendants, which allows me to include ILA models as a specific case and highlight the key role of altruism. Moreover, I take into account the significant intertwining of climate policies and other intergenerational policies, such as those related to capital accumulation and wealth redistribution across generations. Last, but not least, the tractability of my model highlights the mechanisms at play in democratic climate policy choices.

Finally, my paper is connected to the literature on the political economy of overlapping generations' economies, focusing on different topics such as pensions, education, and inequality (see e.g., Andersen (2019); Gonzalez-Eiras and Niepelt (2008); Lancia and Russo (2016); Song (2011) for papers that also combine OLG models with probabilistic voting models). In this literature, as in my paper, political

[9] Calvo and Obstfeld (1988) show that public debt plays a neutral role in the presence of lump-sum transfers. Proposition 1 in Section 3 of my paper confirms this result in a context including a climate externality and policy. Howarth and Norgaard (1992); Marini and Scaramozzino (1995) also consider a climate policy and lump-sum transfers, while Andersen et al. (2020); Kotlikoff et al. (2021) consider public debt rather than lump-sum transfers.

processes lead to some policy inefficiencies since generations yet to be born cannot vote and governments have incentives to reduce the transfer of resources to the future. I contribute to this literature by making connections with the ILA literature and by providing an augmented Keynes-Ramsey rule for the market interest rate. The "closest" papers to my approach are those dealing with education, since education also features long-term externalities. In these papers, as in mine, even if policies do not reach full efficiency, living generations are willing to support education or climate policies, respectively, as young living generations partly benefit from these policies when old, through the reduction of the externality. In both cases, young living generations anticipate capturing some efficiency gains indirectly through general equilibrium effects and intratemporal transfers across generations. However, education modeling strongly differs from climate change modeling since education directly impacts human capital while climate change directly impacts production or utility. Thus, by studying a different type of long-term externality, I contribute to the literature on the political economy of overlapping generations' economies.

The remainder of the paper is structured as follows. In Section 2, I present my modeling assumptions. Section 3 studies the normative approach for policy choices. In Section 4, I analyze the democratic approach to policy choices. Section 5 concludes.

2 Setting

Climate change raises the question of our ability to reduce GHG emissions over the next 30 years, specifically in terms of avoiding significant impacts in the second part of the century (Intergovernmental Panel on Climate Change 2021). As a first approximation, this can be viewed as two periods, each including three generations (i.e., in each period there are old, young, and those not yet born or who have died). I thus consider an OLG model with two periods, denoted as 1 and 2, and three generations of agents, denoted as a, b, and c. Each generation is composed of a continuum of identical agents of mass one. In period 1, agent a is old, her direct descendant agent b is young, and her indirect descendant agent c is not yet born. In the following period 2, agent a is dead, agent b is alive and old, and agent c is alive and young.[10] This simple setting is sufficient to encompass the main dynamic features and to provide key insights into the intergenerational coordination issue.

In period 1, the old agent a is exogenously endowed with $\overline{K} > 0$ units of capital, while the young agent b is exogenously endowed with one unit of labor. In period 2, the old agent b is endogenously endowed with capital, while the young agent c is exogenously endowed with one unit of labor. The endogenous amount of capital of old agent b in period 2 depends on her purchase and accumulation of capital from period 1.

There is a unique final good, which is produced with capital and labor. The production function in a given period $t \in \{1,2\}$ is assumed to have a Cobb-Douglas form $A_t K_t^{\alpha} L_t^{1-\alpha}$, in which $K_t \geq 0$ is the capital employed, $L_t \geq 0$ is the labor employed, $A_t > 0$ is the exogenous total factor productivity, and $\alpha \in [0,1]$ is the exogenous constant capital share. In each period, production is assumed to be performed by young agents, which avoids introducing firms unnecessarily.[11] Thus, in each period, young agents purchase capital from old agents in order to produce the final good. In period 1, one part of the good produced is sold to old agents for consumption, another part is consumed by young agents, and the last part is invested in capital for period 2. The capital depreciates at the exogenous rate δ from period 1 to period 2. In period 2, the good produced is either sold to old agents for consumption or consumed by young agents.

Producing the final good in the first period emits pollution, which lowers the final good production in the second period. Production $A_1 K_1^{\alpha} L_1^{1-\alpha}$ in period 1 generates the pollution emission $\sigma A_1 K_1^{\alpha} L_1^{1-\alpha}$, where σ is the exogenous emission level per good production unit. An emission abatement effort E_1 can be made in period 1 at an increasing and convex cost $\mathscr{C}(E_1)$. The net emission $\sigma A_1 K_1^{\alpha} L_1^{1-\alpha} - E_1$ in period 1 reduces the final good production in period 2 by the amount $\mathscr{D}(\sigma A_1 K_1^{\alpha} L_1^{1-\alpha} - E_1)$, in which $\mathscr{D}(.)$ is increasing and convex.

Capital and final good markets are assumed to exist in each period, and pollution is an externality. The final good is assumed to be the numéraire in each period

[10] Note that considering only two periods does not mean that the world ends after two periods, but simply that the model is cut after two periods.

[11] Assuming that the good is produced by young agents, rather than by a representative competitive firm, simplifies the presentation and does not affect the politico-economic equilibrium.

and the capital purchase prices are denoted as $1+r_1$ and $1+r_2$ in periods 1 and 2, respectively. Note that these prices are the capital purchase prices and not the capital rent prices (otherwise they would be denoted as $1+r_1-\delta$ and $1+r_2-\delta$). In other words, r_2 equals the capital market interest rate from period 1 to period 2. Note that I do not need to model labor markets since young agents are assumed to produce the final good in each period.

I consider a large set of policies so that governments are not policy constrained, in the sense that if a welfare or Pareto normative criterion were to be chosen for policy choices, a Pareto optimal allocation would be reached (see Section 3). For policies directly affecting the intratemporal allocation of resources, I allow for (positive or negative) lump-sum transfers to agents within each period.[12] I denote by M_{1a} and M_{1b} the amounts received in period 1 by agents a and b, respectively, and by M_{2b} and M_{2c} the amounts received in period 2 by agents b and c, respectively.[13] In terms of policies directly affecting the intertemporal allocation of resources, I allow for capital investment and pollution emission policies in period 1. I assume a linear tax on capital investment, with the tax per unit of investment denoted by τ_I, and a linear tax on pollution emission, with the tax per unit of emission denoted by τ_E.[14] The signs of τ_I and τ_E may be positive (i.e., a tax) or negative (i.e., a subsidy). Note that increases in τ_I and τ_E have opposite effects in terms of resource transfers to the second period, since the former favors a decrease in capital investment while the latter favors an increase in emission abatement. Finally, a debt instrument could be used to transfer public funds from one period to another. However, as highlighted by Calvo and Obstfeld (1988), debt instruments play a neutral role in the presence of intratemporal lump-sum transfers and capital markets. Accordingly, no

[12] A real-world example of lump-sum transfers given to old generations would be pay-as-you-go pension policies, while a real-world example of lump-sum transfers taken from young generations would be labor taxes.

[13] In my setting, I could also assume that each old agent may choose to make a direct wealth transfer to her direct descendant. However, this direct transfer would be null in the political economy setting considered. The weight of young agents in the social welfare function is at least as large as the weight of young agents in the old agents' utility function, which means that lump-sum transfers would wipe out direct transfers.

[14] The pollution emission tax could be replaced by a cap-and-trade policy without affecting any of the results in the paper, since the model's features do not treat one environmental policy differently from another.

debt instruments are included in my model.

Agents are assumed to derive utility from their individual consumption, and potentially altruistically from the utility of their direct descendants. I assume the same utility functional form for agents of any generation. The welfare of agent i living at periods t and $t+1$ is assumed to be:

$$U_i = u(C_{ti}) + \beta\left[u(C_{t+1i}) + \lambda U_{i+1}\right], \tag{1}$$

where U_{i+1} is the welfare of the direct descendant of agent i; C_{ti} and C_{t+1i} are the consumption levels of agent i in periods t and $t+1$; the function $u(.)$ is increasing and concave; the exogenous discount factor β characterizes the individual pure time preference for the future relative to the present; and the exogenous factor λ characterizes the altruism of an individual toward her direct descendant.[15] In my model, the utility functional form simplifies, since the periods preceding period 1 and following period 2 are not modeled. The present and future utility flows derived by agents a and b in period 1 and the present utility flows derived by agents b and c in period 2 are respectively:

$$u(C_{1a}) + \lambda\left[u(C_{1b}) + \beta\left[u(C_{2b}) + \lambda u(C_{2c})\right]\right], \tag{2}$$

$$u(C_{1b}) + \beta\left[u(C_{2b}) + \lambda u(C_{2c})\right], \tag{3}$$

$$u(C_{2b}) + \lambda u(C_{2c}), \tag{4}$$

$$u(C_{2c}). \tag{5}$$

Finally, concerning collective preferences that determine policy choices, I consider two different settings: a normative setting and a democratic setting, studied in Sections 3 and 4, respectively.

[15] In line with Galperti and Strulovici (2017), I consider pure altruism, in the sense that if agent a is altruistic toward her direct descendant (i.e., agent b), agent a weighs the total utility of agent b in her own utility. This means that if agent b is also altruistic toward her own descendant (i.e., agent c), agent a indirectly weighs the utility of agent c in her own utility. Assuming pure altruism enables me to connect to the standard ILA model when $\lambda = 1$ and the political objective is driven by the first generation's preferences (see Section 4).

3 Normative policies

In this section, I consider a decentralized economy with given policies and analyze the policy choices satisfying a normative objective that features either a welfare or a Pareto criterion. Individuals make choices in each period to maximize their present and future utility flows in accordance with their budget constraints. They are price and policy takers, and they anticipate their future consumption as a function of prices, policies, and their previous decisions. Markets clear in each period. I denote by K_1 the capital purchased by agent b in period 1, by I_1 the capital investment made by agent b in period 1, by E_1 the emission abatement undertaken by agent b in period 1, and by K_2 the capital purchased by agent c in period 2. The decision process is formalized using a backward induction presentation.

In period 2, the choices of agents b and c are respectively characterized by:

$$\begin{aligned} \max_{C_{2b}} \ & u(C_{2b}) + \lambda u(C_{2c}) \\ \text{s.t. } & C_{2b} = (1+r_2)((1-\delta)K_1 + I_1) + M_{2b}, \end{aligned} \tag{6}$$

$$\begin{aligned} \max_{C_{2c}, K_2} \ & u(C_{2c}) \\ \text{s.t. } & C_{2c} + (1+r_2)K_2 = A_2 K_2^{\alpha} - \mathscr{D}(\sigma A_1 K_1^{\alpha} - E_1) + M_{2c}. \end{aligned} \tag{7}$$

The constraints in (6) and (7) are the budget constraints. The expense of agent b corresponds to the consumption C_{2b}, while her revenue is composed of capital earnings plus a lump-sum transfer. The expense of agent c corresponds to the consumption C_{2c} and the capital purchase K_2, while her revenue is composed of net production value (i.e., production minus emission damage) plus a lump-sum transfer. The clearing condition of the capital market is:

$$K_2 = (1-\delta)K_1 + I_1. \tag{8}$$

In period 1, the choices of agents a and b are respectively characterized by:

$$\begin{aligned} &\max_{C_{1a}} \; u(C_{1a}) + \lambda \Big[u(C_{1b}) + \beta \big[u(C_{2b}) + \lambda u(C_{2c}) \big] \Big] \\ &\text{s.t. } \; C_{1a} = (1+r_1)\overline{K} + M_{1a}, \end{aligned} \tag{9}$$

$$\begin{aligned} \max_{C_{1b}, K_1, I_1, E_1} \; & u(C_{1b}) + \beta \big[u(C_{2b}) + \lambda u(C_{2c}) \big] \\ \text{s.t. } \; & C_{1b} + (1+r_1)K_1 = \\ & A_1 K_1^{\alpha} - \mathscr{C}(E_1) - \tau_E(\sigma A_1 K_1^{\alpha} - E_1) - I_1 - \tau_I I_1 + M_{1b}, \\ & C_{2b} = (1+r_2)((1-\delta)K_1 + I_1) + M_{2b}. \end{aligned} \tag{10}$$

The first constraints in (9) and (10) are the budget constraints. The expense of agent a corresponds to the consumption C_{1a}, while her revenue is composed of capital earnings plus a lump-sum transfer. The expense of agent b corresponds to the consumption C_{1b} and the capital purchase K_1, while her revenue is composed of net production value (i.e., production minus emission abatement cost, emission tax, capital investment cost, and investment tax) plus a lump-sum transfer. The second constraint in (10) corresponds to the anticipated consumption in period 2 as a function of the prices and policies in period 2 and the agent's decisions in period 1. The latter constraint is directly derived from (6). Note that the first-order conditions of (10) relative to I_1 and E_1 can be respectively written as:

$$u'(C_{1b}) = \frac{1}{1+\tau_I} \beta (1+r_2) u'(C_{2b}), \tag{11}$$

$$\mathscr{C}'(E_1) = \tau_E. \tag{12}$$

Equation (11) is the Euler equation characterizing the trade-off between consumption in young age and old age for generation b. Compared with a standard Euler equation, it is slightly modified by the potential presence of the investment tax τ_I. Equation (12) shows that the emission abatement is chosen such that its marginal cost equalizes the emission tax τ_E. In particular, no abatement is undertaken if there is no emission tax. Finally, the clearing condition of the capital market is:

$$K_1 = \overline{K}. \tag{13}$$

The economic equilibrium with given public policies is characterized by (6), (7), (8), (9), (10), and (13).

Proposition 1. *In a decentralized economy, any Pareto optimal allocation can be achieved with lump-sum transfers, a null investment tax* $\tau_I = 0$*, and an emission tax* $\tau_E = \frac{1}{1+r_2}\mathscr{D}'(\sigma A_1 K_1^{\alpha} - E_1)$*, which together satisfy the following policy budget balances:*

$$M_{1a} + M_{1b} - \tau_E(\sigma A_1 K_1^{\alpha} - E_1) - \tau_I I_1 = 0, \tag{14}$$

$$M_{2b} + M_{2c} = 0. \tag{15}$$

Proposition 1 is proved in Appendix A.1, given a standard definition of Pareto optimal allocations. It shows that the set of public policies considered would be sufficient to reach any Pareto optimal allocation. Pareto optimality is ensured by a null investment tax and an emission tax equal to the marginal damage discounted at the market interest rate. An investment tax should not be introduced as capital markets are efficient, while an emission tax should be introduced since pollution represents an externality. The emission tax must be equal to the marginal damage discounted at the market interest rate to ensure consistency between capital investment and emission abatement for resource transfers to the second period. The remaining freedom in the choice of intratemporal lump-sum transfers enables us to reach any Pareto optimal allocation. Note that a public debt instrument is not necessary to achieve this optimal allocation. As already highlighted by Calvo and Obstfeld (1988), in the absence of externalities the combination of intratemporal lump-sum transfers and capital markets allows us to reach any Pareto optimal allocation. Transfers from old to young agents within each period are achieved efficiently by the social planner thanks to lump-sum transfers, while transfers from one period to the next are achieved efficiently by individuals thanks to capital markets. It is also important to note that the interest rate level and the emission tax level in the present context of a long-term externality strongly depend on the Pareto optimal allocation and thus on the lump-sum transfers: the higher the share for late generations relative to early generations, the lower the interest rate will be, and the higher the emission tax.[16]

Proposition 1 implies that Pareto optimal policies could be implemented in a decentralized economy by a time-committed government with a normative objective that includes a welfare or a Pareto criterion.[17] With a welfare criterion, the government could choose policies that would lead to the desired Pareto optimal allocation. With a Pareto criterion, the government could implement Pareto-improving policies as long as the allocation achieved were not Pareto optimal. Since the emission tax level depends on the Pareto optimal allocation achieved, very different levels could be chosen depending on the arbitrary normative objective.

The main issue is that there is no reason for policies derived from a normative objective to be subject to political processes. Because of the overlapping generations in the present context, we would expect political processes to generate successive governments with inconsistent objectives, leading to suboptimal policies. A politically acceptable emission tax is thus likely to be inefficient, with its level being dependent on the political game across generations. The next section analyzes the policy choices obtained with political processes in order to provide policy recommendations that can be supported democratically.

4 Democratic policies

In this section, I consider a decentralized economy with political process microfoundations and analyze the politico-economic equilibrium.

Similar to the previous section, individuals make choices in each period to maximize their present and future utility flows in accordance with their budget constraints. They are price and policy takers, and they anticipate their future consumption as a function of prices, policies, and their previous decisions. Markets clear in

[16] Howarth and Norgaard (1992, 1993) further analyze how the interest rate and emission tax levels depend on the Pareto optimal allocation achieved.

[17] A social objective featuring a welfare criterion involves maximizing a social welfare function that includes all generations. A social objective featuring a Pareto criterion involves targeting Pareto improvements that include all generations.

each period.

In contrast to the previous section, I consider political objectives with democratic micro-foundations by building on probabilistic voting models (Coughlin and Nitzan 1981; Lindbeck and Weibull 1987). These models show that the elected government chooses policies designed to maximize a social welfare function in which the weights given to a group of identical individuals characterize their political power.[18] In the overlapping generation setting, at a given period, the old and young living generations are the only ones who have any political power. I denote by μ the political power of the young generation relative to the old generation in both periods 1 and 2. I distinguish two modes. If $\mu \leq \lambda$, the altruism of the old generation toward the young generation dominates the political power of the young generation, and the relative weight in the social welfare function in each period is assumed to be λ. I call this mode "paternalist", since the social welfare functions in both periods are aligned with the first generation's preferences and are time consistent. If $\mu > \lambda$, the political power of the young generation dominates the altruism of the old generation toward the young generation, and the relative weight in the social welfare function in each period is assumed to be μ. I call this mode "political", since the social welfare functions in both periods are not aligned with any generation's preferences and are time inconsistent. I denote $\gamma = \max\{\mu, \lambda\}$.

In terms of strategic behavior, governments take into account individuals' reactions to policy choices. The first-period government (hereafter called government 1) can also anticipate the policy choices of the second-period government (hereafter called government 2) as a function of its own policy choices. The decision process is formalized using a backward induction presentation.

In terms of policy instruments, I consider two different cases. In the first case, I allow for intratemporal lump-sum transfers, an emission tax, and an investment tax; while in the second case, I only allow for intratemporal lump-sum transfers and an emission tax.

[18]The political power of a group depends on the number of voters and on their ideological strength. When there are more voters in a group, its political power will be higher. When the group's ideological preferences are weak, political candidates will make considerable efforts to attract the group's voters and the group's political power will therefore be higher.

4.1 Equilibrium with investment tax

Government 1 may use intratemporal lump-sum transfers, an emission tax, and an investment tax. Government 2 may use intratemporal lump-sum transfers. Given the similarities with the decentralized economy of the previous section for individual choices, governments 2 and 1 solve respectively:

$$\begin{aligned} \max_{M_{2b},M_{2c}} \quad & u(C_{2b})+\gamma u(C_{2c}) \\ \text{s.t.} \quad & (6),\ (7),\ (8) \text{ and } (15), \end{aligned} \tag{16}$$

$$\begin{aligned} \max_{M_{1a},M_{1b},\tau_E,\tau_I} \quad & u(C_{1a})+\gamma\Big[u(C_{1b})+\beta\left[u(C_{2b})+\lambda u(C_{2c})\right]\Big] \\ \text{s.t.} \quad & (6),\ (7),\ (8),\ (9),\ (10),\ (13),\ (14),\ (15), \text{ and } (16). \end{aligned} \tag{17}$$

The politico-economic equilibrium is characterized by (16) and (17).

Proposition 2. *The politico-economic equilibrium satisfies:*

$$u'(C_{2b}) = \gamma u'(C_{2c}), \tag{18}$$

$$u'(C_{1a}) = \gamma u'(C_{1b}), \tag{19}$$

$$\tau_E = \frac{1}{1+r_2}\mathscr{D}'(\sigma A_1 K_1^{\alpha} - E_1), \tag{20}$$

$$\tau_I = \frac{\gamma-\lambda}{\lambda+\gamma^2\frac{u''(C_{2c})}{u''(C_{2b})}}. \tag{21}$$

Moreover, with the isoelastic utility function $u(x)=\frac{x^{1-\eta}-1}{1-\eta}$, the market interest rate is such that:

$$\frac{1}{1+r_2} = \underbrace{\frac{\gamma^{1-\frac{1}{\eta}}+\lambda}{\gamma^{1-\frac{1}{\eta}}+\gamma}}_{\Omega}\frac{\beta\gamma}{(1+g)^{\eta}}, \tag{22}$$

where $g=\frac{C_{2b}+C_{2c}}{C_{1a}+C_{1b}}-1$ is the consumption growth rate from period 1 to period 2.

Proposition 2 is proved in Appendix A.2. Equations (18) and (19) characterize the choices of intratemporal lump-sum transfers across generations in periods

2 and 1, respectively. Equations (20) and (21) characterize the choices of emission tax and investment tax, respectively, by government 1. The emission tax is chosen to equal the marginal emission damage discounted at the market interest rate. This tax level ensures consistency between capital investment and emission abatement for resource transfers to the second period. The emission tax choice is linked to the other policy choices through the endogenous market interest rate. The market interest rate formula (22), which is an augmented Keynes-Ramsey rule,[19] summarizes these links and highlights how the emission tax level depends on preference characteristics and on the political game.

In the paternalist mode (i.e., $\gamma = \lambda \geq \mu$), the emission tax (20) is at the efficient level and the investment tax (21) is null because the objectives of the successive governments are time consistent. Moreover, the interest rate formula (22) simplifies to $\frac{1}{1+r_2} = \frac{\beta\lambda}{(1+g)^\eta}$. Concerning the impact of individual altruism toward descendants λ, (18) and (19) show that λ favors lump-sum transfers toward the young generation within each period. It thus favors a scenario in which generation b is richer when young and poorer when old, which encourages higher investment by generation b in the first period (see Euler equation (11)). As an increase in investment in the first period is associated with an increase in capital and a decrease in capital price in the second period, individual altruism toward descendants λ ultimately favors a lower interest rate r_2 through intratemporal lump-sum transfers, as highlighted by the simplified interest rate formula. Since the emission tax (20) is equal to the marginal emission damage discounted at the interest rate, individual altruism toward descendants λ also favors a higher emission tax. Finally, when $\lambda = 1$, the simplified interest rate formula is similar to the Keynes-Ramsey rule of the standard ILA model. In contrast to the latter model, the present model disentangles individual pure time preference β and individual altruism toward descendants λ. While these two characteristics play a similar role here, it is interesting to disentangle them as they are not necessarily identical in terms of level. The empirical literature highlights that individual altruism toward descendants is quite low (Hurd

[19]The Keynes-Ramsey rule of the standard ILA model is $\frac{1}{1+r_2} = \frac{\beta}{(1+g)^\eta}$. The Keynes-Ramsey rule is more frequently written as $r_2 = \rho + \eta g$ with $\rho = -\ln(\beta)$, using a Taylor expansion. See equation (2.11) in Barro and Sala-i Martin (2004).

1989; Kopczuk and Lupton 2007; Laitner and Juster 1996; Wilhelm 1996), which suggests that democracies lean toward the political mode ($\mu > \lambda$) rather than the paternalist mode ($\lambda \geq \mu$).

In the political mode (i.e., $\gamma = \mu > \lambda$), the emission tax (20) is below the efficient level and the investment tax (21) is positive because the objectives of the successive governments are time inconsistent. In period 2, generations b and c both vote, while in period 1, generation b votes but generation c does not. Government 1 thus puts less weight on generation c relative to generation b than government 2 does. If government 1 is not strategic with respect to future policies, the emission tax will be efficient, the investment tax will be null, and the interest rate formula (22) will simplify to $\frac{1}{1+r_2} = \frac{\beta\mu}{(1+g)^{\eta}}$. With strategic behavior, government 1 anticipates that government 2 will transfer too much wealth through lump-sum transfers to the new-born generation c. Government 1 thus has incentives to implement an emission tax below the efficient level and a positive investment tax, which both lower the transfer of resources to the second period (i.e., emission abatement and capital investment, respectively). The additional factor $\Omega < 1$ in the interest rate formula (22) emphasizes that the inefficient investment tax increases the interest rate above the efficient level, and it is associated with an emission tax below the efficient level. In the political mode, young generation political power μ affects the equilibrium. If government 1 is not strategic with respect to future policies, young generation political power μ will play a role similar to individual altruism toward descendants λ in the paternalist mode. More specifically, μ will only favor intratemporal lump-sum transfers toward the young generation within each period, a lower interest rate, and a higher emission tax. With strategic behavior, young generation political power μ has an additional opposite effect. It intensifies the time inconsistency of objectives between governments, which favors a higher interest rate and a lower emission tax ($\frac{d\Omega}{d\mu} < 0$). The total impact of μ is ambiguous and further analyzed through numerical comparative statics in Section 4.3. Concerning the impact of individual altruism toward descendants λ in the political mode, the fact that λ eases the time inconsistency of objectives between governments favors a lower interest rate and a higher emission tax ($\frac{d\Omega}{d\lambda} > 0$). The next section studies the politico-economic equilibrium when the inefficient investment tax is not allowed.

4.2 Equilibrium without an investment tax

Given that an investment tax is inefficient, I now consider a set of policy instruments without such a tax. Government 1 may only use intratemporal lump-sum transfers and an emission tax. Government 2 may use intratemporal lump-sum transfers. Thus, governments 2 and 1 solve, respectively:

$$\begin{aligned} \max_{M_{2b},M_{2c}} \quad & u(C_{2b}) + \gamma u(C_{2c}) \\ \text{s.t.} \quad & (6),\ (7),\ (8) \text{ and } (15), \end{aligned} \tag{23}$$

$$\begin{aligned} \max_{M_{1a},M_{1b},\tau_E} \quad & u(C_{1a}) + \gamma\Big[u(C_{1b}) + \beta\left[u(C_{2b}) + \lambda u(C_{2c})\right]\Big] \\ \text{s.t.} \quad & (6),\ (7),\ (8),\ (9),\ (10),\ (13),\ (14),\ (15), \text{ and } (23). \end{aligned} \tag{24}$$

The politico-economic equilibrium is characterized by (23) and (24).

Proposition 3. *The politico-economic equilibrium satisfies:*

$$u'(C_{2b}) = \gamma u'(C_{2c}), \tag{25}$$

$$u'(C_{1a}) = \left(1 - \frac{\gamma - \lambda}{\gamma}\psi\right)\gamma u'(C_{1b}), \tag{26}$$

$$\tau_E = \left(1 - \frac{\gamma - \lambda}{\gamma}\phi\right)\frac{1}{1+r_2}\mathscr{D}'(\sigma A_1 K_1^{\alpha} - E_1), \tag{27}$$

where $\psi > 0$ and $\phi > 0$ are defined in Appendix A.3 by (64) and (65), respectively. Moreover, with the isoelastic utility function $u(x) = \frac{x^{1-\eta}-1}{1-\eta}$, the market interest rate is such that:

$$\frac{1}{1+r_2} = \underbrace{\frac{\left(1+\gamma^{\frac{1}{\eta}}\right)^{\eta}}{\left(1+\gamma^{\frac{1}{\eta}} + \left(1 - \frac{\gamma-\lambda}{\gamma}\psi\right)^{-\frac{1}{\eta}} - 1\right)^{\eta}}}_{\tilde{\Omega}} \frac{\beta\gamma}{(1+g)^{\eta}}, \tag{28}$$

where $g = \frac{C_{2b}+C_{2c}}{C_{1a}+C_{1b}} - 1$ is the consumption growth rate from period 1 to period 2.

Proposition 3 is proved in Appendix A.3. Equations (25) and (26) characterize the choices of intratemporal lump-sum transfers across generations in periods 2 and 1, respectively. Equation (27) characterizes the choice of emission tax by government 1. In contrast to the previous section, the emission tax is not necessarily chosen to equal the marginal emission damage discounted at the market interest rate. Moreover, the market interest rate formula (28) is in general different from the formula presented in the previous section.

In the paternalist mode (i.e., $\gamma = \lambda \geq \mu$), the policy choices and the interest rate formula are identical to those presented in the previous section, since the investment tax was not applied in the previous section, despite being allowed.

In the political mode (i.e., $\gamma = \mu > \lambda$), the policy choices in period 1 differ from those in the previous section. While government 1 can no longer use an investment tax, it is still willing to transfer fewer resources to generation c relative to generation b than government 2 is. If government 1 is not strategic with respect to future policies, the equilibrium will be similar to the previous section. With strategic behavior, government 1 anticipates that government 2 will transfer too much wealth to the new-born generation c. Because government 1 cannot use an investment tax, it has incentives to lower the transfer of resources to the second period with the other policy instruments. The difference between (19) and (26) shows that government 1 provides lower lump-sum transfers toward the young generation b, which leads to lower investment and counterbalances the higher investment that occurs due to the absence of an investment tax. Concerning emission abatement, the absence of an investment tax is associated with the absence of the factor $\Omega < 1$ in formula (28), which corresponds to a lower interest rate and a higher emission tax. On the other hand, as expressed by the additional factor $\tilde{\Omega} < 1$ in formula (28), the lower lump-sum transfers toward the young generation b are associated with a higher interest rate and a lower emission tax (since a lower investment leads to a lower capital and a higher capital price in period 2). Furthermore, the difference between (20) and (27) highlights the fact that the interest rate used to discount future marginal emission damage and compute the emission tax is higher than the market interest rate, since $1 - \frac{\gamma - \lambda}{\gamma}\phi < 1$. However, it is not possible to deduce that the emission tax and abatement levels are lower than those obtained in the previous section. Indeed, the market interest rates cannot be ranked, since the factor Ω has disappeared from the interest rate formula (28). The following section develops a numerical application that compares the emission tax levels obtained with and without an investment tax.

4.3 Comparative statics

This section presents a numerical comparative static analysis to quantitatively study the impacts of the political game, the altruism toward descendants, and the set of policy instruments on the emission tax level. I assume that one period of the OLG model lasts 35 years, $\beta = 0.6$, $\eta = 1.5$, $A_1 = 2$, $A_2 = 6$, $\alpha = 0.4$, $\delta = 0.9$, $\overline{K} = 0.7$, $\sigma = 1$, $\mathscr{C}(x) = 0.2x^2$, and $\mathscr{D}(x) = 0.8x + 0.4x^2$. I run the numerical simulations for different levels of young generation political power μ and different levels of individual altruism toward descendants λ. In all these cases, I consider a set of policy instruments that either include an investment tax or not. I define the emission interest rate r_{2E} as the interest rate used to discount the emission damage for the emission tax computation, which is equal to r_2 in the case with an investment tax and such that $\frac{1}{1+r_{2E}} = (1 - \frac{\gamma-\lambda}{\gamma}\phi)\frac{1}{1+r_2}$ in the case without an investment tax. In Figure 1, the left graph displays the market interest rate per year in percentage terms, while the right graph displays the emission interest rate per year in percentage terms. Both interest rates are displayed as a function of young generation political power μ, from 0.25 to 2 (i.e., the political power of the young generation ranges from one quarter to twice the political power of the old generation). In each graph, the lighter the line, the higher the altruism toward descendants λ: black, dark grey, and light grey correspond to λ equal to 0, 0.5, and 1, respectively. Solid lines represent the cases with an investment tax, while dashed lines represent the cases without an investment tax.

In the paternalist mode (i.e., $\gamma = \lambda \geq \mu$), young generation political power μ plays no role, which implies that interest rates do not change with μ, as shown in Figure 1. In this mode, allowing an investment tax or not leads to the same policy choices and the same market interest rate, which is why the solid and dashed lines are superimposed on each other. Moreover, the emission interest rate corresponds to the market interest rate. With the parametrization chosen and $\lambda = 1$, the interest rate is around 4.6%, which is roughly the same as the interest rate obtained with

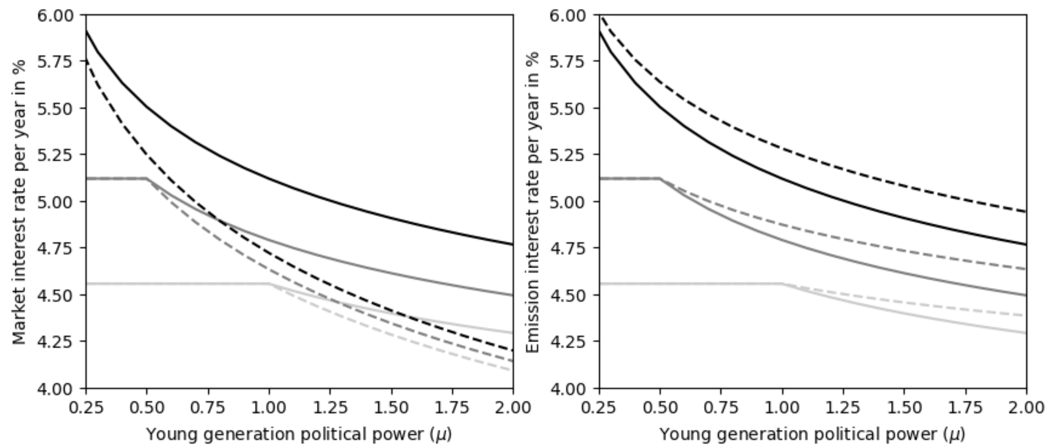

Figure 1: Market interest rate (left figure) and emission interest rate (right figure), as a function of young generation political power μ. Black, dark grey, and light grey correspond to altruism toward descendants λ, equal to 0, 0.5, and 1, respectively. The cases with investment tax are represented by solid lines, while the cases without investment tax are represented by dashed lines.

the ILA model and the parametrization in Nordhaus (2013). Rather than discussing the relevance of this value in absolute terms, the present numerical application aims to highlight how the market and emission interest rates move away from this value when the model moves away from the ILA model. For instance, Figure 1 shows the impact of disentangling λ from β: if λ falls to 0.5, this generates an increase in the interest rate from 4.6% to around 5.1% if μ is low enough to remain inside the paternalist mode.

In the political mode (i.e., $\gamma = \mu > \lambda$), young generation political power μ plays a role and interest rates change with μ, as highlighted in Figure 1. In this mode, it makes a difference whether an investment tax is allowed or not.

With an investment tax, market and emission interest rates are identical, as already observed in Section 4.1. As also observed in Section 4.1, young generation political power μ generates an ambiguous effect on the interest rate. On the one hand, higher political power for young generations gives higher weight to young generations within each period, which lowers the interest rate through intratemporal lump-sum transfers toward young generations. On the other hand, higher political power for young generations leads to higher time inconsistency, which increases the interest rate through the investment tax. Figure 1 shows that the first effect dominates the second since the interest rate is decreasing with μ. For instance, with the parametrization chosen and $\lambda = 0$, the interest rate is around 5.5% for $\mu = 0.5$ and around 5.2% for $\mu = 1$. Thus, the higher the young generation political power, the higher the emission tax. However, young generation political power, which is associated with conflicts between generations, is less effective at promoting an emission tax than the paternalist mode, with its altruism toward descendants. Indeed, although the interest rates obtained in the paternalist mode with $\lambda = 0.5$ and $\lambda = 1$ are 5.1% and 4.6%, respectively, the interest rates obtained with $\mu = 0.5$ and $\mu = 1$ when $\lambda = 0$ are higher, at 5.5% and 5.2%, respectively. In addition, while doubling the individual altruism toward descendants reduces the interest rate by 0.5 points, doubling young generation political power reduces the interest rate by only 0.3 points.

Without an investment tax, market and emission interest rates differ, as already proved in Section 4.2. Figure 1 details how they differ from interest rates obtained when an investment tax is allowed. Similar to the interest rates with an investment tax, the interest rates without such a tax fall when young generation political power rises. Again, the effect of the higher weight of young generations within each period dominates the effect of higher time inconsistency. Thus, an increase in young generation political power leads to an increase in the emission tax level, with or without an investment tax.[20] Moreover, Figure 1 emphasizes that the market and emission interest rates obtained without the investment tax are lower and higher, respectively, than those obtained with the investment tax. For instance, with the chosen parametrization of $\lambda = 0$ and $\mu = 1$, although the market and emission interest rates are around 5.2% with the investment tax, they are around 4.8% and 5.3%, respectively, without the investment tax. Because investment levels are higher without the investment tax, government 1 is willing to transfer fewer resources to period

[20] In contrast, the numerical politico-economic model of Karp and Rezai (2014) shows that an increase in young generation political power leads to a fall in the climate policy level. In their model, climate policy alone plays the role of reducing the transfer of resources to the future if objectives are inconsistent across successive governments. However, this neglects the fact that other policy instruments, such as an investment tax or intratemporal transfers, can be used to reduce the transfer of resources to the future.

2 through emission abatement, which is why it chooses a higher emission interest rate or equivalently a lower emission tax. In other words, if government 1 can reduce the transfer of productive capital to period 2 via an investment tax, it is willing to increase the transfer of environmental capital through a higher emission tax.

Finally, Figure 1 shows that, with or without an investment tax, individual altruism toward descendants λ can play a significant role in increasing emission tax in the political mode as it softens time inconsistency. For instance, with the parametrization chosen and $\mu = 1$, interest rates with an investment tax are around 5.2%, 4.8%, and 4.6% for λ equal to 0, 0.5, and 1, respectively.

5 Conclusion

The majority of the literature provides climate policy recommendations that would not be robust to democratic processes since the models used consider either infinitely-lived individuals or normative social objectives (or both). By contrast, this paper has focused on climate policies that can incorporate democratic processes to provide democratically acceptable climate policy recommendations. I have highlighted how democratic climate policies should be intertwined with other intergenerational policies (i.e., intratemporal transfers across generations and policies related to capital accumulation). In particular, I have shown that implementing climate policies closer to efficient levels provides a rationale for taxes on capital accumulation. I have also demonstrated that democratic climate policy ambitions are highly dependent on young generation political power and on individual altruism toward descendants.

This paper lays the foundations for a larger debate on the crucial question of democratic climate policies. To feed the debate, it would be interesting to explore extensions of my model by considering, for instance, more than two periods and three generations, more detailed climate change modeling, consumption good multiplicity, intragenerational heterogeneity, technological change, and uncertainty. Moreover, the present paper highlights crucial levers of democratic climate policy ambition. If we want to increase this ambition, we need to focus on these levers in order to find ways of stimulating individual altruism toward descendants and of increasing young generation political power.

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Conflict of interest

I declare that I have no relevant material or financial interests that relate to the research described in this paper.

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A Appendices

A.1 Proof of Proposition 1

By definition, an allocation $(C_{1a}, C_{1b}, C_{2b}, C_{2c}, I_1, E_1)$ is Pareto optimal if there exists (ν_b, ν_c) such that:

$$\begin{aligned} \max_{C_{1a},C_{1b},C_{2b},C_{2c},I_1,E_1} \quad & u(C_{1a}) + (\lambda+\nu_b)u(C_{1b}) + (\lambda+\nu_b)\beta u(C_{2b}) + (\lambda^2+\lambda\nu_b+\nu_c)\beta u(C_{2c}) \\ \text{s.t.} \quad & C_{1a}+C_{1b} = A_1\overline{K}^{\alpha} - \mathscr{C}(E_1) - I_1, \\ & C_{2b}+C_{2c} = A_2((1-\delta)\overline{K}+I_1)^{\alpha} - \mathscr{D}(\sigma A_1\overline{K}^{\alpha} - E_1). \end{aligned} \tag{29}$$

By deriving the first order conditions of (29), $(C_{1a}, C_{1b}, C_{2b}, C_{2c}, I_1, E_1)$ achieves a Pareto optimal allocation if and only if there exists (ν_b, ν_c) such that:

$$C_{1a}+C_{1b} = A_1\overline{K}^{\alpha} - \mathscr{C}(E_1) - I_1, \tag{30}$$

$$C_{2b}+C_{2c} = A_2((1-\delta)\overline{K}+I_1)^{\alpha} - \mathscr{D}(\sigma A_1\overline{K}^{\alpha} - E_1), \tag{31}$$

$$u'(C_{1a}) = (\lambda+\nu_b)u'(C_{1b}), \tag{32}$$

$$(\lambda+\nu_b)u'(C_{2b}) = (\lambda^2+\lambda\nu_b+\nu_c)u'(C_{2c}), \tag{33}$$

$$u'(C_{1b}) = \beta u'(C_{2b})\alpha A_2((1-\delta)\overline{K}+I_1)^{\alpha-1}, \tag{34}$$

$$u'(C_{1b})\mathscr{C}'(E_1) = \beta u'(C_{2b})\mathscr{D}'(\sigma A_1\overline{K}^{\alpha} - E_1). \tag{35}$$

Let me now show that in the decentralized economy any Pareto optimal allocation can be reached thanks to lump-sum transfers, a null investment tax $\tau_I = 0$ and an emission tax $\tau_E = \frac{1}{1+r_2}\mathscr{D}'(\sigma A_1 K_1^{\alpha} - E_1)$, satisfying policy budget balances (14) and (15). The first-order conditions of (7) and (10) are:

$$1+r_2 = \alpha A_2 K_2^{\alpha-1}, \tag{36}$$

$$u'(C_{1b}) = \frac{1}{1+\tau_I}\beta(1+r_2)u'(C_{2b}), \tag{37}$$

$$\mathscr{C}'(E_1) = \tau_E, \tag{38}$$

$$1 + r_1 = (1 - \tau_E \sigma)\alpha A_1 K_1^{\alpha-1} + (1-\delta)(1+\tau_I). \tag{39}$$

Combining the policy budget constraint (14), the market clearing condition (13), the first constraints of (9) and (10), and $\tau_I = 0$, I get (30). Combining the policy budget constraint (15), the market clearing conditions (8) and (13), and the constraints of (6) and (7), I get (31). Combining (37) with (8), (13), (36) and $\tau_I = 0$, I get (34). Combining (37) with $\tau_E = \frac{1}{1+r_2}\mathscr{D}'(\sigma A_1 K_1^{\alpha} - E_1)$, $\tau_I = 0$, (13) and (38), I get (35). Finally, for any given v_b and v_c, I can choose (M_{1a}, M_{1b}) and (M_{2b}, M_{2c}) such that (32) and (33) are satisfied, respectively. This concludes the proof.

A.2 Proof of Proposition 2

A politico-economic equilibrium is a subgame perfect Nash equilibrium and is solved backward.

A.2.1 Second period

The government's problem (16) in period 2 writes:

$$\begin{aligned}
\max_{C_{2b}, C_{2c}, K_2, r_2, M_{2b}, M_{2c}} \quad & u(C_{2b}) + \gamma u(C_{2c}) \\
\text{s.t.} \quad & C_{2b} = (1+r_2)((1-\delta)K_1 + I_1) + M_{2b}, \\
& C_{2c} + (1+r_2)K_2 = A_2 K_2^{\alpha} - \mathscr{D}(\sigma A_1 K_1^{\alpha} - E_1) + M_{2c}, \\
& 1 + r_2 = \alpha A_2 K_2^{\alpha-1}, \\
& K_2 = (1-\delta)K_1 + I_1, \\
& M_{2b} + M_{2c} = 0.
\end{aligned} \tag{40}$$

(40) simplifies to the constraints in (40) and:

$$\begin{aligned}
\max_{C_{2b}, C_{2c}} \quad & u(C_{2b}) + \gamma u(C_{2c}) \\
\text{s.t.} \quad & C_{2b} + C_{2c} = A_2((1-\delta)K_1 + I_1)^{\alpha} - \mathscr{D}(\sigma A_1 K_1^{\alpha} - E_1).
\end{aligned} \tag{41}$$

By deriving the first order conditions of (41), (40) finally simplifies to the constraints in (40) and:

$$u'(C_{2b}) = \gamma u'(C_{2c}). \tag{42}$$

A.2.2 First period

By denoting $C = (C_{1a}, C_{1b}, C_{2b}, C_{2c})$, $K = (K_1, K_2)$, $r = (r_1, r_2)$, $\tau = (\tau_E, \tau_I)$ and $M = (M_{1a}, M_{1b}, M_{2b}, M_{2c})$, the government's problem (17) in period 1 writes:

$$\begin{aligned}
\max_{C,K,I_1,E_1,r,\tau,M} \quad & u(C_{1a}) + \gamma u(C_{1b}) + \gamma\beta u(C_{2b}) + \gamma\beta\lambda u(C_{2c}) \\
\text{s.t.} \quad & C_{2b} = (1+r_2)((1-\delta)K_1 + I_1) + M_{2b}, \\
& C_{2c} + (1+r_2)K_2 = A_2 K_2^{\alpha} - \mathscr{D}(\sigma A_1 K_1^{\alpha} - E_1) + M_{2c}, \\
& 1 + r_2 = \alpha A_2 K_2^{\alpha-1}, \\
& K_2 = (1-\delta)K_1 + I_1, \\
& M_{2b} + M_{2c} = 0, \\
& u'(C_{2b}) = \gamma u'(C_{2c}), \\
& C_{1a} = (1+r_1)\overline{K} + M_{1a}, \\
& C_{1b} + (1+r_1)K_1 = A_1 K_1^{\alpha} - \mathscr{C}(E_1) - \tau_E(\sigma A_1 K_1^{\alpha} - E_1) - I_1 - \tau_I I_1 + M_{1b}, \\
& u'(C_{1b}) = \beta u'(C_{2b}) \frac{1+r_2}{1+\tau_I}, \\
& \mathscr{C}'(E_1) = \tau_E, \\
& 1 + r_1 = (1 - \tau_E \sigma)\alpha A_1 K_1^{\alpha-1} + (1-\delta)(1+\tau_I), \\
& K_1 = \overline{K}, \\
& M_{1a} + M_{1b} - \tau_E(\sigma A_1 K_1^{\alpha} - E_1) - \tau_I I_1 = 0.
\end{aligned} \tag{43}$$

(43) simplifies to the constraints in (43) and:

$$\begin{aligned}
\max_{C,I_1,E_1,\tau_I} \quad & u(C_{1a})+\gamma u(C_{1b})+\gamma\beta u(C_{2b})+\gamma\beta\lambda u(C_{2c}) \\
\text{s.t.} \quad & C_{2b}+C_{2c}=A_2((1-\delta)\overline{K}+I_1)^{\alpha}-\mathscr{D}(\sigma A_1\overline{K}^{\alpha}-E_1), \\
& u'(C_{2b})=\gamma u'(C_{2c}), \\
& C_{1a}+C_{1b}=A_1\overline{K}^{\alpha}-\mathscr{C}(E_1)-I_1, \\
& \tau_I=\beta\frac{u'(C_{2b})}{u'(C_{1b})}\alpha A_2((1-\delta)\overline{K}+I_1)^{\alpha-1}-1.
\end{aligned} \tag{44}$$

Given (44), (43) further simplifies to the constraints in (43) and:

$$\begin{aligned}
\max_{C,I_1,E_1} \quad & u(C_{1a})+\gamma u(C_{1b})+\gamma\beta u(C_{2b})+\gamma\beta\lambda u(C_{2c}) \\
\text{s.t.} \quad & C_{2b}+C_{2c}=A_2((1-\delta)\overline{K}+I_1)^{\alpha}-\mathscr{D}(\sigma A_1\overline{K}^{\alpha}-E_1), \\
& u'(C_{2b})=\gamma u'(C_{2c}), \\
& C_{1a}+C_{1b}=A_1\overline{K}^{\alpha}-\mathscr{C}(E_1)-I_1.
\end{aligned} \tag{45}$$

By deriving the first order conditions of (45), (43) then simplifies to the constraints in (43) and:

$$u'(C_{1a})=\gamma u'(C_{1b}), \tag{46}$$

$$u'(C_{1b})=\beta u'(C_{2b})\left[1-\frac{(\gamma-\lambda)u''(C_{2b})}{u''(C_{2b})+\gamma u''(C_{2c})}\frac{u'(C_{2c})}{u'(C_{2b})}\right]\alpha A_2((1-\delta)\overline{K}+I_1)^{\alpha-1}, \tag{47}$$

$$\mathscr{C}'(E_1)=\beta\frac{u'(C_{2b})}{u'(C_{1b})}\left[1-\frac{(\gamma-\lambda)u''(C_{2b})}{u''(C_{2b})+\gamma u''(C_{2c})}\frac{u'(C_{2c})}{u'(C_{2b})}\right]\mathscr{D}'(\sigma A_1\overline{K}^{\alpha}-E_1). \tag{48}$$

With the constraints in (43), the two latter equations finally give:

$$\tau_I=\frac{(\gamma-\lambda)u''(C_{2b})}{\lambda u''(C_{2b})+\gamma^2 u''(C_{2c})}, \tag{49}$$

$$\tau_E=\frac{1}{1+r_2}\mathscr{D}'(\sigma A_1\overline{K}^{\alpha}-E_1). \tag{50}$$

A.2.3 Market interest rate

With $u(x) = \frac{x^{1-\eta}-1}{1-\eta}$, the Euler equation (11) writes:

$$\frac{1}{1+r_2} = \frac{\beta}{1+\tau_I}\left(\frac{C_{1b}}{C_{2b}}\right)^{\eta}. \tag{51}$$

(42) and (46) simplify to $(\frac{C_{2c}}{C_{2b}})^{\eta} = \gamma$ and $(\frac{C_{1b}}{C_{1a}})^{\eta} = \gamma$, respectively, which can be rewritten, respectively:

$$C_{2b} = \frac{C_{2b}+C_{2c}}{1+\gamma^{1/\eta}}, \tag{52}$$

$$C_{1b} = \frac{C_{1a}+C_{1b}}{1+\gamma^{-1/\eta}}. \tag{53}$$

(49) rewrites:

$$\tau_I = \frac{\gamma-\lambda}{\lambda+\gamma^2\left(\frac{C_{2b}}{C_{2c}}\right)^{1+\eta}}, \tag{54}$$

which simplifies with $\frac{C_{2b}}{C_{2c}} = \gamma^{-\frac{1}{\eta}}$ to:

$$\tau_I = \frac{\gamma-\lambda}{\lambda+\gamma^{\frac{\eta-1}{\eta}}}. \tag{55}$$

With (52), (53), and (55), (51) finally rewrites:

$$\frac{1}{1+r_2} = \frac{\beta\gamma}{\left(\frac{C_{2b}+C_{2c}}{C_{1a}+C_{1b}}\right)^{\eta}} \frac{\gamma^{1-\frac{1}{\eta}}+\lambda}{\gamma^{1-\frac{1}{\eta}}+\gamma}. \tag{56}$$

A.3 Proof of Proposition 3

The resolution of the politico-economic equilibrium is similar to the resolution in Appendix A.2. While the government's problem (23) in period 2 is exactly as in the latter case, the government's problem (24) in period 1 is slightly different and simplifies to:

$$\begin{aligned} \max_{C,I_1,E_1} \quad & u(C_{1a}) + \gamma u(C_{1b}) + \gamma\beta u(C_{2b}) + \gamma\beta\lambda u(C_{2c}) \\ \text{s.t.} \quad & C_{2b} + C_{2c} = A_2((1-\delta)\overline{K} + I_1)^{\alpha} - \mathscr{D}(\sigma A_1 \overline{K}^{\alpha} - E_1), \\ & u'(C_{2b}) = \gamma u'(C_{2c}), \\ & C_{1a} + C_{1b} = A_1 \overline{K}^{\alpha} - \mathscr{C}(E_1) - I_1, \\ & u'(C_{1b}) = \beta u'(C_{2b}) \alpha A_2((1-\delta)\overline{K} + I_1)^{\alpha-1}. \end{aligned} \tag{57}$$

The first order conditions of (57) lead to:

$$u'(C_{1a}) = \gamma u'(C_{1b}) + \xi u''(C_{1b}), \tag{58}$$

$$\mathscr{C}'(E_1) = \beta \frac{u'(C_{2b})}{u'(C_{1b})} \left[1 + \xi(\alpha - 1)((1-\delta)\overline{K} + I_1)^{-1} \frac{u'(C_{1b})}{u'(C_{1a})} \right] \mathscr{D}'(\sigma A_1 \overline{K}^{\alpha} - E_1), \tag{59}$$

where ξ, the lagrangian multiplier of the fourth constraint of (57), satisfies:

$$\xi = \frac{\frac{\gamma - \lambda}{\gamma} \frac{u''(C_{2b})}{u''(C_{2c})} \beta u'(C_{2b})}{\left(1 + \frac{u''(C_{2b})}{\gamma u''(C_{2c})}\right) \left(\frac{(1-\alpha)\beta u'(C_{2b})}{(1-\delta)\overline{K} + I_1} - \frac{u''(C_{1b})}{\alpha A_2((1-\delta)\overline{K} + I_1)^{\alpha-1}} \right) - \beta u''(C_{2b}) \alpha A_2((1-\delta)\overline{K} + I_1)^{\alpha-1}}. \tag{60}$$

With $\mathscr{C}'(E_1) = \tau_E$ and $u'(C_{1b}) = \beta u'(C_{2b})(1 + r_2)$, (59) finally gives:

$$\tau_E = \frac{1}{1 + r_2} \left[1 + \xi(\alpha - 1)((1-\delta)\overline{K} + I_1)^{-1} \frac{u'(C_{1b})}{u'(C_{1a})} \right] \mathscr{D}'(\sigma A_1 \overline{K}^{\alpha} - E_1). \tag{61}$$

(58) and (61) can be rewritten, respectively:

$$u'(C_{1a}) = \gamma \left(1 - \frac{\gamma - \lambda}{\gamma} \psi \right) u'(C_{1b}), \tag{62}$$

$$\tau_E = \frac{1}{1 + r_2} \left(1 - \frac{\gamma - \lambda}{\gamma} \phi \right) \mathscr{D}'(\sigma A_1 K_1^{\alpha} - E_1), \tag{63}$$

where ψ and ϕ satisfy, respectively:

$$\psi = -\frac{\xi}{\gamma-\lambda}\frac{u''(C_{1b})}{u'(C_{1b})} > 0, \tag{64}$$

$$\phi = -\frac{\gamma\xi}{\gamma-\lambda}(\alpha-1)((1-\delta)\overline{K}+I_1)^{-1}\frac{u'(C_{1b})}{u'(C_{1a})} > 0. \tag{65}$$

With $u(x)=\frac{x^{1-\eta}-1}{1-\eta}$, the Euler equation (11) writes:

$$\frac{1}{1+r_2} = \beta\left(\frac{C_{1b}}{C_{2b}}\right)^{\eta}. \tag{66}$$

The second constraint in (57) and equation (62) simplify to $(\frac{C_{2c}}{C_{2b}})^{\eta}=\gamma$ and $(\frac{C_{1b}}{C_{1a}})^{\eta}=\gamma(1-\frac{\gamma-\lambda}{\gamma}\psi)$, respectively, which can be rewritten, respectively:

$$C_{2b} = \frac{C_{2b}+C_{2c}}{1+\gamma^{1/\eta}}, \tag{67}$$

$$C_{1b} = \frac{C_{1a}+C_{1b}}{1+\gamma^{-1/\eta}\left(1-\frac{\gamma-\lambda}{\gamma}\psi\right)^{-1/\eta}}. \tag{68}$$

With (67) and (68), (66) finally rewrites:

$$\frac{1}{1+r_2} = \frac{\beta\gamma}{\left(\frac{C_{2b}+C_{2c}}{C_{1a}+C_{1b}}\right)^{\eta}}\frac{\left(1+\gamma^{\frac{1}{\eta}}\right)^{\eta}}{\left(1+\gamma^{\frac{1}{\eta}}+\left(1-\frac{\gamma-\lambda}{\gamma}\psi\right)^{-\frac{1}{\eta}}-1\right)^{\eta}}. \tag{69}$$