UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

WORKING PAPERS IN ECONOMICS

No 643

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January 2016

ISSN 1403-2473 (print)
ISSN 1403-2465 (online)

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The Political Economy of Mitigation and Adaptation*

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December 21, 2015

Abstract

In this paper, we acknowledge that the mitigation of and adaptation to climate change have differential fiscal impacts. Whereas mitigation typically raises fiscal revenues, adaptation is costly to the taxpayer and to a greater extent the more distortionary the tax system is. In an OLG model with majority voting, we analyze how the choices of mitigation and adaptation are distorted under a lump-sum and a distortionary income tax regime. We find that whenever emissions and adaptation exhibit stock characteristics, the levels of mitigation and adaptation are chosen inefficiently low in the political equilibrium under lump-sum taxation. By contrast, the political equilibrium may entail inefficiently high mitigation or inefficiently high adaptation (but not both simultaneously) if the tax system is distortionary. A calibration of our model to the German economy shows that both mitigation and adaptation can be expected to be inefficiently low in the political equilibrium. Furthermore, the standard assumption of a lump-sum tax system when analyzing mitigation and adaptation is found to underestimate the loss in utilitarian welfare relative to a distortionary tax system, although mitigation levels are generally higher under the latter regime.

JEL-**Classification:** D72, D78, H21, H23, Q58

Keywords: Adaptation, Mitigation, Political Economy, Majority Voting, OLG, Environmental Taxes

*We thank Kelly de Bruin, Jurate Jaraite-Kazukauski, Thomas Sterner and seminar participants at the University of Umeå for valuable comments and suggestions. Wolfgang Habla acknowledges the generous financial support from the FORMAS research program COMMONS.

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1 Introduction

Current climate policies consist of two options: the mitigation of greenhouse gas emissions such as CO_2 and the adaptation to the adverse impacts of climate change. While the former is able to raise fiscal revenues (consider an environmental tax or the auctioning of permits under an emissions trading scheme), public adaptation (dykes against rising sea levels or transport infrastructure that is resistant to extreme weather events) requires revenues. It has been estimated that the costs of public adaptation can be quite significant (see, e.g., Egenhofer et al., 2010; Jones et al., 2013; Israel, 2013). The fiscal dimension of climate policies has, however, been largely neglected in economic theory, with the exception of Barrage (2015), and its implications for the political feasibility of these two options will be explored in this paper.

Mitigation policies have highly differential impacts on individuals with different income levels, first because they usually affect low-income individuals to a greater extent than high-income individuals (at least in developed countries, see, e.g., Bach, 2009; Poterba, 1991; Ekins *et al.*, 2011) but also because any revenues from environmental regulation can be spent on redistribution between households. In many European countries, e.g., Germany, Sweden, the UK, Denmark or the Netherlands (see Bosquet, 2000), environmental tax revenues have been used to reduce income taxes or social security contributions, which partly offsets the regressive impacts of the tax itself. As these reductions in taxes and contributions are incurred primarily by the working population and to a much lesser degree by retired individuals, age constitutes a second important dimension along which differential impacts of climate policy can be observed. Finally, young and old individuals enjoy different benefits from mitigation policies simply because of their different time horizons. The young will – on average – benefit more (or longer) from emissions reductions than the old. The same holds true for expenditures on public adaptation that endure over time, such as sea walls and transport infrastructure. These two dimensions – different individual income levels and time horizons – have a significant impact on which policy mix of mitigation and adaptation is chosen in the political process.

Specifically, we consider an Overlapping Generations (OLG) framework with two generations alive at each point in time – the young and the old. The young work, whereas the old are retired. Apart from age, agents differ in their income. They have preferences over a non-dirty (numéraire) and a dirty consumption good such as fossil fuels, over the level of emissions (caused by dirty good consumption) and the level of adaptation investment. All agents vote on the ecotax rate that applies to consumption of the polluting good and over the level of adaptation investments. Given this multi-dimensional issue space, we invoke Shepsle's (1979) concept of structure-induced equilibria. It separates the bi-dimensional policy space into single dimensions by assuming that institutions exist that have been assigned the unique power to determine policies related to their field of responsibility. In our model, the ministry of the environment proposes a green

tax rate for a given level of adaptation investment, while the ministry of finance suggests a level of adaptation investment for a given environmental tax rate. These proposals can be treated as the best responses (reaction functions) of the respective ministries and are rooted in the median voter's preferences regarding the issue at stake. Their intersection describes the structure-induced equilibrium of the voting game.

We compare the political outcome with the choices made by a utilitarian social planner and find that whether mitigation and adaptation are inefficiently low or high crucially depends on the characteristics of the underlying tax system. In particular, we consider the two most prevalent modes of financing – a distortionary income tax system and a lump-sum tax system. The standard case in the environmental economics literature is the latter because it allows one to focus on environmental externalities. Compared to that system, distortionary income taxes are borne mostly by the young generation and necessarily cause efficiency losses. The mode of financing has a twofold impact on the budget constraints of the agents in our model: first, through the recycling of ecotax revenue and, second, through the financing of adaptation. When adaptation is financed and ecotax revenue is recycled through a lump-sum tax system, both mitigation and adaptation are lower in the political equilibrium than their socially optimal levels if both policy options exhibit stock characteristics. This is because voters do not internalize the full marginal damage from the consumption of the polluting good that is imposed on future generations. If, by contrast, distortionary taxes are in place, the median voter may prefer inefficiently high mitigation given a sufficiently high income or inefficiently high adaptation given a sufficiently low income, albeit not both at the same time.

The intuition underlying this result is as follows. Although, due to differences in environmental concerns, the social planner internalizes environmental damage to a greater extent than do individuals, high-income earners benefit more from the regressive nature of ecotaxes relative to low-income individuals. Namely, the decrease in proportional income taxes caused by the additional ecotax revenue exceeds the direct costs of the ecotax for high-income individuals. This fiscal motive due to the recycling of green tax revenue may thus induce the median voter to choose an inefficiently high level of mitigation. Moreover, the financing of adaptation is relatively costly for these individuals such that they desire adaptation investments that are inefficiently low. The reverse case arises when the median voter happens to be a relatively low-income type. For her, the financial relief from additional ecotax revenue through a cut in distortionary taxes is small, but the costs of adaptation are also low. Thus, she votes for inefficiently low mitigation but inefficiently high adaptation investments.

As a consequence, depending on the income of the median voter, mitigation will be higher and adaptation will be lower under a distortionary tax regime compared with the lump-sum tax system, or vice versa. The mode of financing thus plays a key role in how society is able

to combat climate change. Higher mitigation investments may only be politically feasible if the mode of financing is via distortionary taxes. However, adaptation investments desired by the decisive voter can be expected to be lower than under lump-sum taxation in this case.

In a calibration of our model to the German economy, we draw some tentative conclusions on whether mitigation and adaptation levels can be expected to be inefficiently high or low in reality and whether they are higher or lower under a distortionary tax system relative to a system without any fiscal distortions. Furthermore, we compare welfare levels under the different tax regimes and the social optimum. We find that the political equilibrium under both financing regimes yields mitigation and adaptation levels that are lower than their socially optimal levels. However, the relative strength of mitigation and adaptation differs for the two modes of financing and strongly depends on the distortionary factor of the tax system as measured by the marginal costs of funds. Although we find higher levels of mitigation for reasonable parameter estimates of the marginal costs of funds relative to a system of lump-sum taxation, the deadweight loss entailed by the distortionary tax regime always provokes considerably lower adaptation investment and lower overall welfare.

Our paper contributes to three strands of the literature. First, it adds to the (theoretical) literature on mitigation and adaptation. This literature has studied a variety of issues related to adaptation but is still considered in its infancy. Zehaie (2009), Buob and Stephan (2011) and Heuson et al. (forthcoming) study the strategic implications of adaptation in non-cooperative settings. Kane and Shogren (2000), Felgenhauer and de Bruin (2009), Ingham et al. (2007), Auerswald et al. (2011) and Zemel (2015) explore the interactions between mitigation and adaptation under uncertainty. In Bréchet et al. (2013), optimal mitigation and adaptation investments are studied on a macroeconomic level. Analyses of the optimal policy mix in the context of integrated assessment climate-economy models include Tol (2007), de Bruin et al. (2009), Bosello et al. (2010), Agrawala et al. (2011) and Felgenhauer and Webster (2013, 2014). Barrage (2015) acknowledges that distortionary fiscal policy affects the trade-off between mitigation and adaptation in a second-best setting. Whereas Barrage studies *optimal* mitigation and adaptation policies under distortionary taxation, we argue that the redistributive nature of the underlying tax system (be it distortionary or not) matters for the political acceptability of mitigation and adaptation choices. Both margins will likely be distorted because redistribution occurs within *and* between generations. A distortionary tax system adds an inefficiency to the economy but may incentivize the median voter to vote for a higher level of mitigation. However, although the costs of financing adaptation are higher under distortionary taxes compared to a lump-sum tax regime, the redistributive properties of the underlying tax system induce low-income voters to vote for higher adaptation levels.

Second, our paper is related to the literature on the intergenerational aspects of environmen-

tal policy in an OLG framework (see, *e.g.*, Bovenberg and Heijdra, 1998 and 2002; Chiroleu-Assouline and Fodha, 2006; or Karp and Rezai, 2014). In these papers, intergenerational conflicts arise due to differential distributional impacts of environmental policy on the welfare of current and future generations. In our model, the young and old generations have different preferences for mitigation and adaptation not only because of their different time horizons but also because of the different fiscal impacts of these two climate policy options on their respective budget constraints.

Third, the paper contributes to the literature on the political economy of environmental policy, which emphasizes the crucial role that the recycling of ecotax revenue plays with respect to the political feasibility of ecotaxes. Contributions to this literature have been made by Cremer, De Donder, and Gahvari in a series of papers (Cremer *et al.*, 2004, Cremer *et al.*, 2007, Cremer *et al.*, 2008) and by Aidt (2010) and Habla and Roeder (2013). In contrast to these papers, we draw a more realistic picture of climate policy by acknowledging that adaptation constitutes a second major policy option that is costly to the individual tax-payer. Overall, our paper is – to the best of our knowledge – the first to address the political economy of mitigation and adaptation.

2 The Model

2.1 The Economic Environment

We consider an economy with two generations alive in each period t: the young (superscript 'Y') and the old (superscript 'O'). The population grows at a constant rate $n > 0$, and we normalize the size of the current old generation to unity. There are thus $1/(1+n)$ old agents in each period, and the overall size of the population is given by $2+n$. The young are in employment and inelastically supply one unit of labor, earning income $y_{i,t}^{Y}$. The old are retired and receive an exogenous income of $y_{i,t}^{O}$, e.g., from pension benefits. The incomes of the young and the old are distributed over the support $[y_{-}, y_{+}] \subset \mathcal{R}_{+}$ according to the cumulative distribution functions $F(y_t^Y)$ and $F(y_t^O)$. Each income distribution is assumed to be right-skewed, $F(\bar{y}_t^Y), F(\bar{y}_t^O) > 0.5$, implying that median income is below average income. There is no storage technology, and hence individuals do not save and solely live off their pension benefits in old age. The economy produces two goods: a clean (non-energy) numéraire good c and a polluting (energy-related) good d. The latter is taxed at a rate $\theta_t \in \mathcal{R}$. Normalizing the producer price of good d to unity, the consumer

price amounts to $q_t = 1 + \theta_t$.[1] Aggregate consumption of the polluting good is:

$$D_t = (1+n)\int_{y_-}^{y_+} d_{i,t}^{Y} \mathrm{d}F(y_t^Y) + \int_{y_-}^{y_+} d_{i,t}^{O} \mathrm{d}F(y_t^O) \ . \tag{1}$$

Note that variation in a single individual's consumption of the dirty good $d_{i,t}^{j}$ $(j = Y, O)$ has no impact on overall consumption D_t because the mass of one individual is zero. Consumption of the polluting good causes emissions (one unit of the polluting good equals one unit of emissions) and contributes to the existing stock of emissions:

$$E_t = \sum_{x=0}^{t} (1-\delta_E)^{t-x} D_x = (1-\delta_E) E_{t-1} + D_t \ , \tag{2}$$

which equals current emissions plus aggregate pollution from previous periods, where the latter is reduced by the natural decay and removal rate $\delta_E \in [0,1]$ per period, which we assume to be exogenous over time.[2] The reader may regard the polluting good as fossil fuels, the consumption of which generates greenhouse gas emissions and causes global warming. A decay rate equal to unity implies that pollution does not accumulate over time. The stock of emissions in the atmosphere generates disutility $h(E_t, A_t)$ in period t for each young and old agent, with $h_E > 0$ and $h_A < 0$. The damage from emissions can be reduced by investing in adaptation a_t, with the stock of public adaptation A_t evolving according to the following:

$$A_t = (1-\delta_A) A_{t-1} + v(a_t) \ , \tag{3}$$

where $v(a_t)$ is a neoclassical production function for adaptation that satisfies the Inada conditions and $\delta_A \in [0,1]$ is the depreciation rate of adaptation capital per period. For simplicity, we assume the following functional form:

$$h(E_t, A_t) = \phi \times (E_t - A_t) \ . \tag{4}$$

This assumption rules out any strategic interdependencies between the mitigation of emissions and investment in adaptation but captures the stylized fact that the two actions are substitutes in reducing environmental damage.[3]

[1] We perform a partial equilibrium analysis that abstracts from price and wage effects. Equivalently, we could assume that the two goods are produced by a linear technology subject to constant returns to scale in a competitive environment.

[2] In reality, δ_E varies over time and becomes smaller as natural sinks for greenhouse gases become exhausted, see Section 6.

[3] Positive interdependencies arise when, e.g., higher adaptation expenditures lower environmental damage from emissions. An example are ecosystems that become more resilient to climate change when adaptation is increased.

The utilities of old and young agents are given by:

$$U_{i,t}^O = c_{i,t}^O + u(d_{i,t}^O) - h(E_t, A_t) \ , \tag{5}$$

$$U_{i,t}^Y = c_{i,t}^Y + u(d_{i,t}^Y) - h(E_t, A_t) + \rho U_{i,t+1}^O \ , \tag{6}$$

where $0 < \rho \leq 1$ is the utility discount factor and u denotes utility from dirty good consumption, which satisfies $u' > 0, u'' < 0$ and $u''' > 0$. $U_{i,t+1}^O$ is the utility in old age of an individual who is young at time t. The budget constraints read:

$$c_{i,t}^O + (1+\theta_t) d_{i,t}^O = y_{i,t}^O - \tau_t \ , \tag{7}$$

$$c_{i,t}^Y + (1+\theta_t) d_{i,t}^Y = (1-b_t) y_{i,t}^Y - \tau_t \ , \tag{8}$$

with τ_t being a lump-sum tax and b_t being a linear labor income tax (or social security contribution rate) that is borne solely by the young.[4] Assuming an interior solution, optimal consumption of the polluting good is thus implicitly given by:

$$1 + \theta_t = u'(d_{i,t}^j) \quad \Rightarrow \quad d_{i,t}^j = d(\theta_t) \quad \forall \ i,t \quad \text{and for} \quad j = Y, O. \tag{9}$$

As $\partial d(\theta_t)/\partial \theta_t = d'(\theta_t) = 1/u'' < 0$, consumption of the polluting good decreases with the tax rate. Moreover, it is independent of the individual's income and age. In other words, all individuals consume the same amount of the energy-related good. This captures – in the most parsimonious way – the fact that environmental taxation (before redistribution of the associated revenues) is usually found to be regressive (Poterba, 1991; Ekins *et al.*, 2011).

2.2 The Economic Equilibrium

In an economic equilibrium, public budgets need to be balanced. The government invests in public adaptation and needs to finance an exogenously given amount of public spending R_t (transfers, pension payments, etc.).

We consider two financing regimes: first, a regime with lump-sum taxes only, which is the standard case in the environmental economics literature, and second, the more realistic regime in which only distortionary income taxes are an available source of revenue for the government. This allows us to disentangle the effects of the financing regime on the outcome of the political

[4] Although pension benefits are also subject to income taxation in many countries, these benefits are significantly lower than previous incomes from work. Furthermore, tax exemptions often apply such that the effective tax rate on pension benefits is rather small, and we can safely neglect it in our analysis. In Germany, e.g., only a quarter of all pension benefits are taxed; see Deutsche Rentenversicherung (2015).

process. In both regimes, revenue from taxation of the polluting good is given by:

$$\theta_t(2+n)d(\theta_t) = \theta_t D(\theta_t) \ . \tag{10}$$

Importantly, we assume that ecotax revenue is insufficient to meet the government's revenue needs.

2.2.1 Financing by Lump-sum Taxes

In the benchmark case in which lump-sum taxes are at the government's disposal, the public budget reads as:

$$\theta_t D(\theta_t) + (2+n)\tau_t = R_t + a_t \quad \Rightarrow \quad \tau_t(\theta_t, a_t) = \frac{R_t + a_t - \theta_t D(\theta_t)}{2+n} \ . \tag{11}$$

The lump-sum tax thus depends on the endogenously chosen levels of adaptation and the ecotax rate. In particular, the following holds:

$$\frac{\partial \tau_t(\theta_t, a_t)}{\partial \theta_t} = -\frac{D(\theta_t) + \theta_t D'(\theta_t)}{2+n} \ , \tag{12}$$

$$\frac{\partial \tau_t(\theta_t, a_t)}{\partial a_t} = \frac{1}{2+n} > 0 \ . \tag{13}$$

While an increase in adaptation investment necessarily increases the lump-sum tax for a given ecotax rate, the first equation is negative whenever the following holds:

$$D(\theta_t) + \theta_t D'(\theta_t) = D(\theta_t)(1 - \varepsilon_{D,\theta}) > 0 \ , \tag{14}$$

where $\varepsilon_{D,\theta} = -D'(\theta_t)\theta_t / D(\theta_t)$ is the (absolute value of the) demand elasticity of the polluting good with respect to the tax rate. In other words, whenever consumption of the polluting good is inelastic, that is, $\varepsilon_{D,\theta}$ smaller than one, the lump-sum tax decreases with the green tax rate. The intuition is that if a one-percentage-point increase in the green tax aggregate consumption of the dirty good decreases by less than one percent, this increases positive revenue from taxation. This revenue can then be used to reduce the lump-sum tax rate while leaving total public expenditure unchanged.[5]

Inserting expression (11) into the old's and young's utility function yields their indirect

[5]Several studies that estimate long-run price elasticities of energy demand confirm that $\varepsilon_{D,\theta} < 1$; see, *e.g.,* Hunt and Manning (1989) or Small and Van Dender (2007). Estimates range between 0.1 and 0.9 for different sources of energy. The average long-run elasticity is thereby found to be 0.58 (Espey, 1996).

utilities $V_{i,t}^O$ and $V_{i,t}^Y$ as a function of θ_t and a_t:

$$V_{i,t}^O(\theta_t, a_t) = y_{i,t}^O - (1+\theta_t)d(\theta_t) - \tau_t(\theta, a_t) + u(d(\theta_t)) - h(E_t(\theta_t), A_t(a_t)) \ , \tag{15}$$

$$V_{i,t}^Y(\theta_t, a_t) = y_{i,t}^Y - (1+\theta_t)d(\theta_t) - \tau_t(\theta, a_t) + u(d(\theta_t)) - h(E_t(\theta_t), A_t(a_t)) + \rho V_{i,t+1}^O(\theta_t, a_t) \ , \tag{16}$$

where $V_{i,t+1}^O$ denotes indirect utility of a currently young agent in old age. The latter depends on the current green tax rate and current adaptation expenditure, as both of these affect the stocks of emissions and adaptation in period $t+1$ for $\delta_E, \delta_A < 1$.[6]

2.2.2 Financing by Distortionary Taxes

To account for the distortionary nature of income taxation, we assume that a fraction $\eta < 1$ of income taxes is lost during the redistributive process (*e.g.*, Galasso and Profeta, 2007; Cremer *et al.*, 2008).[7] The government's budget in this regime reads as:

$$\theta_t D(\theta_t) + (1+n)(1-\eta)b_t \int_{y^-}^{y^+} y_{i,t}^Y dF(y_t^Y) = R_t + a_t \quad \Rightarrow \quad b_t(\theta_t, a_t) = \frac{R_t + a_t - \theta_t D(\theta_t)}{(1+n)(1-\eta)\bar{y}_t^Y} \ . \tag{17}$$

Specifically, the income tax rate that balances public expenditure and ecotax revenue can be written as a function of θ_t and a_t. It adjusts to marginal changes in these variables according to:

$$\frac{\partial b_t(\theta_t, a_t)}{\partial \theta_t} = -\frac{D(\theta_t)(1-\varepsilon_{D,\theta})}{(1+n)(1-\eta)\bar{y}_t^Y} < 0 \ , \tag{18}$$

$$\frac{\partial b_t(\theta_t, a_t)}{\partial a_t} = \frac{1}{(1+n)(1-\eta)\bar{y}_t^Y} > 0 \ . \tag{19}$$

Lower ecotax revenue or higher adaptation expenditure thus have to be offset by higher income tax rates. Note also that a lower population growth rate leads, *ceteris paribus*, to less ecotax revenue and lower income tax revenue, which implies that the income tax rate must rise to meet a given level of expenditure.

Finally, the old's and young's indirect utilities in the case of distortionary taxation can be

[6] Linear damages effectively separate the decisions made in different periods, and therefore, the policy variables in $t+1$ do not matter for the decision in period t.

[7] The deadweight loss η is related to the Marginal Cost of Public Funds (MCF) for the income tax system through $\eta = 1 - 1/\text{MCF}$, that is, a higher MCF entails a larger deadweight loss.

written as:

$$V_{i,t}^{O}(\theta_t, a_t) = y_{i,t}^{O} - (1+\theta_t)d(\theta_t) + u(d(\theta_t)) - h(E_t(\theta_t), A_t(a_t)) \ , \tag{20}$$

$$V_{i,t}^{Y}(\theta_t, a_t) = [1 - b_t(\theta_t, a_t)]y_{i,t}^{Y} - (1+\theta_t)d(\theta_t) + u(d(\theta_t)) - h(E_t(\theta_t), A_t(a_t)) + \rho V_{i,t+1}^{O}(\theta_t, a_t) \ . \tag{21}$$

The above indirect utility functions of an i-type young and old agent can be used to express their preferences for the green tax rate and public adaptation in economic equilibrium. Both policy variables are determined in the political process described in Section 4.

3 Social Optimum

In this section, we analyze the optimal levels of the green tax rate and public adaptation that would be chosen by a utilitarian social planner. This provides a benchmark against which the results of the political outcome can be assessed.

At time t, the social planner accounts for the welfare of all generations from t to infinity, that is, for the current old plus all current and future young generations.[8] The welfare function can be written as a function of the policy variables of time t:

$$W_t(\theta_t, a_t) = \int_{y_-}^{y_+} V_{i,t}^{O}(\theta_t, a_t)\mathrm{d}F(y_t^{O}) + (1+n)\sum_{x=t}^{\infty}\big((1+n)\rho\big)^{x-t}\int_{y_-}^{y_+}\int_{y_-}^{y_+} V_{i,x}^{Y}(\theta_t, a_t)\mathrm{d}F(y_x^{Y})\mathrm{d}F(y_{x+1}^{O}) \ , \tag{22}$$

where we omit future policy variables for the same reason as above. Note that with a utilitarian welfare function and quasi-linear preferences, redistributive considerations within and between generations do not matter – all agents have a constant marginal utility of income equal to one.

Because the income tax scheme entails distortions and redistributive concerns are not present, it is always optimal to finance a_t and R_t by lump-sum taxes.

The first-order condition of (22) with respect to θ_t reduces to:

$$-D(\theta_t) - (2+n)\frac{\partial \tau_t}{\partial \theta_t} - \frac{2+n}{1-z_E}\phi D'(\theta_t) = 0 \quad \Leftrightarrow \quad \theta_t^{\star} = \frac{2+n}{1-z_E}\phi \ , \tag{23}$$

where $z_E \equiv \rho(1+n)(1-\delta_E)$ and $\rho(1+n) < 1$ for the infinite sum of marginal environmental damages to converge. That is, the social planner weighs the marginal costs to society of increas-

[8] We do not distinguish between private discount rates used by one generation to discount their lifetime utility and the social discount rate at which the social planner trades off the weighted lifetime utility of different generations. See Schneider *et al.* (2012) on intergenerational trade-offs in OLG models and models with an infinitely lived agent.

ing the green tax rate (the first term in the equation to the left) against the marginal benefits of a lower lump-sum tax due to revenue recycling (second term) and of reduced environmental damage (third term). At the optimum, the social planner sets the tax rate equal to the present value of marginal environmental damages (Pigouvian tax).

The first-order condition with respect to a_t can be written as:[9]

$$-(2+n)\frac{\partial \tau_t}{\partial a_t} + \frac{2+n}{1-z_A}\phi v'(a_t) = 0 \quad \Leftrightarrow \quad \frac{2+n}{1-z_A}\phi v'(a_t^\star) = 1 \ , \tag{24}$$

where $z_A \equiv \rho(1+n)(1-\delta_A)$ and again $\rho(1+n) < 1$ for convergence of the infinite sum of marginal environmental damages. The social planner thus equates the present value of the marginal environmental benefits of adaptation with its marginal costs, which equal unity. This is the usual Samuelson condition for the optimal provision of public goods.

4 Political Process

In each period, the young and old vote on the green tax rate θ_t and on public adaptation expenditure a_t (repeated voting), and they do so sincerely. Agents' preferences over the two policy variables are aggregated through a political system of majoritarian voting. Each individual has zero mass, and hence no individual vote can change the outcome of the election.

We examine structure-induced equilibria (SIE) as developed by Kramer (1972) and Shepsle (1979). Agents are assumed to vote simultaneously but separately on the issues at stake.[10] The political system is characterized by the following institutional arrangement. An elected government perfectly represents the preferences of the whole electorate – the young and the old. The policy issues at stake are assigned to perfectly representative ministries. In particular, the ministry of environment proposes an ecotax rate for any *given* level of adaptation, while the ministry of finance suggests a level of adaptation for any *given* environmental tax rate. Proposals are rooted in the median voter's preferences over the issue at stake and can be regarded as the best responses or reaction functions of the ministries. Their intersection characterizes the SIE of the voting game in which the ministries' policy proposals are mutual best responses to one another. The SIE thus introduces issue-by-issue voting and retains the median voter approach in a multi-dimensional issue space.

Sections 4.1 and 4.2 specify every voter's ideal point with respect to the green tax rate and

[9] Both second-order conditions can be shown to hold; see Appendix A.1.

[10] Alternatively, our setting could be framed such that decisions are made sequentially. The natural first stage would then be the decision on the ecotax rate, which specifies the mitigation effort, while adaptation expenditure would be determined in the second stage. As will be shown below, the reaction functions are horizontal and vertical lines, respectively. This is due to our assumption that $h_{EA} = 0$ and implies that mitigation and adaptation are not strategic substitutes (or complements). However, this also means that the outcome of this sequential game (and of the game in reverse order) coincides with the SIE.

public adaptation under the two financing regimes. At the end of each section, the median voter is identified, and the outcome of the political process as measured by the SIE under each regime is compared to the social optimum. In Section 4.3, we compare the outcomes of the different regimes with one another.

4.1 Voting with Lump-sum Taxes

If lump-sum taxes are available, an old or young individual of type i finds her preferred green tax rate, $\theta_{i,t}^O$ or $\theta_{i,t}^Y$, by maximizing indirect utility, equations (15) and (16), with respect to θ_t. The first-order conditions are given by:

$$\frac{\partial V_{i,t}^O}{\partial \theta_t} = -d(\theta_t) - \frac{\partial \tau_t}{\partial \theta_t} - \phi D'(\theta_t) = 0 \ , \tag{25}$$

$$\frac{\partial V_{i,t}^Y}{\partial \theta_t} = -d(\theta_t) - \frac{\partial \tau_t}{\partial \theta_t} - \phi D'(\theta_t)[1 + \rho(1 - \delta_E)] = 0 \ . \tag{26}$$

For $\delta_E < 1$, these optimal conditions differ only in the last term. The first term in each equation describes the individual's direct cost of higher green taxes in terms of higher expenditure, while the second term describes the marginal benefit of higher ecotaxes in terms of a lower lump-sum tax associated with the recycling of ecotax revenue. Finally, the third term is the marginal benefit of higher green taxes in terms of lower environmental damage in period t, where the young generation benefits from this reduction also in period $t+1$ (for $\delta_E < 1$). The preferred tax rate for each generation balances these trade-offs. The second-order conditions hold (see Appendix A.1).

When maximizing indirect utility with respect to a_t, we obtain the following first-order conditions for an old and a young individual of type i:

$$\frac{\partial V_{i,t}^O}{\partial a_t} = -\frac{\partial \tau_t}{\partial a_t} + \phi v'(a_t) = 0 \ , \tag{27}$$

$$\frac{\partial V_{i,t}^Y}{\partial a_t} = -\frac{\partial \tau_t}{\partial a_t} + \phi v'(a_t)[1 + \rho(1 - \delta_A)] = 0 \ , \tag{28}$$

which yield the optimal choices $a_{i,t}^O$ and $a_{i,t}^Y$. Similar to the indirect utility case, for $\delta_A < 1$, only the last term differs across generations because of the different time horizons of old and young individuals. It measures the marginal environmental benefit from adaptation investment that accrues to both generations in period t but continues to have an effect in period $t+1$ for the young generation. The first term in each equation is the marginal cost to each individual of higher adaptation investment in terms of a higher lump-sum tax. Again, the second-order conditions are strictly negative (Appendix A.1).

It is straightforward to derive the following lemma.

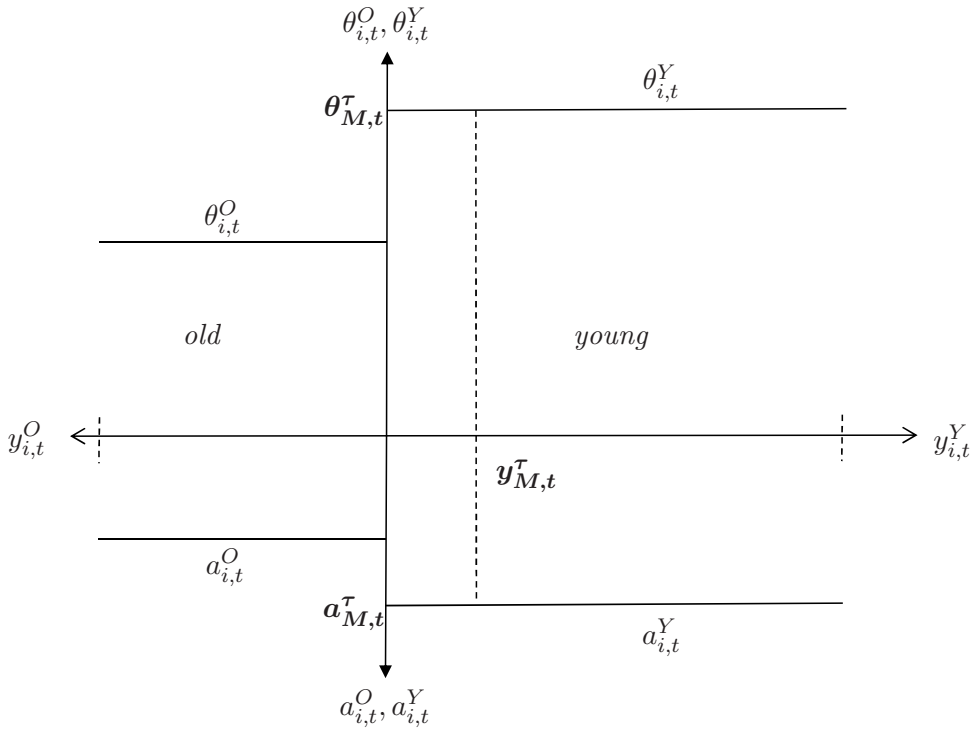

Figure 1: Political equilibrium under lump-sum taxation.

Lemma 1 (The old's and young's preferred mitigation & adaptation levels)
When lump-sum taxes are in place, the old will – for $\delta_E, \delta_A < 1$ – always prefer both a lower green tax rate and lower adaptation investment relative to individuals of the young generation.

This is simply because the young have a longer time horizon and thus appreciate an investment that endures over time to a greater extent than do the old. In the special case of 100% depreciation of pollution and adaptation per period, the old's and young's optimal mitigation and adaptation choices coincide.

Individuals can be ordered according to their age, with respect to both policy instruments, as illustrated by Figure 1, and the median voter(s) can be characterized as follows.

Lemma 2 (The median voter(s) under lump-sum taxation)
In the case of lump-sum taxation, and for $n > 0$, the median voter along both dimensions is a young individual (of any income). Her preferred levels of the green tax rate and the adaptation investment under lump-sum taxation are denoted $\theta^\tau_{M,t}$ and $a^\tau_{M,t}$, respectively.

Note that although the median voters along both dimensions are – unlike in Figure 1 – not necessarily identical and may dispose of different incomes, their optimal choices do not differ from those of other young voters. Furthermore, due to the assumption that the cross-partial

derivative of the damage function is zero, the optimal choices of all individuals and hence of the median voter(s) are independent of the choice of the other policy variable; see equations (26) and (28). In other words, the reaction functions of the median voter(s) with respect to mitigation and adaptation choices are vertical and horizontal lines, respectively, which leads us to the following proposition.

Proposition 1 (Existence and uniqueness of SIE under lump-sum taxation) *There exists a unique SIE, $(\theta^{\tau}_{M,t}, a^{\tau}_{M,t})$, under lump-sum taxation. It is characterized by equations (26) and (28).*

Evaluating the social planner's optimal conditions with respect to the green tax rate and adaptation investment, equations (23) and (24), at the median voter's preferred levels, given by equations (26) and (28), yields:

$$\left.\frac{\partial W}{\partial \theta_t}\right|_{\theta_t=\theta^{\tau}_{M,t}} = -(2+n)\phi D'(\theta^{\tau}_{M,t})\frac{z_E}{1-z_E}\left[1-\frac{1-z_E}{1+n}\right] \geq 0 \qquad \Rightarrow \quad \theta^{\tau}_{M,t} \leq \theta^{*}_{t} \ , \tag{29}$$

$$\left.\frac{\partial W}{\partial a_t}\right|_{a_t=a^{\tau}_{M,t}} = (2+n)\phi v'(a^{\tau}_{M,t})\frac{z_A}{1-z_A} \geq 0 \qquad \Rightarrow \quad a^{\tau}_{M,t} \leq a^{*}_{t} \ , \tag{30}$$

which we summarize in the following corollary.

Corollary 1 (Inefficiently low mitigation & adaptation under lump-sum taxation) *When financing is by lump-sum transfers, then both the ecotax rate and adaptation investments are – for $\delta_E, \delta_A < 1$ – too low in the political equilibrium relative to their social optimum.*

This is not particularly surprising because the social planner also accounts for, in contrast to the median voter(s) at time t, how mitigation and adaptation choices at time t affect all future generations' welfare through reduced environmental damage. For the special case of $\delta_E = \delta_A = 1$, the choices in the political equilibrium coincide with the first-best.

4.2 Voting with Distortionary Taxes

In the case of distortionary income taxation, the first-order conditions of an old and a young individual of type i with respect to the green tax rate are – using equations (20) and (21) – given by:

$$\frac{\partial V^{O}_{i,t}}{\partial \theta_t} = -d(\theta_t) - \phi D'(\theta_t) = 0 \ , \tag{31}$$

$$\frac{\partial V^{Y}_{i,t}}{\partial \theta_t} = -d(\theta_t) - \phi D'(\theta_t)[1+\rho(1-\delta_E)] - \frac{\partial b_t}{\partial \theta_t} y^{Y}_{i,t} = 0 \ . \tag{32}$$

The first term in both equations illustrates the marginal costs of a tax increase as described in the previous section. The second term measures the marginal environmental benefit of higher ecotaxes, which is – for $\delta_E < 1$ – higher for an individual of the young generation. The last term in equation (32) describes the marginal benefit for the young generation in terms of lower distortionary taxes due to revenue recycling. If the second-order conditions hold, as we assume (see Appendix A.1), it is clear that the young obtain greater benefits from a marginal ecotax increase but the same costs. Therefore, they always prefer a higher ecotax rate than do the old. However, in contrast to the old and in contrast to the case of lump-sum taxation, their preferred ecotax rate depends on their income. Specifically, $\partial\theta^Y_{i,t}/\partial y^Y_{i,t} > 0$.

Finally, the first-order conditions of an old and a young individual of type i with respect to adaptation investments yield (the second-order conditions can be shown to hold, see Appendix A.1):

$$\frac{\partial V^O_{i,t}}{\partial a_t} = \phi v'(a_t) > 0 \ , \tag{33}$$

$$\frac{\partial V^Y_{i,t}}{\partial a_t} = \phi v'(a_t)[1 + \rho(1 - \delta_A)] - \frac{\partial b_t}{\partial a_t} y^Y_{i,t} = 0 \ . \tag{34}$$

The old thus prefer – independent of their income – as much adaptation as possible, up to the point at which the marginal productivity of adaptation becomes zero. The reason is that they do not contribute to the provision of adaptation under this regime. The young, by contrast, benefit – for $\delta_A < 1$ – from higher adaptation through lower environmental damage in periods t and $t+1$. Moreover, a higher adaptation investment increases the distortionary income tax, which is harmful to young agents and does so to a greater extent the higher is their income (the last term in equation (34)). Therefore, $\partial a^Y_{i,t}/\partial y^Y_{i,t} < 0$. Old agents thus always prefer higher adaptation investment relative to the young. We can summarize our findings for the distortionary tax regime in the following lemma.

Lemma 3 (The old's and young's preferred mitigation & adaptation levels)
When distortionary taxes are in place, the old prefer a lower green tax rate but higher adaptation investment compared to the young generation.

To characterize the political equilibrium, voters can be ordered according to their age *and* income, as illustrated by Figure 2.

Lemma 4 (The median voter under distortionary taxation)
In the case of distortionary taxation, and for $n > 0$, the median voter along both dimensions is

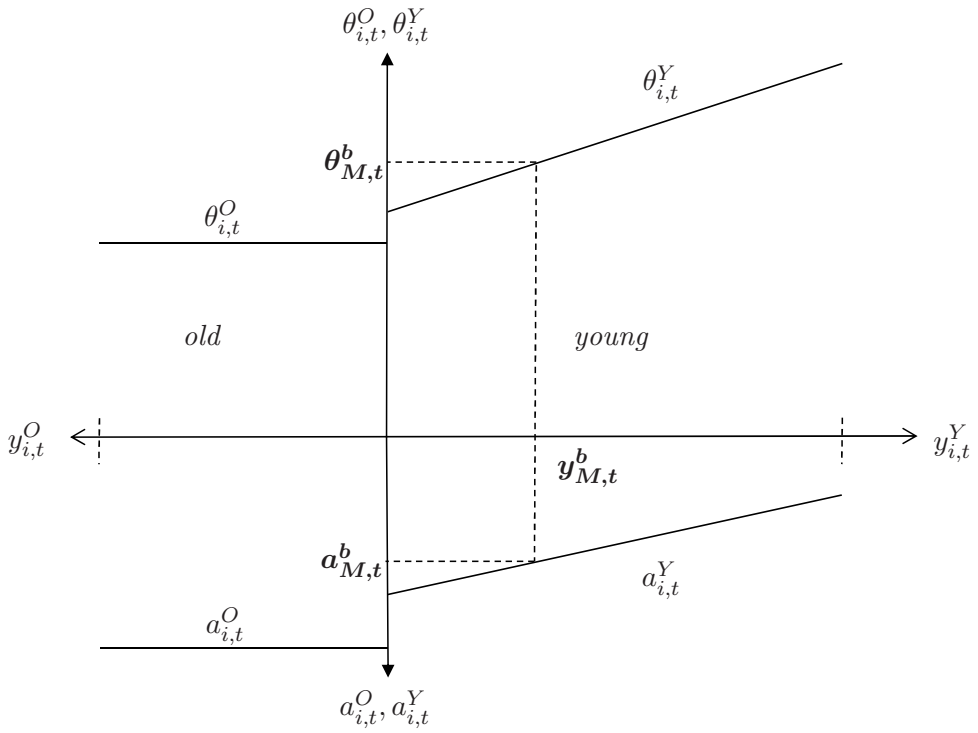

Figure 2: Political equilibrium under distortionary taxation.

a young individual whose income is determined by the following equation:

$$1 + (1+n)F(y^Y_{M,t}) = \frac{2+n}{2} \quad \Leftrightarrow \quad F(y^Y_{M,t}) = \frac{n}{2(1+n)} \ . \tag{35}$$

Her preferred levels of the green tax rate and the adaptation investment under distortionary taxation are denoted $\theta^b_{M,t}$ and $a^b_{M,t}$, respectively.

Note that the income of the median voter lies below the young's median income.

Again, equations (32) and (34) ensure that the reaction functions of the median voter with respect to mitigation and adaptation choices are vertical and horizontal, respectively, which leads us to the following proposition.

Proposition 2 (Existence and uniqueness of SIE under distortionary taxation) *Assuming that the median voter's second-order condition with respect to θ_t holds, there exists a unique SIE, $(\theta^b_{M,t}, a^b_{M,t})$, under distortionary taxation, which is characterized by equations (32) and (34), both evaluated at the median voter's level of income $y^Y_{M,t}$.*

Evaluating the social planner's optimal condition with respect to the green tax rate and adaptation investment, equations (23) and (24), at the median voter's preferred levels, equation

(32) and (34), yields:

$$\left.\frac{\partial W}{\partial \theta_t}\right|_{\theta_t=\theta^b_{M,t}} = D(\theta_t)(1-\varepsilon_{D,\theta})\left[1-\frac{(2+n)y^Y_{M,t}}{(1+n)(1-\eta)\bar{y}_t}\right] - \phi D'(\theta_t)\frac{z_E(n+z_E)(2+n)}{(1-z_E)(1+n)} \ , \tag{36}$$

$$\left.\frac{\partial W}{\partial a_t}\right|_{a_t=a^b_{M,t}} = -1+\frac{(2+n)y^Y_{M,t}}{(1-z_A)(1+\rho(1-\delta_A))(1-\eta)\bar{y}_t} \ . \tag{37}$$

Both equations can be positive or negative. It is straightforward to show that:

$$\theta^b_{M,t} \gtreqless \theta^*_t \quad \Leftrightarrow \quad y^Y_{M,t} \gtreqless \underbrace{\left[1-\frac{z_E}{1-z_E}\frac{\phi D'(\theta_t)(n+z_E)}{(1+n)d(\theta_t)(1-\varepsilon_{D,\theta})}\right]}_{>1}\frac{1+n}{2+n}(1-\eta)\bar{y}_t \ , \tag{38}$$

$$a^b_{M,t} \gtreqless a^*_t \quad \Leftrightarrow \quad y^Y_{M,t} \lesseqgtr \underbrace{(1-z_A)(1+\rho(1-\delta_A))}_{<1}\frac{1+n}{2+n}(1-\eta)\bar{y}_t \ , \tag{39}$$

which implies that even for $\delta_E = \delta_A = 1$, efficiency will not prevail in the political equilibrium. We characterize the efficiency properties of the SIE in the following corollary.

Corollary 2 (Efficiency properties of SIE under distortionary taxation)
In the case of distortionary taxation, the median voter prefers inefficiently high mitigation for sufficiently high income or inefficiently high adaptation for sufficiently low income but not both simultaneously. For intermediate values of income, she may desire both inefficiently low mitigation and *inefficiently low adaptation (as in the case of lump-sum taxation).*

The intuition for why the median voter may prefer inefficiently high mitigation is that, due to the regressive nature of the ecotax, she may benefit more from an increase in the ecotax and – as a quid pro quo – from a lower income tax if she is wealthy enough relative to the voter with average income. In this case, the proportional decrease in the income tax plus the environmental benefit of a higher ecotax exceed the less than proportional increase in ecotax payments. In other words, although the median voter cares less about damages than does the social planner, the fiscal motives arising from the revenue recycling of the ecotax and the associated redistribution are sufficiently strong to induce her to vote for inefficiently high mitigation. By contrast, when the income of the median voter is sufficiently low relative to average income, inefficiently high adaptation is chosen in the political equilibrium because the associated increase in proportional income taxes is outweighed by the gain in environmental quality due to higher adaptation (the latter is the same for all individuals). In Section 6, we will examine whether and when emissions net of adaptation, $E_t - A_t$, are inefficiently high or low in the political equilibrium. In addition, we will analyze whether and when utilitarian welfare under income taxation is higher compared to lump-sum taxation despite the distortions in the tax system.

4.3 Comparison of SIE under the Different Financing Regimes

We can also compare the outcomes of the political process under the different financing regimes. The median voters under the two regimes may differ. However, in the lump-sum taxation case, the median voter under the distortionary tax system prefers the same mitigation and adaptation levels as all agents of her generation. Therefore, we evaluate the first-order condition of the median voter under distortionary taxation, equations (32) and (34), at her preferred levels of mitigation and adaptation under lump-sum taxation, (26) and (28), respectively, (and not vice versa):

$$\left.\frac{\partial V^b_{M,t}}{\partial \theta_t}\right|_{\theta_t=\theta^\tau_{M,t}} = -D(\theta_t)(1-\varepsilon_{D,\theta})\left[\frac{1}{2+n} - \frac{y^Y_{M,t}}{(1+n)(1-\eta)\bar{y}^Y_t}\right] , \tag{40}$$

$$\left.\frac{\partial V^b_{M,t}}{\partial a_t}\right|_{a_t=a^\tau_{M,t}} = \left[\frac{1}{2+n} - \frac{y^Y_{M,t}}{(1+n)(1-\eta)\bar{y}^Y_t}\right] . \tag{41}$$

Clearly, both equations can be positive or negative, but if one is positive, the other is negative, and vice versa. This implies:

$$\theta^\tau_{M,t} \gtreqless \theta^b_{M,t} \quad \Leftrightarrow \quad a^\tau_{M,t} \lesseqgtr a^b_{M,t} \quad \Leftrightarrow \quad y^Y_{M,t} \lesseqgtr \frac{1+n}{2+n}(1-\eta)\bar{y}^Y_t , \tag{42}$$

and leads us to the following corollary.

Corollary 3 (Comparison of SIE)
Distortionary taxation will induce a median voter with an income higher (lower) than $(1+n)(1-\eta)\bar{y}^Y_t/(2+n)$ *to choose higher (lower) mitigation and lower (higher) adaptation relative to the case under the lump-sum tax regime. If his income equals* $(1+n)(1-\eta)\bar{y}^Y_t/(2+n)$*, his marginal incentives to vote are aligned under both regimes.*

The intuition for the knife-edge case of identical choices under both regimes is that any increase in the lump-sum tax due to higher adaptation (respectively, a lower green tax rate), which imposes costs of $1/(2+n)$ on all individuals, is exactly the equal for a median voter with this particular income level as the increase in the distortionary income tax for the same purpose.

5 Comparative Statics

Two key parameters upon which our above results hinge are demography in the form of the population growth rate and the efficiency of the income tax system as measured by the marginal cost of funds. Subsequently, we will analyze the effects of marginal changes in these parameters on the first-best outcome and the political equilibrium.

5.1 Demographic Change

Demography plays an important role in our model. Not only does it directly affect the political outcome by determining the median voter, it also indirectly affects the political equilibrium by changing individuals' preferences. In this section, we analyze the impact of a (permanent) change in n on the levels of mitigation and adaptation chosen by voters and the social planner. We focus on young voters, as the median voter will continue to be part of the young generation as long as $n > 0$.[11] Assuming that the income distribution as a whole remains unaffected by population growth, we can establish the following lemma.

Lemma 5 (Mitigation, adaptation and demographic change)
The following conditions hold for the optimal levels of mitigation and adaptation:

$$\frac{\partial \theta_t^*}{\partial n} = \frac{1-\rho(1-\delta_E)}{(1-z_E)^2}\phi > 0 \ , \qquad \frac{\partial a_t^*}{\partial n} = -\frac{\frac{1-\rho(1-\delta_A)}{(1-z_A)^2}\phi v'(a_t^*)}{SOC_{a^*}} > 0 \ , \tag{43}$$

$$\frac{\partial \theta_{i,t}^{Y,\tau}}{\partial n} = \frac{\phi d'(\theta)(1+\rho(1-\delta_E))}{SOC_{\theta^\tau}^Y} > 0 \ , \qquad \frac{\partial a_{i,t}^{Y,\tau}}{\partial n} = \frac{\frac{\partial^2 \tau_t}{\partial a_t \partial n}}{SOC_{a^\tau}^Y} > 0 \ , \tag{44}$$

$$\frac{\partial \theta_{i,t}^{Y,b}}{\partial n} = \frac{\phi d'(\theta)(1+\rho(1-\delta_E)) + \frac{\partial^2 b_t}{\partial \theta_t \partial n} y_{i,t}^Y}{SOC_{\theta^b}^Y} \gtreqless 0 \ , \qquad \frac{\partial a_{i,t}^{Y,b}}{\partial n} = \frac{\frac{\partial^2 b_t}{\partial a_t \partial n} y_{i,t}^Y}{SOC_{a^b}^Y} > 0 \ , \tag{45}$$

where $\partial^2 \tau_t/(\partial a_t \partial n) = -1/(2+n)^2 < 0$, $\partial^2 b_t/(\partial \theta_t \partial n) = \big(d(\theta_t)+\theta_t d'(\theta_t)\big)/\big((1+n)^2(1-\eta)\bar{y}_t^Y\big) > 0$ and $\partial^2 b_t/(\partial a_t \partial n) = -1/\big((1+n)^2(1-\eta)\bar{y}_t^Y\big) < 0$.

Obviously, a lower population growth rate decreases the socially optimal ecotax and adaptation investments because less of the environmental damage needs to be internalized. A similar reasoning applies to the young's desired levels of adaptation and mitigation. Under lump-sum taxation, they choose a lower ecotax and lower adaptation investments with a lower n because otherwise the same environmental damage would affect fewer individuals. This also holds in the political equilibrium. Graphically, the horizontal lines in Figure 1 indicating the voters' optimal choices would, in parallel, shift downward for the green tax rate and upward for the level of adaptation (for both generations). If, by contrast, distortionary taxes are in place, a second effect appears that makes the young's and thus the median voter's reaction to a decrease in n with respect to the ecotax ambiguous. To observe the intuition underlying this effect, note that $\partial^2 b_t/\partial \theta_t \partial n > 0$, that is, a lower n (higher b_t) makes ecotax increases more effective in reducing distortionary taxes and thus increases the attractiveness of the ecotax rate for any given income of a young individual. Depending on the relative strength of the two effects at work, the young's preferred level of mitigation may rise or fall. The effects are illustrated in Figure 3.

[11] The comparative statics with respect to the choices of old voters can be found in Appendix A.2.

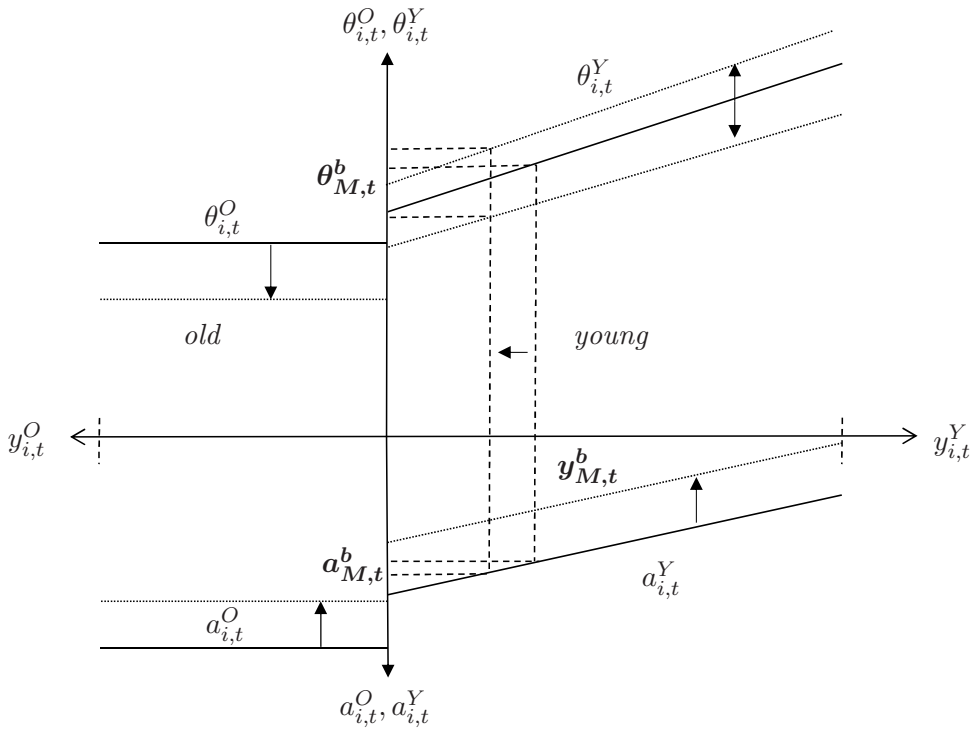

Figure 3: Effects of lower population growth under distortionary taxation.

Additionally, a decrease in the population growth rate increases the share of the old. While this has no bearing in the case of lump-sum taxes, it does have an effect in the presence of distortionary taxes; namely, the median voter shifts to a young agent of lower income. This effect (indicated by the horizontal arrow in Figure 3) mitigates the positive effect described above because lower income individuals prefer lower ecotax rates. While the mitigation level in the political equilibrium may rise or fall, the adaptation investment unambiguously falls. Furthermore, in the first-best and under lump-sum taxation, lower ecotaxes and adaptation investment imply that environmental damage caused by $E_t - A_t$ increases, while this is not as clear in the case of distortionary taxation.

5.2 The Deadweight Loss of Taxation

If the economy becomes more efficient, i.e., the marginal costs of funds marginally fall, we naturally observe effects only in the case of distortionary taxation. The social optimum and the political equilibrium under lump-sum taxation remain unaffected. Furthermore, as the old are not contributing to the distortionary tax system, their choices also remain the same. In particular, we have:

Lemma 6 (Mitigation, adaptation and changes in η)

The following conditions hold for the equilibrium levels of mitigation and adaptation:

$$\frac{\partial \theta^b_{M,t}}{\partial \eta} = -\frac{\frac{D(\theta_t)(1-\varepsilon_{D,\theta})}{(1+n)(1-\eta)^2\bar{y}^Y_t} y^Y_{M,t}}{SOC^Y_{\theta^b}} > 0 \ , \qquad \frac{\partial a^b_{M,t}}{\partial \eta} = \frac{\frac{1}{(1+n)(1-\eta)^2\bar{y}^Y_t} y^Y_{M,t}}{SOC^Y_{a^b}} < 0 \ . \tag{46}$$

A decline in η will reduce the mitigation and increase the adaptation chosen by young voters and thus by the median voter. The intuition is that a decrease in η makes the recycling of ecotax revenue in the form of lower income taxes less attractive for young voters of any income because any given income tax now entails less distortion. For the same reason, it becomes – for any income level – more attractive to finance adaptation investments. A lower deadweight loss of taxation is thus favorable to adaptation investment at the cost of a lower green tax rate in the political equilibrium. Whether emissions net of adaptation, $E_t - A_t$, rise or fall depends on the specific parameter constellation.

6 Numerical Illustration and Welfare Analysis

In this section, we illustrate our results numerically by calibrating the model to the German economy of the year 2010 (for reasons of data availability), i.e., for the year 2010, $t = 1$. This exercise allows us to draw some tentative conclusions on whether mitigation and adaptation levels can be expected to be inefficiently high or low in reality and whether they are higher or lower under a distortionary tax system relative to one without any fiscal distortions. Furthermore, we compare welfare levels under the different tax regimes and the social optimum. In this sense, the following analysis can be understood as an initial stage in which a constitutional planner (as in Cremer *et al.*, 2000) chooses the regime that maximizes overall welfare, given that mitigation and adaptation levels are determined by majority voting.

Individual data on the distribution of taxable labor income (on an annual basis) were obtained from the Federal Statistical Office in Germany. Data on population size were taken from the OECD population statistics database. To compute n, we divide the number of retired individuals above the age of 65 (16 873 018 people) by the number of working individuals between the ages of 20 and 64 (49 693 261 people). The pensioner/contributor ratio $1/(1+n)$ is 0.34, and thus, n equals 1.95. One period in our model corresponds to 45 years. By equation (36), we have $F(y^Y_{M,1}) = 0.33$, which yields $y^Y_{M,1}$=11 570€.[12] Average income levels for the young and

[12]Our income data contain the income of only those individuals who submitted an annual tax declaration. This ignores approximately 7 mio. individuals. We assign these missing income data in such a way that the relative shares within each income interval remain constant. We also conduct a sensitivity analysis and assign the missing income data to only the lower half of the income distribution because the low income agents are less likely to gain from submitting their tax declaration. Our results are qualitatively robust to this change.

old are $\bar{y}_1^O$=14 000€ and $\bar{y}_1^Y$=22 700€.[13]

We assume a logarithmic utility function (for which all second-order conditions outlined in the Appendix hold) and a logarithmic adaptation production function:[14]

$$u\big(d(\theta_t)\big) = x + \omega \ln\big(d(\theta_t)\big)\ , \quad v(a_t) = \gamma \ln(a_t). \tag{47}$$

The parameter values δ_E, δ_A, ρ and η are based on estimates in the literature. It is a challenge to combine estimates for the uptake of anthropogenic CO_2 by biological and abiological sinks into a single parameter.[15] The IPCC (2007) states in the "Executive Summary" of Chapter 7: "About half of a CO_2 pulse to the atmosphere is removed over a timescale of 30 years; a further 30% is removed within a few centuries; and the remaining 20% will typically stay in the atmosphere for many thousands of years." As one period in our model corresponds to 45 years, we take the IPCC's estimate as a lower bound. For public adaptation, we take implicit scrapping rates for net government capital stocks in the US as a reference point. Those have been estimated at approximately 4% per year (Kamps, 2006), which implies a δ_A of 0.84. This is close to what Agrawala et al. (2011) and Felgenhauer and Webster (2013) use in their studies (5% depreciation per year). We are restricted by the condition $\rho(1+n) < 1$, that is, $\rho < 0.34$ for the n we employ. Using a discount rate of 3% per year as in Nordhaus and Boyer (2000), we find $\rho = 0.264 < 0.33$.[16] Kleven and Kreiner (2003, 2006) estimate the marginal costs of public funds for Germany and report a lower bound of 1.55 for a proportional tax reform. For our modeling framework, this implies an η of 0.37 (see fn. 7). As the distortionary tax system is at the heart of this analysis, we perform some sensitivity analyses by varying η from 0.17 to 0.57.

We calibrate the remaining parameters such that the model produces

1. an increase in the stock of emissions E_t in the first period ($t = 1$) relative to the initial stock, *i.e.*, E_1/E_0, which is equivalent to the observed increase over the last 45 years. According to measurements of annual mean CO_2 concentrations at Mauna Loa, the concentration rose from 318.50 ppm (parts per million) in 1962 to 383.79 ppm in 2007, *i.e.*, by 20.50%

[13] Because these data are computed on an annual basis, we have to multiply each income level by 45 to account for our two-generations framework.

[14] The parameter $x > 0$ is set such that the welfare of future generations does not immediately become negative when d falls toward zero (this is because θ has to rise due to population growth. Otherwise, environmental damage would rise excessively). For convenience, we set $x = R_t = 10\ 000$, both of which we assume to be time-invariant.

[15] Long-term biological sinks for greenhouse gases are dissolution in the oceans and chemical neutralization by reaction with carbonates and basic igneous rocks. The uptake capacity is reservoir-specific and depends on the state of the system, *i.e.*, on the initial level and the additional flux of greenhouse gases released into the atmosphere; see Archer et al. (1997).

[16] Nordhaus (2007) argues that information on intertemporal preferences can be inferred from observations of investment decisions on capital markets and, therefore, that a positive discount rate can be employed. Note that in our model, the discount rate is equal to the rate of pure time preference because the growth rate of per capita GDP is equal to zero.

	Social Optimum	Lump-sum taxes	Distortionary taxes $\eta = 0.17$	$\eta = 0.27$	$\eta = 0.37$	$\eta = 0.47$	$\eta = 0.57$
θ_1	97.04	67.07	66.89	67.01	67.15	67.36	67.66
a_1	3 384	3 088	1 273	1 120	966	812	659
E_1	2 483	3 026	3 030	3 027	3 024	3 018	3 011
A_1	406	402	357	351	344	335	325
$E_1 - A_1$	2 077	2 624	2 673	2 676	2 680	2 683	2 686
b_1	-	-	0.13	0.15	0.17	0.21	0.26
τ_1	84 493	84 555	-	-	-	-	-
V_1^Y $(\times 10^4)$	526.80	527.56	518.79	513.29	506.05	496.09	481.52
V_1^O $(\times 10^4)$	110.95	111.24	119.63	119.62	119.61	119.59	119.58
W $(\times 10^5)$	230.30	229.88	226.76	224.28	221.03	216.54	209.98

Table 1: Social optimum and political equilibria under the different regimes for the year 2010.

(see IPCC, 2015);

2. a politically determined tax rate that approximately equals the actual German ecotax rate on gasoline (65€ per tonne of CO_2), i.e., $\phi = 15$;

3. a tax rate b that is in a plausible range for Germany (the all-in average personal income tax rates at the average wage vary between 21 and 39% for different family types in Germany according to the OECD, 2015);[17]

4. the *annual* (not per period) consumption of the polluting good is equivalent to the annual CO_2 emissions per capita in Germany: approximately 10 tonnes in 2010 according to PBL Netherlands Environmental Assessment Agency and the Institute for Environment and Sustainability of the European Commissions Joint Research Centre (2014);

5. a reduction of damages through the use of adaptation of approximately 10%. This implies a γ of 50.

For the calculation of all future generations' welfare, we need to take into account that the future levels of mitigation and adaptation change over time under all regimes and in the social optimum due to population growth. For details, the reader is referred to the Appendix.

Table 1 presents our simulation results. The political equilibrium under both financing regimes yields mitigation and adaptation levels that are lower than their socially optimal levels. This necessarily entails lower welfare in the political equilibrium. However, the relative strength of mitigation and adaptation differs between the two modes of financing. While the equilibrium

[17]Note that ecotax revenue in Germany is recycled through cuts in pension contribution rates; see Habla and Roeder (2013) for further details. For our analysis, it does not make any difference whether the ecotax revenue is used to reduce income tax or social security contribution rates except that the income tax scheme is progressive in Germany whereas the social security scheme is proportional/ linear.

	Social Optimum	Lump-sum taxes	Distortionary taxes $\eta = 0.17$	$\eta = 0.27$	$\eta = 0.37$	$\eta = 0.47$	$\eta = 0.57$
θ_1	48.90	43.81	43.47	43.56	43.68	43.84	44.09
a_1	2 073	2 017	1 925	1 693	1 461	1 229	997
E_1	2 832	3 012	3 025	3 022	3 017	3 010	3 001
A_1	382	380	378	372	364	336	345
$E_1 - A_1$	2 450	2 631	2 647	2 650	2 653	2 655	2 656
b_1	-	-	0.28	0.32	0.37	0.44	0.54
τ_1	145 240	145 280	-	-	-	-	-
V_1^Y $(\times 10^4)$	273.69	273.74	257.59	251.42	243.29	232.09	215.70
V_1^O $(\times 10^4)$	106.38	106.44	120.96	120.95	120.94	120.93	120.91
W $(\times 10^5)$	57.234	57.226	55.91	54.85	53.46	51.54	48.73

Table 2: Social optimum and political equilibria under the different regimes for the year 2055.

ecotax is lower under distortionary taxation for a low η (and slightly higher for a higher η), adaptation investment in this regime falls short of the equilibrium investment under lump-sum taxation. In line with Lemma 6, the ecotax rate rises and adaptation investments fall with a higher η. When the marginal costs of public funds increase, mitigation investments become slightly higher while adaptation investments become lower than under the lump-sum tax regime; see equation (43). Nevertheless, even higher mitigation levels under the distortionary tax regime are not sufficient to provoke lower environmental damages because of significantly lower adaptation investments. The additional distortions of the income tax scheme also weigh on aggregate welfare. While the young would always be better off under a lump-sum tax regime *on average*, the reverse holds for the old generation. This is simply because all individuals contribute under lump-sum taxation, which decreases the young's and increases the old's financial burden. Aggregate welfare is only slightly lower under lump-sum taxation relative to that under the social optimum but significantly lower under all distortionary tax regimes.

To illustrate numerically the role of demographic change in our model, we assume that n decreases (permanently) from 1.95 to 0.58 as projected by the OECD for the year 2055. As we cannot reasonably speculate about technologies and income distributions in 2055, we hold all else constant at 2010 levels. The first effect of this change in n is that the median voter's income is now determined by $F(y^Y_{M,1}) = 0.18$, which yields $y^Y_{M,1}$=7 650 €. Table 2 shows that – compared to before – mitigation levels decrease in the social optimum and under the two financing regimes. For adaptation investments, however, a different picture emerges. Those are now lower in the social optimum and under a lump-sum tax regime compared to the higher n from before but higher than before under distortionary taxation. The reason is that the median voter effect now dominates: although the preferred adaptation investments of the young decline with demographic change (see equation 44), the median voter's preferences move closer to those

of old agents, who prefer higher adaptation. Ultimately, mitigation and adaptation levels do not differ as much as they did previously. Quantitatively, our main results do not change. The lump-sum tax scheme still outperforms the distortionary tax scheme both with respect to emissions net of adaptation and total welfare. Again, the loss in utilitarian welfare would be largely underestimated in the lump-sum tax regime.

7 Discussion

We have made some simplifying assumptions that merit further discussion regarding the robustness of our results.

7.1 Damage Function

To obtain analytical solutions, we restricted environmental damages to be linear (as in Habla and Roeder, 2013). This helps us to focus on the single-country case and avoids complications regarding expectations of future tax rates that necessarily depend on the stock of emissions and adaptation capital. In the case of convex damages, we would have had to derive Markov-perfect equilibria of this voting game, which is a nearly impossible task, given the complexity of the model in other respects. Convex damages and the associated positive cross-partial derivative of the damage function with respect to mitigation and adaptation would make the two options strategic substitutes. Increased mitigation would automatically imply lower adaptation, and vice versa. We argue that this would only weaken our obtained results quantitatively, not qualitatively.

7.2 Public Budgets

We have assumed that lump-sum taxes are borne by all generations – the young and the old. This is an asymmetry relative to the distortionary tax regime, under which only the young contribute to the financing of the public budget. However, even if the young were to carry the burden of a lump-sum tax alone, this would not change our results qualitatively. The old would prefer an even lower ecotax compared to the young because they would not benefit from revenue recycling through a lower lump-sum tax (see equation 25), but they would vote for a level of adaptation that is as high as possible (equation 27). By contrast, a higher ecotax would become more attractive for the young generation due to revenue recycling (equation 26). Investment in adaptation (equation 28), however, would become more expensive for the young generation. Overall, the gap between the two generations' preferred levels of mitigation and adaptation would widen, but the median voter would still be an individual of the young generation. Compared to the distortionary tax regime, mitigation (adaptation) chosen in the political equilibrium with

lump-sum taxation could still be higher (lower), and this becomes more likely (see equation 43 where $2+n$ would have to be replaced by $1+n$).

7.3 Delayed Effects of Mitigation

We assumed that mitigation and adaptation in period t reduce environmental damage in the same period. However, it could well be that mitigation efforts in period t take effect one period later whereas adaptation reduces the more immediate damages of climate change. Delayed mitigation effects affect our results quantitatively but not qualitatively. In this case, mitigation becomes less valuable for both the old and the young generation, which is why the two generations (and thus the median voter) vote for a lower ecotax rate. However, the trade-off concerning the costs and benefits of adaptation remains unchanged. In sum, we obtain a political equilibrium characterized by the same level of adaptation investment but a lower level of mitigation in each period.

7.4 Preferences

An advantage of modeling agents' preferences with a quasi-linear utility function is that in the case of lump-sum taxation, heterogeneity among agents is limited to their different time horizons. We are thus able to contrast our results under distortionary taxation, in which case the income distribution plays a role, with the standard results in environmental economics where only an environmental externality is present. Additionally, with quasi-linear preferences, we are able to capture in the most elegant way the fact that environmental taxation is usually regressive. Yet, one may argue that the absolute amount of energy expenditures increases with income (albeit less than proportionally). Such an income effect could be captured by the Gorman-polar specification as employed in Habla and Roeder (2013). When higher income voters consume more of the energy-related good than do low-income voters (but at a rate that is less than proportional to the difference in income), this reduces (increases) the incentives of the former (latter) to vote for higher ecotaxes. Given that the median voter consumes less of the dirty good compared to the individual with average consumption, income effects thus mean that an inefficiently high ecotax, independent of the financing regime, is more likely because the socially optimal tax rate is oriented at average consumption. Adaptation investment would remain unaffected by the introduction of income effects in the social optimum and under all other regimes.

One may also argue that generations are dynastically linked due to intergenerational altruism. Then, the old generation in period t would additionally derive utility from their future generations' utility levels. Assuming that the income type is passed on to the next generation, both the young and old would vote for higher mitigation and adaptation levels because they

take into consideration the beneficial effects on future generations. Nevertheless, if altruism is only one-sided, the young do not internalize the impact of their dirty good consumption on their parents' utility and on other parents' offspring. In other words, the political equilibrium is still different from the social optimum, but compared to no altruism, mitigation and adaptation are closer to their socially optimal levels.

8 Conclusion

This paper has studied the political economy of mitigation and adaptation investments within an OLG model. The two climate policy options have different impacts on public budgets; while mitigation raises revenue, adaptation requires public funds. The mode whereby the government finances its expenditures and thus recycles ecotax revenues has been shown to be crucial in determining the political support for mitigation and adaptation investments. When public expenditures are financed via lump-sum taxes, individuals of each generation are, independent of their income level, equally affected by climate policies. The only difference arises from the different benefits of these policies due to an individual's age. If, by contrast, distortionary taxes are in place, then higher income individuals profit relatively more from the increased revenue from mitigation policies, while these voters simultaneously incur relatively higher costs for adaptation investments. We have shown that if the decisive voter possesses relatively high income, then a distortionary tax scheme entails higher mitigation and lower adaptation investments compared to a lump-sum tax scheme (and possibly also compared to their socially optimal levels). When we observe that countries prefer high levels of mitigation, as in Germany, this may well have to do with the financing regime and the implied redistribution effects of environmental taxation.

We calibrated our model to the German economy. Our results provide an initial indication of how the two modes of financing impact environmental quality and social welfare. While under a distortionary tax scheme, mitigation may be higher for reasonable levels of distortions, we find that financing via lump-sum taxation yields lower environmental damages and higher overall welfare. The reason is that adaptation may fall significantly short of its optimal level in the political equilibrium. In other words, analyses that implicitly or explicitly assume that a lump-sum tax system is in place may underestimate environmental damages and the loss in utilitarian welfare.

Appendix

A.1 Single-peakedness

Note that for the derivations below, the first-order conditions are occasionally plugged into the second-order conditions. For the social optimum, the second-order conditions read:

$$\text{SOC}_{a^*} \equiv \frac{\partial^2 W}{\partial a_t^2} = \phi v''(a_t)\frac{2+n}{1-z_A} < 0 \ , \tag{A.1}$$

$$\text{SOC}_{\theta^*} \equiv \frac{\partial^2 W}{\partial \theta_t^2} = D'(\theta_t) < 0 \ . \tag{A.2}$$

The second-order conditions for the different generations under lump-sum taxation are given by:

$$\text{SOC}^O_{a_\tau} \equiv \frac{\partial^2 V^O_{i,t}}{\partial a_t^2} = \phi v''(a_t) < 0 \ , \tag{A.3}$$

$$\text{SOC}^Y_{a_\tau} \equiv \frac{\partial^2 V^Y_{i,t}}{\partial a_t^2} = \phi v''(a_t)[1+\rho(1-\delta_A)] < 0 \ , \tag{A.4}$$

$$\text{SOC}^O_{\theta_\tau} \equiv \frac{\partial^2 V^O_{i,t}}{\partial \theta_t^2} = d'(\theta_t) < 0 \ , \tag{A.5}$$

$$\text{SOC}^Y_{\theta_\tau} \equiv \frac{\partial^2 V^Y_{i,t}}{\partial \theta_t^2} = d'(\theta_t) < 0 \ . \tag{A.6}$$

For the regime with distortionary taxation, the second-order conditions can be written as:

$$\text{SOC}^O_{a_b} \equiv \frac{\partial^2 V^O_{i,t}}{\partial a_t^2} = \phi v''(a_t) < 0 \ , \tag{A.7}$$

$$\text{SOC}^Y_{a_b} \equiv \frac{\partial^2 V^Y_{i,t}}{\partial a_t^2} = \phi v''(a_t)[1+\rho(1-\delta_A)] < 0 \ , \tag{A.8}$$

$$\text{SOC}^O_{\theta_b} \equiv \frac{\partial^2 V^O_{i,t}}{\partial \theta_t^2} = d'(\theta_t)\left[-d(\theta_t)\frac{u'''}{u''} - 1\right] < 0 \quad \text{iff the relative prudence} - \frac{d(\theta_t)u'''}{u''} > 1 \ , \tag{A.9}$$

$$\begin{aligned}\text{SOC}^Y_{\theta_b} \equiv \frac{\partial^2 V^Y_{i,t}}{\partial \theta_t^2} &= d'(\theta_t)\left[2\frac{y^Y_{i,t}}{\tilde{y}_t} - 1\right] + d''(\theta_t)\left[\theta_t\frac{y^Y_{i,t}}{\tilde{y}_t} - (2+n)\phi[1+\rho(1-\delta_E)]\right] \\ &= \underbrace{d'(\theta_t)\frac{y^Y_{i,t}}{\tilde{y}_t}}_{<0} + \left[\frac{y^Y_{i,t}}{\tilde{y}_t} - 1\right]\underbrace{\left[d'(\theta_t) - d''(\theta_t)\frac{d(\theta_t)}{d'(\theta_t)}\right]}_{>0 \quad \text{iff} \quad -\frac{d(\theta_t)u'''}{u''}>1} \ ,\end{aligned} \tag{A.10}$$

where we exploited – for the last two equations – the fact that $d'(\theta_t) = 1/u'' < 0$ and $d''(\theta_t) = -u'''/(u'')^3$. Furthermore, $\tilde{y}_t \equiv (1+n)(1-\eta)\bar{y}^Y_t/(2+n)$.

$u''' > -u''/d(\theta_t)$ is a necessary *and* sufficient condition for equation (A.9) to be negative. How-

ever, it is *not* sufficient for equation (A.10) to be negative. Therefore, we assume that the latter equation is negative for all income levels.

A.2 Comparative statics

For the levels of mitigation and adaptation desired by the old, the following holds:

$$\frac{\partial \theta_{i,t}^{O,\tau}}{\partial n} = \frac{\phi d'(\theta)}{\mathrm{SOC}_{\theta^\tau}^{O}} > 0 \ , \qquad \frac{\partial a_{i,t}^{O,\tau}}{\partial n} = -\frac{\frac{1}{(2+n)^2}}{\mathrm{SOC}_{a^\tau}^{O}} > 0 \ , \tag{A.11}$$

$$\frac{\partial \theta_{i,t}^{O,b}}{\partial n} = \frac{\phi d'(\theta)}{\mathrm{SOC}_{\theta^b}^{O}} > 0 \ , \qquad \frac{\partial a_{i,t}^{O,b}}{\partial n} = 0 \ . \tag{A.12}$$

A.3 Numerical illustration: Time-varying levels of mitigation and adaptation

To calculate the welfare of all future generations, we first need to derive the future levels of mitigation and adaptation under all regimes and in the social optimum. It holds true that in any given period t, mitigation and adaptation levels are determined as described above, as the proportion of old and young individuals remains constant over time, assuming that the income distribution also remains the same. However, this does not imply that the politically determined levels of mitigation and adaptation and the socially optimal ones are not time-invariant. The reason is that from an individual voter's and from the social planner's perspective, the marginal benefits (and possibly costs) of mitigation (and adaptation) change over time due to population growth. In the simplest case, let us assume that public expenditure needs to be scaled up proportionally to population. That is, equations (11) and (17) for period $t+1$ change relative to period t in the following way (changes are in bold):

$$\boldsymbol{(1+n)}\theta_{t+1} D(\theta_{t+1}) + \boldsymbol{(1+n)}(2+n)\tau_{t+1} = \boldsymbol{(1+n)} R_{t+1} + a_{t+1} \ , \tag{A.13}$$

$$\boldsymbol{(1+n)}\theta_{t+1} D(\theta_{t+1}) + (1+n)^{\boldsymbol{2}}(1-\eta) b_{t+1} \int_{y^-}^{y^+} y_{i,t+1}^{Y} dF(y_{t+1}^{Y}) = \boldsymbol{(1+n)} R_{t+1} + a_{t+1} \ . \tag{A.14}$$

Consequently, equations (13) and (19) also change as follows (while (12) and (18) remain unchanged):

$$\frac{\partial \tau_{t+1}(\theta_{t+1}, a_{t+1})}{\partial a_{t+1}} = \frac{1}{\boldsymbol{(1+n)}(2+n)} > 0 \ , \tag{A.15}$$

$$\frac{\partial b_{t+1}(\theta_{t+1}, a_{t+1})}{\partial a_{t+1}} = \frac{1}{(1+n)^{\boldsymbol{2}}(1-\eta)\bar{y}_{t+1}^{Y}} > 0 \ . \tag{A.16}$$

The first-order conditions (FOCs) in the social optimum at time $t+1$ thus read as follows:

$$-D(\theta_{t+1}) - (2+n)\frac{\partial \tau_{t+1}}{\partial \theta_{t+1}} - \frac{\boldsymbol{(1+n)}(2+n)}{1-z_E}\phi D'(\theta_{t+1}) = 0 \quad \Leftrightarrow \quad \theta^{\star}_{t+1} = \frac{\boldsymbol{(1+n)}(2+n)}{1-z_E}\phi \ , \tag{A.17}$$

$$-(2+n)\frac{\boldsymbol{\partial \tau_{t+1}}}{\boldsymbol{\partial a_{t+1}}} + \frac{2+n}{1-z_A}\phi v'(a_{t+1}) = 0 \quad \Leftrightarrow \quad \frac{2+n}{1-z_A}\phi v'(a^{\star}_{t+1}) = \frac{1}{\boldsymbol{1+n}} \ . \tag{A.18}$$

The social planner chooses a higher tax rate in period $t+1$ because the marginal environmental benefits of a tax increase have grown (a tax increase now decreases individual consumption of all $(1+n)(2+n)$ individuals); the efficient level of adaptation investment has also increased relative to period t because the marginal costs of providing this public good are shared among more individuals.

The FOCs of an old and young individual at time $t+1$ under lump-sum taxation are:

$$\frac{\partial V^{O}_{i,t+1}}{\partial \theta_{t+1}} = -d(\theta_{t+1}) - \frac{\partial \tau_{t+1}}{\partial \theta_{t+1}} - \boldsymbol{(1+n)}\phi D'(\theta_{t+1}) = 0 \ , \tag{A.19}$$

$$\frac{\partial V^{Y}_{i,t+1}}{\partial \theta_{t+1}} = -d(\theta_{t+1}) - \frac{\partial \tau_{t+1}}{\partial \theta_{t+1}} - \boldsymbol{(1+n)}\phi D'(\theta_{t+1})[1+\rho(1-\delta_E)] = 0 \ , \tag{A.20}$$

$$\frac{\partial V^{O}_{i,t+1}}{\partial a_{t+1}} = -\frac{\boldsymbol{\partial \tau_{t+1}}}{\boldsymbol{\partial a_{t+1}}} + \phi v'(a_{t+1}) = 0 \ , \tag{A.21}$$

$$\frac{\partial V^{Y}_{i,t+1}}{\partial a_{t+1}} = -\frac{\boldsymbol{\partial \tau_{t+1}}}{\boldsymbol{\partial a_{t+1}}} + \phi v'(a_{t+1})[1+\rho(1-\delta_A)] = 0 \ . \tag{A.22}$$

Similarly, the respective FOCs under distortionary taxation read:

$$\frac{\partial V^{O}_{i,t+1}}{\partial \theta_{t+1}} = -d(\theta_{t+1}) - \boldsymbol{(1+n)}\phi D'(\theta_{t+1}) = 0 \ , \tag{A.23}$$

$$\frac{\partial V^{Y}_{i,t+1}}{\partial \theta_{t+1}} = -d(\theta_{t+1}) - \boldsymbol{(1+n)}\phi D'(\theta_{t+1})[1+\rho(1-\delta_E)] - \frac{\partial b_{t+1}}{\partial \theta_{t+1}} y^{Y}_{i,t+1} = 0 \ , \tag{A.24}$$

$$\frac{\partial V^{O}_{i,t+1}}{\partial a_{t+1}} = \phi v'(a_{t+1}) > 0 \ , \tag{A.25}$$

$$\frac{\partial V^{Y}_{i,t+1}}{\partial a_{t+1}} = \phi v'(a_{t+1})[1+\rho(1-\delta_A)] - \frac{\boldsymbol{\partial b_{t+1}}}{\boldsymbol{\partial a_{t+1}}} y^{Y}_{i,t+1} = 0 \ . \tag{A.26}$$

As in the social optimum, the green tax rates desired by individual voters increase over time for the same reason as above. The same holds for the individuals' adaptation choices (except for those of old individuals under the distortionary tax regime because they do not share the costs of financing adaptation at all). In period $t+2$, the terms $1+n$ in the above equations are replaced by $(1+n)^2$, in period $t+3$ by $(1+n)^3$, and so forth.

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