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Abstract

We study the interaction of climate policies and investments into fossil and renewable energy generation capacity if policies are set by democratically elected governments and can lead to stranded assets. We develop an overlapping generations model, where elections determine carbon taxation and green investment subsidies, and individuals make investments into fossil and renewable capacity. We find that some fossil investments become stranded assets, if the party offering the higher carbon tax is unexpectedly elected. In contrast, if the individuals have perfect foresight, there are no stranded assets, climate damages are fixed and carbon taxation only serves redistributive purposes. Then, there is either no or prohibitive carbon taxation and energy generation completely relies on renewables in the latter case. Green investment subsidies can be used by governments to bind the hands of their successor. If the party representing the young generation is in power, it can use a high subsidy to reduce or even avoid potentially stranded assets in the next period. With endogenous reelection probability, we show that this party can also use investment subsidies strategically to influence the elections. The party that represents the old generation abstains from both types of climate policies to avoid a redistribution of income towards the young generation.

Keywords: Stranded Assests, Political Economy, Fossil Fuel, Renewable Energy, Carbon Tax, Investment Subsidy

JEL classification: D72, H23, Q54, Q58

1. Introduction

In order to avoid dangerous anthropogenic climate change, drastic mitigation policies are necessary to curb greenhouse gas emissions. Concerning fossil reserves, McGlade and Ekins (2015) estimate that about one third of global oil, one half of global gas and 80% of coal reserves must be left unburned to limit global warming to 2°C. Semieniuk et al. (2022) calculate that plausible policies lead to stranded assets in the upstream oil and gas sector worth over $1 trillion and Edwards et al. (2022) find that fossil power plants worth up to $1.4 trillion might become stranded. In some countries, such as India, potentially stranded assets are highly concentrated in the hands of few owners (von Dulong, 2023). Investors already acknowledge the risk of asset stranding (Sen and von Schickfus, 2020; Bolton and Kacperczyk, 2021) and the macrofinancial transition risks of destabilizing the economic and financial system have to be considered (Van der Ploeg and Rezai, 2020a; Campiglio and van der Ploeg, 2022). However, we still see significant investments into the fossil energy sector (IEA, 2023c). This raises the question how such fossil investments influence the implementation of climate policies if governments act in the interest of their voters, who might have undertaken such investments.

In this paper, we study the interaction of investments in fossil energy production and climate policies that are endogenously chosen by elected governments that, instead of maximizing social welfare, cater climate policies to their party's voters. In a model of overlapping generations, we account for the fact that investments in one period will generate returns in the next period, i.e. that fossil asset stranding today will hurt individuals that invested in these assets before. We show how uncertainty about election results can lead to stranded assets under rational expectations. Further, we show that, under uncertain election outcomes, it is nevertheless optimal for individuals to invest in fossil assets. Our results also highlight that governments can use green investment subsidies to bind the hands of their successors and avoid stranded assets.

Economists have only started to investigate the political implications of asset stranding (von Dulong et al., 2023) and most existing papers take climate policy uncertainty as exogenous (van der Ploeg and Rezai, 2020b; Diluiso et al., 2021; Bretschger and Soretz, 2022). A notable exemption that is closely related to our paper is Kalkuhl et al. (2020), who obtain quite extreme results. They consider a model where policy makers cannot commit to announced carbon taxes and choose to deviate after investments have been made due to lobbying power or fiscal considerations. As a result, time-consistent policies imply either zero or prohibitively high carbon taxes, with the latter leading to zero fossil investments.

We analyze an overlapping generations model with both endogenous climate policy choice and endogenous investment decisions. Investments can be used to either build up fossil fuel based (black) energy generation capacity or renewables based (green) capacity. The investments into both capacities depend on the expectation with respect to future carbon taxes and current green investment subsidies. If individuals have perfect foresight, our results are in line with Kalkuhl et al. (2020), i.e. the carbon tax is either zero or prohibitive, with black investments being zero in the latter case. In case of uncertain election outcomes, both green and black investments depend on the expected carbon tax rate and the current green investment subsidy. If individuals expect one party to win with a high probability and their expectations are met, there are no stranded assets. In contrast, if individuals expect the party offering the lower tax rate to win, their expectations aren't met and the green investment subsidy is low, some black investments become stranded assets.

The green investment subsidy may be used by the government to bind the hands of its successor. If the party representing the young generation holds office (Y-government) and its reelection probability is small, it can use a high subsidy rate to ensure that the succeeding government will not implement a high carbon tax in the next period, so that no black capacity gets stranded. With endogenous election probability, the party will also use the subsidy to manipulate the election probability in its favor. Our result suggests that a Y-government will reduce the subsidy rate to boost black capacity investments. Consequently, the individuals of its generation will have to bear higher losses if the elections are lost, which gives them an incentive to vote for their party. In contrast, the party representing the old generation abstains from climate policies to avoid a redistribution of income in favor of the young generation.

We structure the remainder of the paper as follows: in Section 2 we introduce the model. We solve for the energy market equilibrium and the preferred tax rates of the parties in Sections 3 and 4. Investment decisions are analyzed in Section 5 and Section 6 turns to the government's decision with respect to the subsidy rate. Section 7 concludes.

2. Model

2.1. Basic assumptions

We consider an overlapping generations model in discrete time, so that at every point in time t two generations, an old one and a young one, are alive. Both generations consist of atomistic individuals and the generations' size is normalized to unity. While the lifespan of the old generation ends in period t, young individuals live until the end of the following period $t+1$. The utility function of individual j of generation $i = y, o$ is given by

$$V(b_t^{ij}, g_t^{ij}, c_t^{ij}, E_t) = U(b_t^{ij} + g_t^{ij}) + c_t^{ij} - H(E_t) \tag{1}$$

$$= \beta\left[b_t^{ij} + g_t^{ij}\right] - \frac{\gamma}{2}\left[b_t^{ij} + g_t^{ij}\right]^2 + c_t^{ij} - hE_t, \tag{2}$$

where b_t^{ij} denotes black energy (fossil fuel) consumption, g_t^{ij} green energy (renewable) consumption and c_t^{ij} consumption of a final (numéraire) good x. Climate damages caused by the CO_2 stock E_t are covered by the linear damage function $H(E_t) = hE_t$.[1] The parameters β, γ and h are positive.

Specialized capital goods (wind turbines, solar panels, coal power plants, etc.), i.e. energy generation capacities, are required to produce energy.[2] By appropriate unit choice, we assume that every capacity unit allows the production of one unit of energy, so that Z_t denotes both the black capacity at time t and the maximal amount of black energy generated at time t, i.e. aggregated black energy supply b_t^s cannot exceed capacity Z_t. Analogously, Q_t denotes the green capacity and the maximal amount of green energy available at time t, so that aggregated green energy supply g_t^s cannot be greater than capacity Q_t. We assume

$$Z_{t+1} = z_t, \tag{3}$$

$$Q_{t+1} = q_t. \tag{4}$$

Thus, similar to Battaglini and Harstad (2016), there is an investment lag implying that capacity investments z_t and q_t in period t build up new capacity in the next period $t+1$.

[1] Linear damage functions are widely used in the literature - cf. Hoel (2011), Battaglini and Harstad (2016), Kollenbach and Schopf (2022), and Eichner and Kollenbach (2022). According to Golosov et al. (2014), the relation between the stock of CO_2 and temperature is concave, while the relation of temperature and climate damages is convex. Thus, a linear damage functions can be considered a good approximation.

[2] The accumulation of a green energy generation capacity is discussed by Tsur and Zemel (2011) and Kollenbach (2017b). Among others, Campbell (1980), Cairns (2001), and Kollenbach (2017a) analyze fossil fuel related capital investments.

Furthermore, the capacity of period t depreciates completely, so that the capacity of period $t+1$ only depends on investments in period t. In case of green energy, we assume that no other production factors are necessary, because the main inputs such as solar radiation or wind are freely available. In contrast, black energy production requires fossil fuels such as coal or gas. We consider the fuel reserves to be practically unlimited but costly to extract.[3]

Burning fossil fuels unleashes CO_2, which accumulates in the atmosphere according to

$$E_t = b_t^s + \delta E_{t-1} = \sum_{n=0}^{t} \delta^{t-n} b_n^s + \delta^t E_0, \tag{5}$$

where $1-\delta \in [0,1]$ is the natural regeneration rate and $E_0 \geq 0$ the emission stock endowment.[4] We assume $\beta > 2[1+\rho\delta]h$, where $\rho \in [0,1]$ is the discount factor.

The final good x is produced by means of labor l_t according to the linear production function $x = F(l_t) = al_t$, with $a > 0$ denoting labor productivity. Labor, in turn, is inelastically supplied by the young generation, i.e. each young individual inelastically supplies one unit of labor receiving labor income L. Income is used to finance consumption of energy and the final good, and to invest into energy generation capacity.[5] The corresponding investment costs are given by z_t in case of black capacity investments and by αq_t, with $\alpha > 1$, in case of green capacity investments. Thus, the budget constraint of a young individual reads

$$L + \frac{T}{2} = c_t^{yj} + z_t^j + [\alpha - \sigma_t] q_t^j + p_b b_t^{yj} + p_g g_t^{yj}, \tag{6}$$

where p_b and p_g are the prices of black and green energy, respectively, $\sigma_t \in [0, \alpha - 1)$ is a subsidy for green capacity investments, and T is a governmental transfer. Due to (3) and (4), every young individual will own a part Z_{t+1}^j and Q_{t+1}^j, respectively, of the energy generation capacities installed in the following period $t+1$, while the current capacities Z_t and Q_t are completely owned by the old generation. Selling the corresponding energy is the only source of income for the old generation in t. The budget constraint of an old individual j reads

$$p_b b_t^{sj} - M(b_t^{sj}) - \theta_t b_t^{sj} + p_g g_t^{sj} + \frac{T}{2} = c_t^{oj} + p_b b_t^{oj} + p_g g_t^{oj}, \tag{7}$$

[3]According to Andruleit et al. (2012), the static range of coal reserves and resources exceeds 5000 years.

[4]See Battaglini and Harstad (2016) for a similar approach.

[5]The case where only a fraction of the young generation invests into energy generation capacities is left for future research.

where θ_t is a fossil fuel tax , g_t^{sj} green energy supply, b_t^{sj} black energy supply and

$$M(b_t^{sj}) = \frac{m}{2}\left[b_t^{sj}\right]^2 \tag{8}$$

the corresponding extraction cost function of fossil fuels. We assume that one unit of fuel is needed to produce one unit of black energy.[6] By assuming that the government's budget is balanced in every period, we get

$$T = \theta_t b_t^s - \sigma_t q_t. \tag{9}$$

Thus, the transfer T is positive if the fuel tax revenues exceed the expenditure for subsidies. The energy markets are cleared by $b_t^s = \sum_j b_t^{sj} = \sum_i \sum_j b_t^{ij}$ and $g_t^s = \sum_j g_t^{sj} = \sum_i \sum_j g_t^{ij}$.

2.2. Political system

Following Alesina and Tabellini (1990), we consider two parties Y and O, which may hold office during period t and determine the fuel tax rate θ_t and the green capacity subsidy σ_t. Because all individuals of a generation are alike with the exception of ideological preferences, we assume that party Y [O] represents the young [old] generation. That is, party $i = Y, O$ sets the policy instruments such that they maximizes welfare W_t^i of the young/old generation at time t, which yields the preferred tax rates θ_t^Y and θ_t^O, and preferred subsidy rates σ_t^Y and σ_t^O. Which party holds office is determined by majority voting. We compare the benchmark case with certainty about electoral outcomes with the case with exogenously given election probabilities as well as with endogenously determined election probabilities. To solve the latter case, we assume that each individual has preferences in favor of party Y, which are given by $\Psi^{ij} + \chi$, with Ψ^{ij} denoting an ideological bias of generation i's individual j and χ indicating the general popularity of party Y. Both Ψ^{ij} and χ are uniformly distributed around mean 0 with density ξ^i and ν, respectively.[7] Thus, individual j of generation i votes for party Y if

$$W_t^{iY} + \Psi^{ij} + \chi \geq W_t^{iO} \tag{10}$$

holds. For a given realization of the popularity χ, the indifferent voter in generation i is characterized by her ideological preferences $\tilde{\Psi}^i = W_t^{iO} - W_t^{iY} - \chi$. All individuals with a

[6] Alternatively, θ_t denotes the price of an emission certificate if an ETS is implemented. An extraction cost function, which convexly increases in fuel extraction is also used by Tsur and Zemel (2005).

[7] Cf. Persson and Tabellini (2002, chap. 13) for a similar approach.

higher Ψ^{ij} vote for party Y, whereas all individuals with a lower Ψ^{ij} vote for party O. We assume that politicians are partisan and implement their parties' preferred fuel taxes after the elections. The vote share of party O is given by $vs^O = \frac{1}{2}\xi^o\left[\tilde{\Psi}^o + \frac{1}{2\xi^o}\right] + \frac{1}{2}\xi^y\left[\tilde{\Psi}^y + \frac{1}{2\xi^y}\right]$. In the following, we assume that $\xi^o = \xi^y = \xi$, i.e. that ideological preferences have the same distribution in both generations. Then, party's O probability of winning the elections at time t is given by

$$\pi_t = \frac{\nu}{2}\left\{\left[W_t^{oO} - W_t^{oY}\right] + \left[W_t^{yO} - W_t^{yY}\right]\right\} + \frac{1}{2}. \tag{11}$$

The probability that the young party wins the elections is $1 - \pi_t$. We see that the party representing the generation that has more to lose if the other party is elected and implements its preferred policy has a higher probability to win the elections.

2.3. Timing

The timing in our model is is illustrated in Fig. 1. At the beginning of each period,

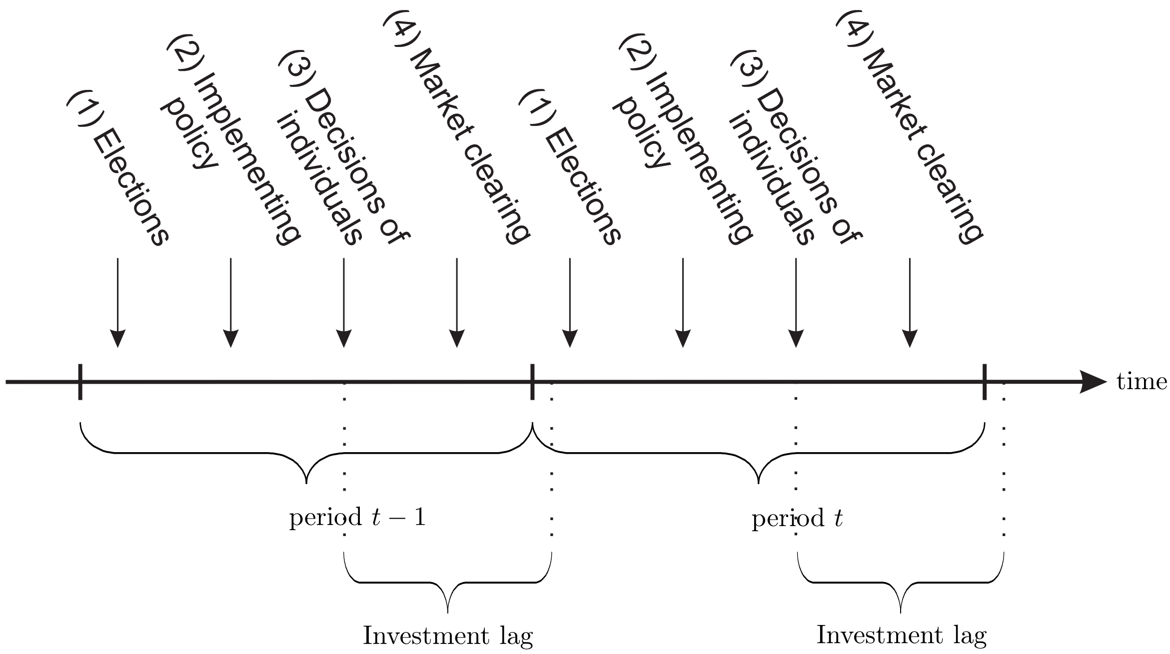

Figure 1: Timing

elections are held and the winning party sets the fuel tax and the green capacity subsidy. Subsequently, individuals non-cooperatively determine their consumption levels $c_t^{ij}, b_t^{ij}, g_t^{ij}$, young individuals decide how much to invest into generation capacities and old individuals set the energy supply levels b_t^{sj}, g_t^{sj}. Finally, the markets are cleared, where we assume that all individuals are price takers. Due to the investment lag, investments made in $t-1$

are not relevant for the energy market equilibrium of that period but for the equilibrium of the following period t. This implies that the investment decision of period $t-1$ depends on the subsidy σ_{t-1} and on the expectations about the election outcome in period t, which determine the expected tax rate $\mathrm{E}(\theta_t) = \Theta_t$.

We determine the market equilibrium of period t by solving the four stages

1) Determine subsidy σ_{t-1},
2) Determine investments at time $t-1$,
3) Determine fuel tax θ_t given the election outcome at time t,
4) Determine energy demand, supply and market equilibrium at time t

by backward induction in the following sections.

3. Energy market

First, we present the individuals' decisions with respect to energy consumption, energy supply and capacity investments given the fuel tax rate θ_t, the capacity subsidy σ_t, and the energy generation capacities Z_t and Q_t. Subsequently, we describe the energy market equilibrium at time t, which is then used to determine the preferred tax rate of party Y and O, the capacity investments of period $t-1$, and the preferred subsidy rate of party Y and O at time $t-1$.

Because individuals of one generation only differ in their ideological preferences, which do not affect the aforementioned decisions, we consider one representative individual per generation.

3.1. The individuals' decision rules

By substituting (7) into (2), the indirect utility function of the representative old individual net of ideological preferences reads

$$\begin{aligned}\tilde{V}(b_t^o + g_t^o, b_t^s, g_t^s) = \beta\,[b_t^o + g_t^o] - \frac{\gamma}{2}\,[b_t^o + g_t^o]^2 + p_b b_t^s - \frac{m}{2}(b_t^s)^2 - \theta_t b_t^s + p_g g_t^s \\ + \frac{T}{2} - p_b b_t^o - p_g g_t^o - hE_t.\end{aligned} \tag{12}$$

The individual maximizes (12) with respect to b_t^0, g_t^o, b_t^s and g_t^s given the capacity constraints $Z_t \geq b_t^s$ and $Q_t \geq g_t^s$. Due to the atomistic population structure, the individual neglects her impact on the emission stock E_t. Assuming an interior solution with respect to energy consumption b_t^o and g_t^o, the corresponding first-order conditions yield

$$U'(b_t^o + g_t^o) = \beta - \gamma[b_t^o + g_t^o] = p_b = p_g = p_t, \tag{13}$$

$$p_t = mb_t^s + \theta_t + \lambda_b, \tag{14}$$

$$p_t = \lambda_g. \tag{15}$$

The complementary slackness conditions read

$$(a) : \lambda_b \geq 0,\ \lambda_b[Z_t - b_t^s] = 0, \qquad (b) : \lambda_g \geq 0,\ \lambda_g[Q_t - g_t^s] = 0. \tag{16}$$

According to (13), the old individual increases her consumption of both kinds of energy until her marginal utility from energy consumption equals the energy price p_t. Because black and green energy are perfect substitutes, p_t denotes the price for both energy types. Green energy generation is not associated with any other costs than capacity investments. Consequently, (15) and (16)(b) imply that the complete stock Q_t is used.[8] In contrast, some black capacity may remain unused in period t, i.e. some black capacity may become a stranded asset. In this case, $\lambda_b = 0$ and (14) implies that black energy supply is increased until the energy price equals the sum of marginal extraction costs and the fuel tax.

For the representative young individual we get

$$\begin{aligned}\tilde{V}(b_t^y + g_t^y, z_t, q_t) = \beta\,[b_t^y + g_t^y] - \frac{\gamma}{2}\,[b_t^y + g_t^y]^2 + L + \frac{T}{2} - z_t - [\alpha - \sigma_t]q_t \\ - p_t[b_t^y + g_t^y] - hE_t + \rho\tilde{V}(b_{t+1}^o + g_{t+1}^o, b_{t+1}^s, g_{t+1}^s).\end{aligned} \tag{17}$$

(17) is maximized with respect to b_t^y, g_t^y, z_t and q_t given the expected fuel tax rate $\mathrm{E}(\theta_{t+1}) = \Theta_{t+1}$, the expected energy price $\mathrm{E}(p_{t+1}) = P_{t+1}$ and the expected black energy supply $\mathrm{E}(b_{t+1}^s) = B_{t+1}$ of period $t+1$. Assuming an interior solution with respect to energy consumption b_t^y and g_t^y, the first-order conditions yield

$$U'(b_t^y + g_t^y) = \beta - \gamma[b_t^y + g_t^y] = p_t, \tag{18}$$

$$\rho\,[P_{t+1} - mB_{t+1} - \Theta_{t+1}] = 1, \qquad \text{if } Z_{t+1} - B_{t+1} = 0, \tag{19}$$

$$\rho P_{t+1} = \alpha - \sigma_t. \tag{20}$$

Analogous to (13), (18) implies that energy consumption of the young individual equates marginal utility with the energy price. (20) shows that the discounted value of the expected marginal gain from green capacity investments (left-hand side) has to equal the respective marginal costs (right-hand side). In case of black capacity investments, the

[8] We neglect the case of a low energy demand that is not sufficient to fully use the green energy capacity, because this case is of little interest in the context of the energy transition.

analogous statement is only true if the individual expects that the complete capacity is used in the following period. If this is not the case, an additional black capacity investment unit causes costs but is not expected to generate any returns in the next period and is, therefore, not optimal. In other words, the young individual does not invest into what she expects to become a stranded asset.

By using (19) and (20) we get

$$Z_{t+1} = \frac{\alpha - \sigma_t - 1}{\rho m} - \frac{\Theta_{t+1}}{m}, \tag{21}$$

which constitutes a negative correlation of black capacity investments $z_t = Z_{t+1}$ with both the green capacity subsidy and the expected tax rate. If marginal investment costs of black and green capacity are identical ($\alpha - \sigma_t = 1$), green capacity investments are superior, because green energy supply is not taxed and not associated with extraction costs as in case of fossil fuels. In contrast, if $\alpha - \sigma_t > 1$, black capacity investments are positive as long as the expected tax rate falls short of $\frac{\alpha - \sigma_t - 1}{\rho}$.

3.2. Energy market equilibrium

Aggregate energy demand is given by

$$D(p_t) = 2\frac{\beta - p_t}{\gamma}, \tag{22}$$

while green energy supply is Q_t and the black energy supply function reads

$$b_t^s(p_t) = \min\left\{ Z_t, \frac{p_t - \theta_t}{m} \right\}. \tag{23}$$

An equilibrium on the energy market requires $D(p_t) = Q_t + b_t^s(p_t)$ to hold, which yields

$$p_t = \begin{cases} \frac{2m\beta + \gamma\theta_t}{2m+\gamma} - \frac{\gamma m Q_t}{2m+\gamma}, & \text{if } b_t^s \leq Z_t, \\ \beta - \frac{\gamma}{2}\left[Q_t + Z_t\right], & \text{if } b_t^s = Z_t, \end{cases} \tag{24}$$

$$b_t^s = \begin{cases} \frac{2\beta - 2\theta_t - \gamma Q_t}{2m+\gamma}, & \text{if } b_t^s \leq Z_t, \\ Z_t, & \text{otherwise.} \end{cases} \tag{25}$$

The energy market equilibrium is illustrated in Fig. 2. In the left panel, we assume that the black capacity is not completely used, i.e. that some black investments made in $t-1$ are stranded assets. Then, $\lambda_b = 0$ and the intersection of the λ_g line with the demand curve determines total energy consumption $b_t + Q_t$ and the energy price in equilibrium. Because green energy is only used if it is cheaper than black energy, the intersection of

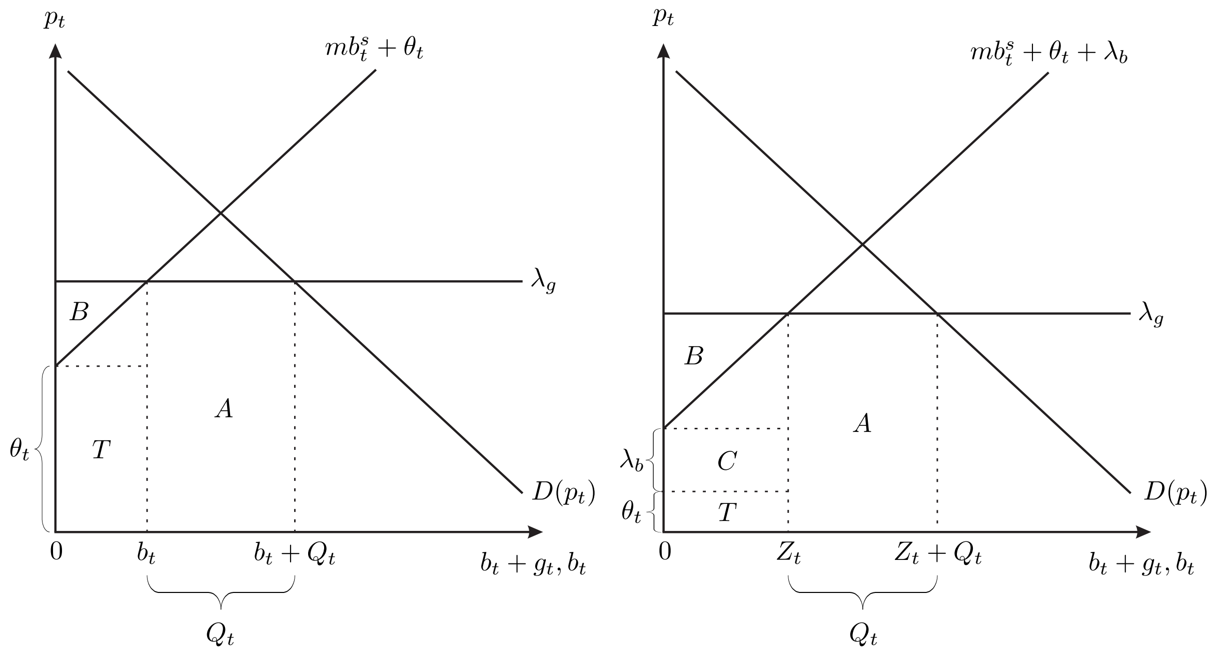

Figure 2: Equilibrium on the energy market with $b_t^s < Z_t$ (left panel) and $b_t^s = Z_t$ (right panel)

the λ_g line and the marginal black energy costs curve gives black energy consumption b_t. The difference between total energy consumption and black energy supply needs to equal green capacity Q_t, which determines the level of λ_g. Because green energy production is not associated with variable costs, area A denotes the green capacity rent. Profits from black energy supply are given by B and tax revenues by T. While tax revenues are equally distributed among the old and young generation, both the profits from black energy supply and the green capacity rent belong to the old generation. Differentiating the first lines of (24) and (25) with respect to the capacities Q_t and Z_t, and the tax rate θ_t yields

$$(a)\ \frac{\partial p_t}{\partial Q_t} = -\frac{\gamma m}{2m+\gamma} < 0, \qquad (b)\ \frac{\partial p_t}{\partial Z_t} = 0, \qquad (c)\ \frac{\partial p_t}{\partial \theta_t} = \frac{\gamma}{2m+\gamma} > 0, \tag{26}$$

$$(a)\ \frac{\partial b_t^s}{\partial Q_t} = -\frac{\gamma}{2m+\gamma} < 0, \qquad (b)\ \frac{\partial b_t^s}{\partial Z_t} = 0, \qquad (c)\ \frac{\partial b_t^s}{\partial \theta_t} = -\frac{2}{2m+\gamma} < 0. \tag{27}$$

Thus, a higher green capacity Q_t reduces the energy price, because the marginal green capacity rent λ_g needs to be lower to ensure the complete utilization of Q_t. Due to the lower energy price, black energy supply is also reduced implying that a higher green capacity Q_t not only leads to more energy consumption but also to a substitution of black energy by green energy. The effect of a higher capacity on the green capacity rent is ambiguous, because a higher Q_t increases the rent, while a lower price reduces it. An increase of the black capacity does not affect the equilibrium, because the capacity is not completely used.

In case of a higher tax rate θ_t, the marginal black energy cost curve is shifted upwards, so that λ_g increases to ensure that there is no excess demand for green energy. Consequently, both energy price and green capacity rent increase with the tax rate. With respect to black energy supply, two opposing effects emerge. On the one hand, a higher energy price boosts black energy supply. On the other hand, a higher tax reduces black energy supply. According to (27), the latter effect dominates.

Suppose now that the black capacity constraint binds (right panel of Fig. 2). Then, the ordinate-intercept of the marginal black energy cost curve equals the sum of $\lambda_b \geq 0$ and θ_t. Again, the intersection of the λ_g line with the demand curve determines total energy consumption and the energy price. However, λ_b is now such that the intersection of the λ_g line with the marginal black energy costs curve implies a black energy supply of $b_t^s = Z_t$, while λ_g ensures that the difference between total energy consumption and Z_t equals Q_t. As in case of a non-binding capacity constraint, areas A and T denote the green capacity rent and the tax revenues, respectively. The profits of black energy supply are now given by the sum of B and C, where C is the black capacity rent.

Differentiating the second lines of (24) and (25) with respect to the capacities Q_t and Z_t, and the tax rate θ_t yields

$$(a)\ \frac{\partial p_t}{\partial Q_t} = -\frac{\gamma}{2} < 0, \qquad (b)\ \frac{\partial p_t}{\partial Z_t} = -\frac{\gamma}{2} < 0, \qquad (c)\ \frac{\partial p_t}{\partial \theta_t} = 0, \tag{28}$$

$$(a)\ \frac{\partial b_t^s}{\partial Q_t} = 0, \qquad (b)\ \frac{\partial b_t^s}{\partial Z_t} = 1 > 0, \qquad (c)\ \frac{\partial b_t^s}{\partial \theta_t} = 0. \tag{29}$$

Because both capacities are completely used, an increase of Q_t and Z_t lowers the energy price. However, a higher green capacity does not affect black energy supply, due to the binding black capacity constraint. In contrast, the binding constraint implies that every additional black capacity unit is used and, therefore, increases fuel supply. The binding black capacity constraint also explains why the tax rate neither affects the energy price nor black energy supply. Rather, differentiating $p_t = mZ_t + \theta_t + \lambda_b$ shows that a higher tax rate only reduces the black capacity rent. That is, the higher the tax rate, the smaller [larger] area C [T] in Fig. 2 (right panel).

By taking (3) and (4) into account, the expected energy price of period $t+1$ can be written as $P_{t+1} = P_{t+1}(q_t, z_t, \Theta_{t+1})$, with $\frac{\partial P_{t+1}}{\partial q_t} < 0$, $\frac{\partial P_{t+1}}{\partial z_t} \leq 0$, and $\frac{\partial P_{t+1}}{\partial \Theta_{t+1}} \geq 0$. Substituting into (20) and (21) yields $z_t = z_t(\sigma_t, \Theta_{t+1})$ and $q_t = q_t(\sigma_t, \Theta_{t+1})$, with

$$(a)\ \frac{\partial z_t}{\partial \sigma_t} = -\frac{1}{\rho m} < 0, \qquad (b)\ \frac{\partial z_t}{\partial \Theta_{t+1}} = -\frac{1}{m} < 0, \tag{30}$$

$$(a)\ \frac{\partial q_t}{\partial \sigma_t} = \frac{\frac{1}{\rho m}\frac{\partial P_{t+1}}{\partial z_t} - \frac{1}{\rho}}{\frac{\partial P_{t+1}}{\partial q_t}} > 0, \qquad (b)\ \frac{\partial q_t}{\partial \Theta_{t+1}} = \frac{\frac{1}{m}\frac{\partial P_{t+1}}{\partial z_t} - \frac{\partial P_{t+1}}{\partial \Theta_{t+1}}}{\frac{\partial P_{t+1}}{\partial q_t}} \geq 0. \tag{31}$$

Ceteris paribus, both a higher subsidy and a higher expected tax rate boost green capacity investments but depress black capacity accumulation.

4. Preferred tax rates

If party $i = O, Y$ holds office in period t, it sets the fuel tax θ_t^i such that it maximizes welfare

$$\begin{aligned} W_t^o = {} & \beta\left[b_t^o(\theta_t) + g_t^o(\theta_t)\right] - \frac{\gamma}{2}\left[b_t^o(\theta_t) + g_t^o(\theta_t)\right]^2 - p_t(\theta_t)\left[b_t^o(\theta_t) + g_t^o(\theta_t)\right] \\ & + p_t(\theta_t) b_t^s(\theta_t) - \frac{m}{2}\left[b_t^s(\theta_t)\right]^2 - \theta_t b_t^s(\theta_t) + p_t(\theta_t) Q_t \\ & + \frac{\theta_t b_t^s(\theta_t) - \sigma_t q_t(\sigma_t, \Theta_{t+1})}{2} - h\left[b_t^s(\theta_t) + \delta E_{t-1}\right], \end{aligned} \tag{32}$$

$$\begin{aligned} W_t^y = {} & \beta\left[b_t^y(\theta_t) + g_t^y(\theta_t)\right] - \frac{\gamma}{2}\left[b_t^y(\theta_t) + g_t^y(\theta_t)\right]^2 - p_t(\theta_t)\left[b_t^y(\theta_t) - g_t^y(\theta_t)\right] + L \\ & - [\alpha - \sigma_t] q_t(\sigma_t, \Theta_{t+1}) - z_t(\sigma_t, \Theta_{t+1}) + \frac{\theta_t b_t^s(\theta_t) - \sigma_t q_t(\sigma_t, \Theta_{t+1})}{2} \\ & - h\left[b_t^s(\theta_t) + \delta E_{t-1}\right] + \rho\left\{\pi_{t+1} W_{t+1}^{oO} + [1 - \pi_{t+1}] W_{t+1}^{oY}\right\}. \end{aligned} \tag{33}$$

of the generation the party represents. Restricting our analysis to non-negative tax rates, the first-order conditions give[9]

$$\theta_t^O = \begin{cases} \theta_t^{Ob} = \frac{4m+\gamma}{2} Q_t + \frac{4m+2\gamma}{\gamma} h - \frac{2m}{\gamma}\beta, & \text{if } b_t^s \leq Z_t, \\ \theta_t^{OZ} = 0, & \text{if } b_t^s = Z_t, \end{cases} \tag{34}$$

$$\theta_t^Y = \begin{cases} \theta_t^{Yb} = -\frac{\gamma}{2} Q_t + \frac{4m+2\gamma}{4m+\gamma}[1 + \rho\delta] h + \frac{2m}{4m+\gamma}\beta, & \text{if } b_t^s \leq Z_t, \\ \theta_t^{YZ} = -\frac{\gamma}{2} Q_t - \frac{2m+\gamma}{2} Z_t + \beta, & \text{if } b_t^s = Z_t. \end{cases} \tag{35}$$

Consider a binding black capacity constraint. Then, environmental damages are fixed, so that the preferred tax rates do not depend on h. Rather, the tax only redistributes the black capacity rent. While the rent belongs to the old generation only, 50% of tax revenues are distributed to the young generation. Consequently, party O prefers a tax

[9] See Appendix A.1. Note that the linearity of the damage function implies that the probability π_{t+1} and the expected tax rate Θ_{t+1} do not depend on the current tax rate θ_t. The analysis of the preferred subsidy rates is postponed to section 6, because it requires the expected tax rate .

rate of zero, so that there is no redistribution. In contrast, the preferred tax $p_t - mZ_t$ of party Y eliminates λ_b implying that 50% of the black capacity rent is redistributed to the young generation. In case of a non-binding black capacity constraint, both party O and party Y prefer a higher tax rate if the environmental problem is more serious, i.e. if the marginal climate damage h is higher. In case of party Y, the term $[1 + \rho\delta]$ reflects that the young generation of period t suffers from higher emissions in the current and in the following period.

The effect of a higher green capacity differs between the tax rates. A higher green capacity increases the preferred tax rate of party O but decreases the preferred tax rate of party Y. Both effects are driven by the green capacity rent. (26)(a) shows that the energy price and, therefore, the marginal rent decreases with a higher capacity. To counter this effect, party O takes (26)(c) into account, i.e. that a higher tax boosts the energy price. Because the young generation only has to pay for the green capacity rent, party Y prefers the tax rate to decrease with Q_t, so that the depressing effect of a higher capacity Q_t on the marginal rent is amplified.

Finally, let us verify whether the tax rates can be used to implement the social optimum. The taxation of black energy is only necessary, if the black capacity does not equal its socially optimal value. Consequently, θ_t^{OZ} is only optimal in the knife-edge case that the black capacity Z_t is socially optimal. In contrast, θ_t^{YZ} is never socially optimal, because the social planner has no interests in income redistribution as long as the individuals' marginal utilities are identical, which is ensured by (13) and (18). In case of a sub-optimally high black capacity, neither θ_t^{Ob} nor θ_t^{Yb} can implement the socially optimal fuel use, because both tax rates take only the climate damages into account that occur during the lifespan of the old or young generation, respectively. In contrast, a social planner does consider all following generations and, therefore, the climate damages for all points in time $\tilde{t} \geq t$.[10] Proposition 1 follows directly.

Proposition 1 *Neither of the preferred tax rates of party O and Y is socially optimal.*

5. Optimal investments

The capacities Q_t and Z_t are equal to the investments made in the preceding period $t-1$. Because the optimization problem is the same for every young generation, (19) and

[10]This argument abstracts from the knife-edge case that the inefficiencies embodied in $Q(t)$ exactly outweigh the inefficiencies of θ_t^{Ob} or θ_t^{Yb}, respectively.

(20) hold. Thus, the capacity investments made in $t-1$ depend on the subsidy rate σ_{t-1} and the expectations of the young generation in $t-1$ about the energy price, fuel supply and the fuel tax rate in period t. The representative young individual of period $t-1$ expects that party O [Y] wins and implements its preferred tax rate θ_t^o [θ_t^y] with probability π [$1-\pi$].

5.1. Perfect foresight

At first, suppose that the young generation of period $t-1$ has perfect foresight, so that $\Theta_t = \theta_t$, where θ_t is given by either (34) or (35). In Appendix A.2 we prove

Proposition 2 *Suppose that the young generation of period $t-1$ has perfect foresight.*

- *If party O wins the elections in period t, the tax rate θ_t is zero, and capacities are given by*

$$Z_t = \frac{\alpha - \sigma_{t-1} - 1}{m\rho}, \quad Q_t = \frac{2}{\gamma}\beta + \frac{1}{\rho m} - \frac{2m+\gamma}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho m}.$$

- *If party Y wins the elections in period t, the tax rate θ_t equals $p_t - mZ_t$, and capacities are given by*

$$Z_t = 0, \quad Q_t = \frac{2}{\gamma}\left[\beta - \frac{\alpha - \sigma_{t-1}}{\rho}\right].$$

With perfect foresight, the black capacity constraint binds, because of the investment costs. In period $t-1$, the representative young individual equates the expected marginal profits to the marginal investment costs. However, investment costs are sunk in period t, so that the individual would like to supply more black energy in t than possible due to the limited capacity.

If party O wins the elections in period t, the young individual of period $t-1$ anticipates a tax rate of $\theta_t = 0$. Consequently, the representative young individual anticipates that she completely acquires the rents of both black and green capacity investments in the next period and invests into both technologies. In contrast, if party Y wins the elections in period t, the young individual of period $t-1$ anticipates that the black capacity rent is completely acquired by the government and partly redistributed to the young generation of period t. Consequently, black capacity investments are nil and energy generation completely relies on green technologies.

5.2. Imperfect foresight

In case of imperfect foresight, the representative individual of the young generation at time $t-1$ expects party O to win the elections in the next period with probability π_t and

	θ_t^{Ob}	θ_t^{OZ}
θ_t^{Yb}	(I)	(II)
θ_t^{YZ}	(III)	(IV)

Table 1: Tax rate combinations

party Y to win with probability $1-\pi_t$. Because party $i=O,Y$ sets $\theta_t \in \left\{\theta_t^{ib}, \theta_t^{iZ}\right\}$, the expected tax rate Θ_t is determined by one of the four combinations of Tab. 1. However, Proposition 3, which is proven in Appendix A.3, rules out the combinations (I) and (III).

Proposition 3 *If the individuals have no perfect foresight and party O wins the elections, it implements a tax rate of $\theta_t = \theta_t^{OZ} = 0 < \min\{\theta_t^{Yb}, \theta_t^{YZ}\}$ and no black capacity becomes a stranded asset.*

The case $\theta_t \in \left\{\theta_t^{Yb}, \theta_t^{Ob}\right\}$ is ruled out, because Proposition 2 implies that the black capacity constraint binds if $\theta_t = \min\left\{\theta_t^{Yb}, \theta_t^{Ob}\right\}$. In case of $\theta_t \in \left\{\theta_t^{YZ}, \theta_t^{Ob}\right\}$, the tax rate θ_t^{YZ} is such that the complete black scarcity rent is taxed away. Because the black capacity constraint doesn't bind if party O wins, $\theta_t^{Ob} > \theta_t^{YZ}$. Therefore, the profits from black energy sales (area B in Fig. 2) decrease, more tax revenues per black energy unit are redistributed to the young generation (higher area T), and the green scarcity rent (area A) increases. Proposition 3 implies that the last effect, which benefits the old generation, is outweighed by the other two effects. Consequently, party O will implement $\theta_t^{OZ}=0$ if it wins the elections in period t.

5.2.1. Case (II)

In contrast, party Y may implement either θ_t^{Yb} or θ_t^{YZ}. In the first case, that is for $\theta_t \in \left\{\theta_t^{Yb}, \theta_t^{OZ}\right\}$, the expected tax rate and energy price are given by $\Theta_t = \pi_t \theta_t^{OZ} + [1-\pi_t]\theta_t^{Yb} = [1-\pi_t]\theta_t^{Yb}$ and $P_t = \pi_t\left\{\beta - \frac{\gamma}{2}\left[Z_t + Q_t\right]\right\} + [1-\pi_t]\left[\frac{2m}{2m+\gamma}\beta + \frac{\gamma}{2m+\gamma}\theta_t^{Yb} - \frac{\gamma m}{2m+\gamma}Q_t\right]$. Substituting into (20) and (21), and solving yield

$$Z_t = \frac{\frac{1-\pi_t}{m}\frac{2m+\pi_t\gamma}{4m+\gamma}\left\{\beta - 2[1+\rho\delta]h\right\} + \frac{[\alpha-\sigma_{t-1}]\pi_t - 1}{\rho m}}{\frac{1-\pi_t}{m}\pi_t\frac{\gamma}{2}+1}, \tag{36}$$

$$Q_t = \frac{\frac{2}{\gamma}\left[1 - \frac{[1-\pi_t]^2\gamma}{4m+\gamma}\right]\beta + \frac{\pi_t}{\rho m} - [2m+\pi_t\gamma]\frac{\alpha-\sigma_{t-1}}{\rho m\gamma} + 2\frac{1-\pi_t}{m}\frac{2m+\pi_t[2m+\gamma]}{4m+\gamma}\left[1+\rho\delta\right]h}{\frac{1-\pi_t}{m}\pi_t\frac{\gamma}{2}+1}. \tag{37}$$

The capacities in period t are equal to the investments made in $t-1$. Therefore, (36) and (37) imply that black capacity investments decrease with marginal environmental damages h, while green capacity investments increase with h, which is driven by the expected tax rate Θ_t. The fiercer the environmental problem the higher the tax rate set by party Y in t and, therefore, the higher the expected tax rate. Consequently, the young generation of $t-1$ expects that it can use the less black capacity in period t the higher h, so that it reduces its black capacity investments. To substitute for the missing energy generating capacity, green capacity investments increase.

Ceteris paribus, (36) and (37) also show that black [green] capacity investments decrease [increase] with the green subsidy rate σ_{t-1}. A higher subsidy rate renders green capacity investments less costly, so that they increase in σ_{t-1}. However, the corresponding additional capacity will drive black capacity out of the market in period t implying a reduction of black capacity investments, because the young generation will not invest what it expects to become a stranded asset.

At first, suppose that party O wins the elections in period t. Then, it implements the tax rate $\theta_t = \theta_t^{oZ} = 0$, so that $b_t^s = Z_t$ and

$$p_t = \frac{\frac{[1-\pi_t]\gamma\pi_t}{4m+\gamma}\{\beta - 2[1+\rho\delta]h\} + \frac{\gamma}{2}\frac{1-\pi_t}{\rho m} + \frac{\alpha-\sigma_{t-1}}{\rho}}{\frac{1-\pi_t}{m}\pi_t\frac{\gamma}{2} + 1} \tag{38}$$

hold.[11] Because the tax rate that party Y would like to implement increases in marginal environmental damage h, young individuals of period $t-1$ invest more into green capacity and less into black capacity the higher h. If party O then wins the election at time t, the former effect outweighs the latter with respect to the price p_t, which decreases in h. Ceteris paribus, the positive effect of a higher subsidy on green capacity investments outweighs the negative effect on black capacity investments, so that the total energy generation capacity $Q_t + Z_t$ increases with the subsidy rate explaining the depressing effect of σ_{t-1} on the price at time t.

If party Y wins the elections in period t, it implements the tax rate

$$\theta_t^{Yb} = \frac{\frac{\alpha-\sigma_{t-1}}{\rho} + \pi_t\frac{\gamma}{2}\frac{\alpha-\sigma_{t-1}-1}{\rho m} - \frac{2m+\pi_t\gamma}{4m+\gamma}\{\beta - 2\left[1+\rho\delta\right]h\}}{\frac{1-\pi_t}{m}\pi_t\frac{\gamma}{2} + 1}. \tag{39}$$

[11] If $b_t^s \leq Z_t$, we find $b_t^s = \frac{\gamma}{2m+\gamma}\frac{\frac{1-\pi_t}{m}\frac{2m+\pi_t[2m+\gamma]}{4m+\gamma}\{\beta-2[1+\rho\delta]h\}+\pi_t\frac{\alpha-\sigma_{t-1}-1}{\rho m}+2\frac{\alpha-\sigma_{t-1}}{\rho\gamma}}{\frac{1-\pi_t}{m}\pi_t\frac{\gamma}{2}+1}$, which is positive by $\beta > 2[1+\rho\delta]$. The black capacity constraint does not bind if $\beta - 2[1+\rho\delta] > \frac{[4m+\gamma]\{2m[\alpha-\sigma_{t-1}]+\gamma\}}{4\rho m^2} + \frac{4m+\gamma}{2m\rho[1-\pi_t]}$. A positive tax rate θ_t^{Yb} is ensured by $\beta-2[1+\rho\delta] < \frac{4m+\gamma}{2m+\gamma\pi_t}\left[\frac{\alpha-\sigma_{t-1}}{\rho} + \frac{\gamma}{2}\pi_t\frac{\alpha-\sigma_{t-1}-1}{\rho m}\right]$. Because $\frac{[4m+\gamma]\{2m[\alpha-\sigma_{t-1}]+\gamma\}}{4\rho m^2} + \frac{4m+\gamma}{2m\rho[1-\pi_t]} > \frac{4m+\gamma}{2m+\gamma\pi_t}\left[\frac{\alpha-\sigma_{t-1}}{\rho} + \frac{\gamma}{2}\pi_t\frac{\alpha-\sigma_{t-1}-1}{\rho m}\right]$, our restriction to non-negative tax rates ensures a binding black capacity constraint in case of $\theta_t = \theta_t^{OZ} = 0$.

The tax rate has straightforward properties. The larger the environmental damages of one additional emission unit the higher the tax rate. Because the young generation of period t also suffers from environmental damages in the next period, the effect is the stronger the lower the natural regeneration rate $(1-\delta)$ and the higher the discount factor ρ. Ceteris paribus, the tax rate is the lower the higher the subsidy rate σ_{t-1}, because of the positive [negative] effect of the subsidy rate on green [black] capacity investments, which alleviates the environmental problem. Substituting (39) into (25) and taking account of (37) yield

$$b_t^s = \frac{2}{4m+\gamma}\left\{\beta - 2\left[1+\rho\delta\right]h\right\}. \tag{40}$$

Unsurprisingly, the same effects of h, ρ, and δ that boost the tax rate lower the use of black energy. However, the subsidy rate σ_{t-1} has no direct effect on black energy supply at time t, because the positive effect of a lower tax rate and the negative effect of a higher green capacity cancel each other out. Finally, the energy price at time t reads

$$p_t = \frac{\frac{\alpha-\sigma_{t-1}}{\rho} + \frac{\pi_t\gamma}{2\rho m}\left[\alpha-\sigma_{t-1}-1\right] - \frac{\gamma\pi_t^2}{4m+\gamma}\left\{\beta-2[1+\rho\delta]h\right\}}{\frac{1-\pi_t}{m}\pi_t\frac{\gamma}{2}+1}. \tag{41}$$

As in case of an O-government at time t, the energy price decreases with the subsidy rate ceteris paribus, because of the positive effect of σ_{t-1} on total energy capacity. However, higher environmental damages h boost the energy price. This implies that the effect of a higher green capacity is dominated by the combined effects of a lower black capacity and a higher tax rate.

To ensure a non-binding black capacity constraint,

$$\sigma_{t-1} < \tilde{\sigma}_{t-1} = \alpha - \frac{1}{\pi_t} - \frac{2\rho m\{\beta-2[1+\rho\delta]h\}}{4m+\gamma} \tag{42}$$

has to hold. That is, $\theta_t \in \left\{\theta_t^{Yb}, \theta_t^{OZ}\right\}$ is only possible if the subsidy rate σ_{t-1} was set sufficiently low. Otherwise, the high subsidy rate boosted green investments and depressed black investments sufficiently such that the black capacity constraint binds in period t, i.e. the economy is in case (IV).

5.2.2. Case (IV)

In case (IV), $\theta_t \in \left\{\theta_t^{YZ}, \theta_t^{OZ}\right\}$ holds with an expected tax rate of $\Theta_t = [1-\pi_t]\big[\beta - \frac{\gamma}{2}Q_t - \frac{2m+\gamma}{2}Z_t\big]$ and an expected energy price of $P_t = \beta - \frac{\gamma}{2}Q_t - \frac{\gamma}{2}Z_t$. Substituting into (20) and (21), and solving yield

$$Z_t = \frac{\alpha-\sigma_{t-1}}{\rho m} - \frac{1}{\rho m\pi_t}, \tag{43}$$

$$Q_t = \frac{2}{\gamma}\beta - \frac{2m+\gamma}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho m} + \frac{1}{\rho m \pi_t}. \tag{44}$$

Similar to case (II), the black [green] capacity investments decrease [increase] with the subsidy rate ceteris paribus. If party O wins the elections in t, it implements $\theta_t^{oZ} = 0$. In case that party Y wins, the tax rate reads $\theta_t = \frac{1}{\rho \pi_t}$. In both cases the complete black capacity is used in period t and the energy price reads

$$p_t = \frac{\alpha - \sigma_{t-1}}{\rho}. \tag{45}$$

Ceteris paribus, a higher subsidy rate decreases the price, because the positive effect of the subsidy on green capacity investments outweighs the negative effect on black capacity investments, so that the total energy generation capacity increases.

The expectations about the elections outcome play a crucial role. If the individuals rather expect party Y to win the elections in period t, i.e. if $\pi_t \to 0$, (42) does not hold and $\theta_t \in \left\{\theta_t^{yZ}, \theta_t^{oZ}\right\}$. In contrast, if π_t is close to unity, individuals rather expect party O to win the elections. Consequently, their black capacity investments are more oriented to a tax rate of zero and, therefore, higher than in case of $\pi_t \to 0$. If party Y then wins, the investments are too high and some become stranded assets.

5.2.3. Case (II) or Case (IV)

Before turning to the analysis of the optimal subsidy rate, we discuss whether case (II) and case (IV) describe stable equilibria. This is the case, if the best option of a Y-government in period t is to implement the tax rate θ_t^{Yb} $\left[\theta_t^{YZ}\right]$ when facing case (II) [(IV)] capacities as given by (36) and (37) [(43) and (44)]. For this purpose, we substitute (36) - (41) and (43) - (45) into (32) and (33) and take account of (13) and (18), so that welfare of old and young individuals, given that party O, Y holds office, can be written as

$$W_t^{oO}\Big(Q_t(\sigma_{t-1}, \pi_t), Z_t(\sigma_{t-1}, \pi_t), p_t(\sigma_{t-1}, \pi_t), \theta_t^O, \sigma_t^O, Q_{t+1}(\sigma_t^O, \pi_{t+1})\Big), \tag{46}$$

$$W_t^{oY}\Big(Q_t(\sigma_{t-1}, \pi_t), b_t^s(\sigma_{t-1}, \pi_t), p_t(\sigma_{t-1}, \pi_t), \theta_t^Y(\sigma_{t-1}, \pi_t), \sigma_t^Y, Q_{t+1}(\sigma_t^Y, \pi_{t+1}))\Big), \tag{47}$$

$$\begin{aligned} &W_t^{yO}\Big(Q_t(\sigma_{t-1}, \pi_t), Z_t(\sigma_{t-1}, \pi_t), p_t(\sigma_{t-1}, \pi_t), \theta_t^O, \sigma_t^O, Q_{t+1}(\sigma_t^O, \pi_{t+1})), \\ &\qquad Z_{t+1}(\sigma_t^O, \pi_{t+1}), \pi_{t+1}, W_{t+1}^{oO}(\sigma_{t-1}), W_{t+1}^{oY}(\sigma_{t-1})\Big), \end{aligned} \tag{48}$$

$$\begin{aligned} &W_t^{yY}\Big(Q_t(\sigma_{t-1}, \pi_t), b_t^s(\sigma_{t-1}, \pi_t), p_t(\sigma_{t-1}, \pi_t), \theta_t^Y(\sigma_{t-1}, \pi_t), \sigma_t^Y, Q_{t+1}(\sigma_t^Y, \pi_{t+1}), \\ &\qquad Z_{t+1}(\sigma_t^Y, \pi_{t+1}), \pi_{t+1}, W_{t+1}^{oO}(\sigma_{t-1}), W_{t+1}^{oY}(\sigma_{t-1})\Big). \end{aligned} \tag{49}$$

Welfare of the young generation in period t is higher with a the tax rate θ_t^{Yb} than with the tax rate θ_t^{YZ} if

$$\begin{aligned}\Delta^{II} = W_t^{yY}\Big(&Q_t^{II}(\sigma_{t-1},\pi_t), b_t^s(\sigma_{t-1},\pi_t), p_t(\sigma_{t-1},\pi_t), \theta_t^{Yb}(\sigma_{t-1},\pi_t), \sigma_t^Y,\\ &Q_{t+1}(\sigma_t^Y,\pi_{t+1}), Z_{t+1}(\sigma_t^Y,\pi_{t+1}), \pi_{t+1}, W_{t+1}^{oO}(\sigma_{t-1}), W_{t+1}^{oY}(\sigma_{t-1})\Big)\\ -W_t^{yY}\Big(&Q_t^{II}(\sigma_{t-1},\pi_t), Z_t^{II}(\sigma_{t-1},\pi_t), p_t(\sigma_{t-1},\pi_t), \theta_t^{YZ}(\sigma_{t-1},\pi_t), \sigma_t^Y,\\ &Q_{t+1}(\sigma_t^Y,\pi_{t+1}), Z_{t+1}(\sigma_t^Y,\pi_{t+1}), \pi_{t+1}, W_{t+1}^{oO}(\sigma_{t-1}), W_{t+1}^{oY}(\sigma_{t-1})\Big) > 0\end{aligned} \tag{50}$$

and

$$\begin{aligned}\Delta^{IV} = W_t^{yY}\Big(&Q_t^{IV}(\sigma_{t-1},\pi_t), b_t^s(\sigma_{t-1},\pi_t), p_t(\sigma_{t-1},\pi_t), \theta_t^{Yb}(\sigma_{t-1},\pi_t), \sigma_t^Y,\\ &Q_{t+1}(\sigma_t^Y,\pi_{t+1}), Z_{t+1}(\sigma_t^Y,\pi_{t+1}), \pi_{t+1}, W_{t+1}^{oO}(\sigma_{t-1}), W_{t+1}^{oY}(\sigma_{t-1})\Big)\\ -W_t^{yY}\Big(&Q_t^{IV}(\sigma_{t-1},\pi_t), Z_t^{IV}(\sigma_{t-1},\pi_t), p_t(\sigma_{t-1},\pi_t), \theta_t^{YZ}(\sigma_{t-1},\pi_t), \sigma_t^Y,\\ &Q_{t+1}(\sigma_t^Y,\pi_{t+1}), Z_{t+1}(\sigma_t^Y,\pi_{t+1}), \pi_{t+1}, W_{t+1}^{oO}(\sigma_{t-1}), W_{t+1}^{oY}(\sigma_{t-1})\Big) > 0\end{aligned} \tag{51}$$

hold, where (Z_t^{II}, Q_t^{II}) and (Z_t^{IV}, Q_t^{IV}) are the capacities as given by (36), (37) and (43), (44), respectively. In Appendix A.4, we prove

Proposition 4 *If party Y holds office in period t, it prefers a case (II) type policy if $\sigma_{t-1} \neq \tilde{\sigma}_{t-1}$ and is indifferent between a case (II) type policy and a case (IV) type policy if $\sigma_{t-1} = \tilde{\sigma}_{t-1}$.*

Proposition 4 has the important implication that party Y, if in office at period t, is never worse off with the tax rate θ_t^{Yb} than with the tax rate θ_t^{YZ}. Thus, if the subsidy σ_{t-1} falls short of $\tilde{\sigma}_{t-1}$, party Y sets the fuel tax equal to θ_t^{Yb} implying that a part of the black capacity Z_t becomes stranded assets. If the subsidy exceeds $\tilde{\sigma}_{t-1}$, party Y would still prefer the tax rate θ_t^{Yb}. However, because $\sigma_{t-1} > \tilde{\sigma}_{t-1}$ violates (42), the black energy supply associated with θ_t^{Yb} exceeds the black capacity Z_t, so that party Y is restricted to case (IV) policies and sets the tax rate θ_t^{YZ}.[12]

6. Subsidy

The results of the previous sections allow us to analyze which subsidy rate is set by party Y or O in period $t-1$, which is the last step in our backward induction.

[12]Note that $Z_t > b_t^s$ also yields (42) if Z_t is given by (43) and b_t^s by $b_t^{s,II,IV}$ as defined in Appendix A.4.

6.1. Exogenous election probability

At first, suppose that the election probability is exogenously given. If party O holds office at period $t-1$, it maximizes W^{oO}_{t-1} with respect to σ_{t-1}, which yields

$$\frac{dW^{oO}_{t-1}}{d\sigma_{t-1}} = -\frac{\sigma_{t-1}}{2}\frac{\partial Q_t}{\partial\sigma_{t-1}} - \frac{Q_t}{2} \leq 0 \qquad\qquad \sigma_{t-1}\frac{dW^{oO}_{t-1}}{d\sigma_{t-1}} = 0. \tag{52}$$

Because $\frac{\partial Q_t}{\partial\sigma_{t-1}}$ is positive for both case (II) and case (IV), the Kuhn-Tucker-condition implies $\sigma^O_{t-1} = 0$. Because the old generation does not benefit from subsidizing green investments but has to bear a part of the costs, party O prefers a subsidy rate of zero.

If party Y holds office in $t-1$, it maximizes W^{yY}_{t-1} with respect to σ_{t-1}. The corresponding first-order condition reads

$$\frac{dW^{yY}_{t-1}}{d\sigma_{t-1}} = \frac{Q_t}{2} - \left[\alpha - \frac{\sigma_{t-1}}{2}\right]\frac{\partial Q_t}{\partial\sigma_{t-1}} - \frac{\partial Z_t}{\partial\sigma_{t-1}} + \rho\left\{\pi_t\frac{dW^{oO}_t}{d\sigma_{t-1}} + [1-\pi_t]\frac{dW^{oY}_t}{d\sigma_{t-1}}\right\} = 0, \tag{53}$$

where

$$\frac{dW^{oO}_t}{d\sigma_{t-1}} = \frac{Z_t+Q_t}{2}\frac{\partial p_t}{\partial\sigma_{t-1}} + [p_t - mZ_t]\frac{\partial Z_t}{\partial\sigma_{t-1}} + p_t\frac{\partial Q_t}{\partial\sigma_{t-1}} - h\frac{\partial Z_t}{\partial\sigma_{t-1}}, \tag{54}$$

$$\begin{aligned}\frac{dW^{oY}_t}{d\sigma_{t-1}} &= \frac{b^s_t+Q_t}{2}\frac{\partial p_t}{\partial\sigma_{t-1}} + [p_t - mb^s_t - \theta_t]\frac{\partial b^s_t}{\partial\sigma_{t-1}} - \frac{b^s_t}{2}\frac{\partial\theta_t}{\partial\sigma_{t-1}} \\ &\quad + p_t\frac{\partial Q_t}{\partial\sigma_{t-1}} + \frac{\theta_t}{2}\frac{\partial b^s_t}{\partial\sigma_{t-1}} - h\frac{\partial b^s_t}{\partial\sigma_{t-1}}.\end{aligned} \tag{55}$$

According to (53), the optimal subsidy rate equates the marginal benefits of a higher subsidy with the marginal costs. The marginal benefits of period $t-1$ are given by higher net grants for capacity investments, reflected by the first term of (53) and a reduction of black capacity investment costs ($\partial Z_t/\partial\sigma_{t-1} < 0$). The marginal costs of period $t-1$ are given by higher green capacity investments ($\partial Q_t/\partial\sigma_{t-1} > 0$). With respect to period t, party Y considers the expected marginal effect of a higher subsidy rate. If the young generation of period $t-1$ remains in power in period t, the marginal effect is given by $\frac{dW^{oO}_t}{d\sigma_{t-1}}$ and by $\frac{dW^{oY}_t}{d\sigma_{t-1}}$ otherwise. In the former case, the first term of (54) reflects the price effect of a higher subsidy rate on the net revenues from energy sales. The second and third term are the energy production effects. Finally, the last term indicates the environmental effect, i.e. that a higher subsidy reduces black capacity investments and, therefore, climate damages. In case that the party representing the young generation of period t wins the election at period t, the three effects are supplemented by two tax effects. First, the third term of (55) indicates the change of net tax payments caused by a change of the tax rate. Second, the fifth term represents the change of tax refunds caused by a changing black energy production. The tax terms are missing in (54), because an O-government will implement the tax rate $\theta_t^{OZ} = 0$ at time t.

Suppose that the economy is in case (II), i.e. that (42) holds. Then, we find that a higher subsidy depresses the energy price p_t, so that the price effects are negative. If party Y holds office in period t, black energy supply b_t^s is not affected by the subsidy rate σ_{t-1}, while the tax rate θ_t decreases with the subsidy. Thus, the black energy production effect, the second tax effect and, in particular, the environmental effect of (55) vanish. By solving (53), we get

$$\begin{aligned}\sigma_{t-1}^{II} = & \frac{2\gamma\pi_t}{4m^2 + 4m\gamma[1-\pi_t]^2\pi_t + \gamma^2\pi_t^2[1-\pi_t]}\Bigg\{ m[3-2\pi_t][1-\alpha\pi_t] \\ & - \rho m[1-\pi_t]\frac{2m[1-2\pi_t] + \pi_t\gamma}{4m+\gamma}\Big[\beta - 2[1+\rho\delta]h\Big] \\ & + \rho\pi_t h\Big[2m + \pi_t\gamma[1-\pi_t]\Big]\Bigg\}. \end{aligned} \tag{56}$$

The opposing signs of the terms in curly brackets reflect the opposing effects discussed above. In particular, if party Y holds office in period $t-1$, it faces opposing effects of marginal climate damages h, because the climate damage parameter directly influences the equilibrium of period t. For example, (37) shows that the green capacity investments are the higher the more serious the environmental problem. Furthermore, the energy price p_t increases with h if party Y holds office in period t. Consequently, revenues from green energy sales in period t are boosted. On the other hand, (36) shows that black capacity investments are the lower the higher marginal climate damages. Given an O-government in period t, also the energy price p_t decreases in h. Both lead to lower revenues from black energy sales. Which effects dominate, i.e. whether σ_{t-1}^{II} increases or decreases with h, depends on the election probability π_t. If $\pi_t < \frac{2m}{4m-\gamma}$, the positive effects dominate, so that the subsidy rate increases with marginal climate damages.

Consider now case (IV). No matter if party Y or O is in power in period t, the price p_t decreases with the subsidy rate, while the tax rate of period t is independent from the subsidy rate. Because all black capacity is used in case (IV), the environmental effect in both (54) and (55) is positive. Solving (53) yields

$$\sigma_{t-1}^{IV} = \frac{\gamma\,[1-\alpha+2\rho h]}{2m}. \tag{57}$$

In contrast to case (II), the optimal subsidy rate unambiguously increases with the environmental damage parameter h. The reason is that capacities, the energy price p_t and the tax rates θ_t^{YZ} and θ_t^{OZ} are independent from the climate damage parameter in case (IV). Consequently, a higher h has no direct effects on a case (IV) equilibrium in period t. However, the binding black capacity constraint implies that in period $t-1$ a Y-government can reduce future climate damages by increasing the subsidy rate, which reduces black capacity investments. The higher marginal climate damages h, the more a Y-government will use this channel.

Whether a Y-government should choose σ_{t-1}^{II} or σ_{t-1}^{IV} depends on the parameters of the model. In Appendix A.5, we prove proposition 5.

Proposition 5 *Suppose that party Y holds office in period $t-1$.*
(i) If $\alpha \in [\max\{\alpha^{\min II}, \alpha^{\Delta II}\}, \alpha^{II}]$, the subsidy rate σ_{t-1}^{II} is feasible.
(ii) If $\alpha \in [\alpha^{\min IV}, \min\{\alpha^{IV}, \alpha^{\Delta IV}\}]$, the subsidy rate σ_{t-1}^{IV} is feasible.
(iii) If the two parameter spaces from (i) and (ii) overlap, σ_{t-1}^{II} is only superior to σ_{t-1}^{IV}, if $\alpha \leq \tilde{\alpha}$.
The thresholds are given by

$$
\begin{aligned}
\alpha^{\min II} &= \frac{1}{\pi_t} + \frac{2\rho m\{\beta - 2[1+\rho\delta]h\}}{4m+\gamma}, \\
\alpha^{\min IV} &= 1 + \frac{2\rho\gamma h}{2m+\gamma}, \\
\alpha^{II} &= \alpha^{\min II} + \frac{2\rho m + \rho\gamma\pi_t[1-\pi_t]}{3-2\pi_t}\left\{\frac{h}{m} - \frac{\beta - 2[1+\rho\delta]h}{\pi_t[4m+\gamma]}\right\} \\
\alpha^{\Delta II} &= \alpha^{\min II} - \frac{2\rho\gamma\pi_t}{2m+\gamma\pi_t}\left\{\frac{m[\beta - 2[1+\rho\delta]h]}{4m+\gamma} - \pi_t h\right\} \\
\alpha^{IV} &= 1 + 2\rho h \\
\alpha^{\Delta IV} &= \alpha^{\min II} + \frac{2\rho\gamma h}{2m+\gamma} - \frac{\gamma[1-\pi_t]}{[2m+\gamma]\pi_t} - \frac{\gamma}{2m+\gamma}\frac{2\rho m\{\beta - 2[1+\rho\delta]h\}}{4m+\gamma}, \\
\tilde{\alpha} &= \frac{1}{[4m+\gamma]^2\pi_t\left\{4m[4m+\gamma]\left[m+[m+\gamma]\pi_t[1-\pi_t]\right] + \gamma\pi_t^2[\gamma[4m+\gamma]+8m^2]\right\}} \\
&\quad \Bigg\{2\Bigg[m^2[4m+\gamma]^2\Big[4m^2 + 4m\gamma\pi_t[1-\pi_t]^2 + \gamma^2\pi_t^2[1-\pi_t]\Big]\Big[[4m+\gamma][2m+\gamma\pi_t] \\
&\quad - 2\rho h\pi_t[4m+\gamma][\gamma\pi_t + 2m[1+\pi_t]] + 4\rho m^2\pi_t[\beta - 2[1+\rho\delta]h]\Big]^2\Bigg]^{0.5} \\
&\quad + [4m+\gamma]\Bigg[[2m+\gamma]\gamma^3\pi_t^3[1+2\rho h] + 2m\gamma^3\pi_t^2[3+4\rho h] \\
&\quad + 16m^4\Big[2 + 4\pi_t[1-\pi_t] + \pi_t[\rho + 2\rho\pi_t[1-\pi_t]][\beta - 2[1+\rho\delta]h] + 4\rho h\pi_t[1+\pi_t]\Big]\Bigg] \\
&\quad + 8[4m+\gamma]m^3\gamma\Big[1 + 4\pi[2-\pi_t^2] + 6\rho h\pi_t[1+\pi_t] + \pi_t^2\Big[4\rho h[2-\pi_t]
\end{aligned}
$$

$$+ \rho[2-\pi_t][\beta - 2[1+\rho\delta]h]\Big]\Big] + 4[4m+\gamma]m^2\gamma^2\pi_t\Big[3[1+\pi_t]$$

$$+ 2\rho h[1+\pi_t] + 4\pi_t[1-\pi_t] + 6\rho h\pi_t[2-\pi_t] + \rho\pi_t^2\Big[\beta - 2[1+\rho\delta]h\Big]\Big]\Big\}.$$

To understand proposition 5, suppose that both π_t and $\beta - 2[1+\rho\delta]h$ are small. Then, it can be shown that $0 < \alpha^{\min IV} < \alpha^{IV} < \alpha^{\Delta IV} < \alpha^{\min II} < \alpha^{\Delta II} < \alpha^{II}$ holds, which allows us to illustrate the evolution of the subsidy rate σ_{t-1} dependent on α as in Fig. 3.[13] The

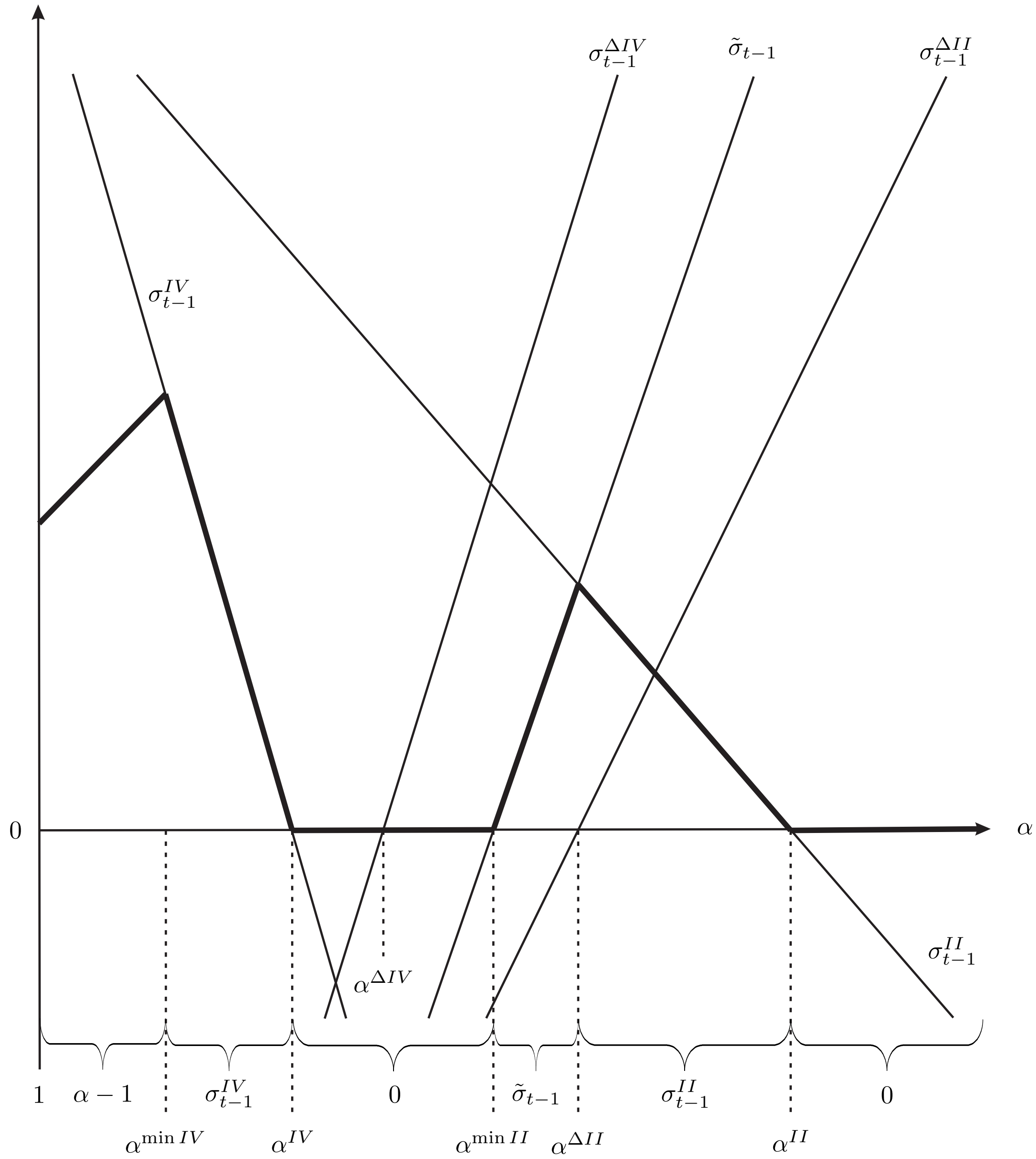

Figure 3: The optimal subsidy rate depending on α

σ^{II}_{t-1}, σ^{IV}_{t-1} and $\tilde{\sigma}_{t-1}$ curves illustrate the linear relationship between σ^{II}_{t-1}, σ^{IV}_{t-1}, $\tilde{\sigma}_{t-1}$ and

[13]See Appendix 5.

α. The differences $\sigma_{t-1}^{\Delta II} = \tilde{\sigma}_{t-1} - \sigma_{t-1}^{II}$ and $\sigma_{t-1}^{\Delta IV} = \tilde{\sigma}_{t-1} - \sigma_{t-1}^{IV}$ also linearly depend on α and are illustrated by the corresponding curves. The subsidy σ_{t-1}^{II} can be only set if it is positive and falls short of $\tilde{\sigma}_{t-1}$. The former implies $\alpha < \alpha^{II}$ and the latter $\alpha > \alpha^{\Delta II}$. Finally, $\tilde{\sigma}_{t-1} > 0$ yields $\alpha^{\min II}$. In case of the subsidy σ_{t-1}^{IV}, the difference $\sigma_{t-1}^{\Delta IV}$ needs to be negative and the subsidy rate positive, which gives $\min\{\alpha^{IV}, \alpha^{\Delta IV}\}$ as upper limit for the parameter space allowing for σ_{t-1}^{IV}. The lower limit $\alpha^{\min IV}$ is given by the requirement that σ_{t-1}^{IV} falls short of $\alpha - 1$.[14]

Because of the small π_t, the Y-government of period $t-1$ expects to lose the next elections with a high probability. Consequently, there is a high risk that some black capacity investments made in $t-1$ end up as stranded assets. This implies a high incentive for the Y-government to influence the next government in a way that reduces the carbon tax set in period t, i.e. the Y-government wants to bind the hands of its successor.

If α is close to unity, i.e. if green capacity investments are cheap, the Y-government can avoid the risk of stranded assets by granting a subsidy $\sigma_{t-1} \to \alpha - 1$, which (almost) equates the costs of black and green capacity investments ensuring a reallocation of all investments to green capacity. This is beneficial for the young generation of period $t-1$ for two additional reasons. First, without a black capacity, there are no additional climate damages and no extraction costs in the next period. Second, the profits of clean energy production in period t belong completely to the young generation of $t-1$, while half of the subsidy costs are born by the old generation. The higher α, i.e. the more expensive green capacity investments, the higher the subsidy rate $\sigma_{t-1} \to \alpha - 1$. At $\alpha^{\min IV}$, the high subsidy costs are no longer optimal and the optimal subsidy policy switches to the σ_{t-1}^{IV} regime. With this regime, the Y-government of period $t-1$ ensures that its successor either sets $\theta_t = 0$ (if the elections are won) or $\theta_t = \theta_t^{YZ}$ (if the elections are lost) implying that the complete black capacity is used in period t. Thus, the Y-government can successfully bind the hand of the next government. Under the σ_{t-1}^{IV} regime, higher green capacity costs lead to a lower subsidy. That is, it becomes increasingly beneficial for the young generation of period $t-1$ to avoid high green capacity investments but to bear the additional climate and extraction costs in the following period. At α^{IV}, this incentive becomes so strong that the Y-government would be prefer a negative subsidy. Because this is ruled out by assumption, the subsidy level remains nil for all $\alpha \in [\alpha^{IV}, \alpha^{\min II})$.

[14]Note that $\tilde{\sigma}_{t-1} < \alpha - 1$ holds, so that $\sigma_{t-1}^{II} < \tilde{\sigma}_{t-1}$ implies $\sigma_{t-1}^{II} < \alpha - 1$.

However, note that this zero subsidy still exceeds the critical value $\tilde{\sigma}_{t-1}$ and is, therefore, sufficient to bind the hands of the government of period t. At $\alpha^{\min II}$, the optimal subsidy policy switches into the $\tilde{\sigma}_{t-1}$ regime. The reason is that the young generation of period $t-1$ can no longer expect to be in a case (IV) situation with a subsidy rate of zero if its party losses the elections in period t. Rather, in period t a Y-government will implement a case (II) policy, because $0 < \tilde{\sigma}_{t-1}$. To bind the hands of such a government, the Y-government of period $t-1$ grants the smallest subsidy ensuring that there will be no stranded assets in the next period. With more expensive green capacity investments, the subsidy rate $\tilde{\sigma}_{t-1}$ increases to counter the incentive of more black capacity investments. At $\alpha^{\Delta II}$, the optimal case (II) subsidy rate σ_{t-1}^{II} becomes feasible. That is, for $\alpha > \alpha^{\Delta II}$ it is no longer optimal for the Y-government of period $t-1$ to fully bind its successors hands but to accept that some black capacity investments will strand in period t if the elections are lost. To reduce the amount of possibly stranded black capacity, the subsidy rate σ_{t-1}^{II} is granted. As in case of σ_{t-1}^{IV}, higher green capacity investments costs reduce the subsidy and imply a subsidy rate of zero for all $\alpha \geq \alpha^{II}$.

If the assumptions of a small election probability π_t does not hold, the parameter spaces allowing for σ_{t-1}^{II} and σ_{t-1}^{IV} may overlap. In this case, the Y-government of period $t-1$ will choose the subsidy rate which maximizes welfare. The corresponding welfare difference $W_{t-1}^{yY}(\sigma_{t-1}^{II}) - W_{t-1}^{yY}(\sigma_{t-1}^{IV})$ describes a parabola open downwards with the zeros at $\alpha = \pm\tilde{\alpha}$, so that σ_{t-1}^{II} will be chosen if $\alpha < \tilde{\alpha}$. It is noteworthy that cheap green capacity investments now imply the subsidy rate σ_{t-1}^{II}, while the opposite is true for a small election probability π_t. To rationalize this recall that black capacity investments are low in case of a small α. Together with the Y-government's high probability of winning the next elections, this implies that black capacity investments are not at a high risk to become stranded. Consequently, the Y-government has only small incentives to bind the hands of its successor and grants only the small subsidy rate σ_{t-1}^{II}. However, if green capacity investments are expensive, more black capacity investments are at risk, so that the Y-governments opts for the σ_{t-1}^{IV} subsidy rate, which ensures that there are no stranded assets in period t.

6.2. Endogenous election probability

In this section, we relax the assumption of a fixed election probability. Thus, we assume that the probability π_t is given by (11) and is, therefore, subject to the different welfare functions that may emerge in period t. According to (46) - (49), these functions depend on the subsidy rate σ_{t-1} and the election probability π_t constituting

$$\pi_t = \pi_t(\sigma_{t-1}). \tag{58}$$

By substituting into (32) and (33) for period $t-1$ and maximizing with respect to σ_{t-1}, we can determine the preferred subsidy rates.

For this purpose, it is useful to rewrite (11) as

$$\pi_t = \frac{\nu}{2}\Big(\Delta W_t^{OY}(\sigma_{t-1}, \pi_t)\Big) + \frac{1}{2}, \tag{59}$$

with

$$\Delta W_t^{OY}(\sigma_{t-1}, \pi_t) := \Big[W_t^{oO}(\sigma_{t-1}, \pi_t) + W_t^{yO}(\sigma_{t-1}, \pi_t)\Big] - \Big[W_t^{oY}(\sigma_{t-1}, \pi_t) + W_t^{yY}(\sigma_{t-1}, \pi_t)\Big]$$

as the welfare difference at time t between an O-government and a Y-government. By differentiating with respect to the subsidy rate, we find

$$\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}} = \frac{\frac{\nu}{2}\frac{\partial \Delta W_t^{OY}(\sigma_{t-1},\pi_t)}{\partial \sigma_{t-1}}}{1 - \frac{\nu}{2}\frac{\partial \Delta W_t^{OY}(\sigma_{t-1},\pi_t)}{\partial \pi_t}}. \tag{60}$$

If the welfare difference increases with both the subsidy rate and the election probability and is [in]sensitive with respect to the latter, a ruling party Y can increase the chances of its generation to also form the government in period t by lowering [increasing] the subsidy rate. To determine the sign of (60), we differentiate between the cases (II) and (IV).

At first, consider case (IV). No matter which party is in power at period t, the capacities Q_t and Z_t are completely used and the energy price is given by (45). Therefore, also energy consumption of the two generations and emissions are not affected by the government. Therefore, the welfare difference ΔW_t^{OY} can be rewritten as

$$\Delta W_t^{OY,IV}(\sigma_{t-1}, \pi_t) = \alpha[q_t^Y - q_t^O] + [z_t^Y - z_t^O] + \rho \Delta W_{t+1}^O,$$

with

$$\Delta W_{t+1}^O = \big[\pi_{t+1} W_{t+1}^{oO} + [1-\pi_{t+1}] W_{t+1}^{oY}\big]_O - \big[\pi_{t+1} W_{t+1}^{oO} + [1-\pi_{t+1}] W_{t+1}^{oY}\big]_Y$$

as the difference between the expected welfare of the old generation in period $t+1$ given that either party O or party Y holds office in period t. Because the investments q_t and z_t of period t and ΔW_{t+1}^O do not depend on the subsidies of period $t-1$, the numerator of

(60) is zero. This implies that in case (IV) the election probability π_t cannot be influenced by adjusting the subsidy in the period prior to the elections.

In case (II), $\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}}$ can be positive or negative. If party Y holds office in $t-1$, it considers that the the subsidy level affects π_t. Thus, the first order condition for maximizing W_{t-1}^{yY} with respect to σ_{t-1} (which is given by (53) for exogenous election probabilities) becomes

$$\frac{\mathrm{d}W_{t-1}^{yY}}{\mathrm{d}\sigma_{t-1}} = \frac{Q_t}{2} - \left[\alpha - \frac{\sigma_{t-1}}{2}\right]\left(\frac{\partial Q_t}{\partial \sigma_{t-1}} + \frac{\partial Q_t}{\partial \pi_t}\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}}\right) - \left(\frac{\partial Z_t}{\partial \sigma_{t-1}} + \frac{\partial Z_t}{\partial \pi_t}\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}}\right)$$
$$+ \rho\left\{\pi_t\frac{\partial W_t^{oO}}{\partial \sigma_{t-1}} + [1-\pi_t]\frac{\partial W_t^{oY}}{\partial \sigma_{t-1}} + \frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}}\left([W_t^{oO} - W_t^{oY}] + \pi_t\frac{\partial W_t^{oO}}{\partial \pi_t} + [1-\pi_t]\frac{\partial W_t^{oY}}{\partial \pi_t}\right)\right\} = 0 \tag{61}$$

The closed-form expression of $\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}}$ in case (II) is quite complicated and therefore delegated to Appendix A.6. Depending on the parameters of the model, it can be positive or negative. This implies, that following (61), party Y uses the subsidy to influence the elections in the following period and therefore deviates strategically from the subsidy with fixed election probabilities which is given by (56). To shed more light on the strategic behavior we make use of a numerical example, with the parameters listed in Tab. 2.[15]

Parameter	Value
β	49,805
γ	0.005
m	0.0116
ρ	0.3066
δ	0.5144
α	2.5844
h	21,508.5222
ν	20
E_0	0
L	2,000,000,000

Table 2: Parameter values for the numerical example

We find that a Y-government grants a subsidy of $\sigma_{t-1}^s = 0.612131$ leading to a reelection probability of $\pi_t^s = 0.957525$. To interpret these values, we also calculate the subsidy rate $\breve{\sigma}_{t-1}$ a Y-government would implement that faces an exogenous reelection probability of $\pi_t = 0.957525$. According to our result, a Y-government would want to

[15]See Appendix A.7 for more details.

heavily subsidize green capacity investments implying $\breve{\sigma}_{t-1} \to \alpha > \sigma^s_{t-1}$.[16] The comparison of $\breve{\sigma}_{t-1}$ and σ^s_{t-1} shows that the strategic considerations induce a Y-government to reduce the subsidy rate. This result might seem counter-intuitive first, because one would expect a Y-government to be in favor of green capacity investments to reduce the climate damages in the next period. To rationalize the result, recall that the party Y of period $t-1$ will represent the old generation in period t. According to (11), the party has two channels to increase its voting share in period t. It can either increase the losses of its generation if the elections will be lost or decrease the losses of the other generation if the elections will be won. Our results suggest that the first channel is dominant. That is, the Y-government grants less subsidies, so that green capacity investments are lower and black capacity investments are higher than with an exogenous reelection probability. If the elections are lost, this implies that more black capacities end as stranded assets or that more black capacity rent is redistributed to the other generation. Both induces to the individuals that turn old in period t to reelect the government. If the second channel is dominant, a Y-government would grant a higher subsidy in $t-1$ leading to less black capacity, so that the young generation of the next period can gain less from taxing this capacity.

7. Conclusion

In this paper, we study the interaction of climate policies and investments into fossil and renewable energy generation capacities if the policies are set by democratically elected governments. In an overlapping generations model individuals invest into black and green energy generation capacity of the next period. Elections are held in every period to determine climate policies, i.e. a carbon tax and a green investment subsidy, where the parties represent the interest of the young generation (Y) and the old generation (O), respectively. Climate policies are used for two purposes, the redistribution of income between generations and the internalization of climate damages. To avoid income redistribution in favor of the young generation, an O-government will always abstain from climate policies. In contrast, a Y-government offers non-negative tax and subsidy rates.

The carbon tax affects environmental damages only if some black investments become

[16] Alternatively, the exogenous probability that would induce a Y-government to set a subsidy rate of $\sigma_{t-1} = 0.612131$ is $\breve{\pi}_t = 0.0146 < \pi^s_t$.

stranded assets. If this is not the case, the carbon tax is used for redistribution only, and is either equal to zero (O-government) or equal to the black scarcity rent (Y-government). In particular, this result occurs if the individuals have perfect foresight with respect to the election outcome. Then, there is either no or prohibitive carbon taxation and energy generation completely relies on renewables in the latter case. In case that the election outcome is uncertain, we show that some black investments become stranded assets in period t if the green investments subsidy of period $t-1$ was sufficiently low and party Y, which offers a positive tax rate, wins the elections at time t although the individuals expected party O to win with a high exogenously given probability. Then, the individuals adjusted their investments to both a low green investment subsidy and a low expected tax rate. However, after the elections they face a high tax rate implying that not the complete black capacity will be used. It is noteworthy that a Y-government always prefers stranding some black capacity and will only allow the use of the complete capacity if it is small. An important implication of our model is that the black capacity is small if the green investment subsidy of the previous period was sufficiently high.

With an exogenously given election probability, the subsidy rate set by a Y-government depends on the severity of environmental damages, the costs of green capacity investments and its reelection probability. If environmental damages are high, the reelection probability is small and green investment costs low, the subsidy set is such that the black capacity is small and completely used in the next period. In contrast, with high green investment costs, the subsidy is not sufficiently high to ensure that a Y-government will not let some capacities become stranded assets in the next period. If the reelection probability is high, this relation may reverse.

Due to the investment lag, the green investment subsidy can be used to influence the election outcome of the next period. An O-government will not make use of this opportunity, because the current old generation will not be alive in the next period. In contrast, party Y will use the subsidy in a strategic way. Our results suggest that a Y-government sets a lower subsidy than with an exogenous election probability. This increases black capacity investments and, therefore, the potential losses of the current young generation if the elections in the next period will be lost, which induces the individuals of the current young generation to vote for their party.

Our analysis can be extended in several directions. Population growth will affect the relative size of generations and, therefore, the election probability. If capacities are not completely depreciated within one period, the evolution of the economy will become path-depended affecting the decision problems of every period. Finally, the redistribution motive will be affected if only a fraction of the young generation invests into energy generation capacity. We leave these extensions for further research.

A. Appendix

A.1. Preferred tax rates

Differentiating (32) with respect to θ_t yields

$$\frac{\partial W^{oO}}{\partial \theta_t} = \frac{dp_t}{d\theta_t} b_t^s - b_t^s + \frac{dp_t}{d\theta_t} Q_t + \frac{1}{2}\left[\theta_t \frac{db_t^s}{d\theta_t} + b_t^s\right] - [b_t^o + g_t^o]\frac{dp_t}{d\theta_t} - h\frac{db_t^s}{d\theta_t}.$$

If the black capacity constraint does not bind, we set $\frac{\partial W^{oO}}{\partial \theta_t} = 0$ and substitute $\frac{dp_t}{d\theta_t} = \frac{\gamma}{2m+\gamma}$, $\frac{db_t^s}{d\theta_t} = -\frac{2}{2m+\gamma}$, $b_t^s = \frac{2\beta - 2\theta_t - \gamma Q_t}{2m+\gamma}$, and $b_t^o + g_t^o = \frac{\beta}{\gamma} - \frac{1}{\gamma}\left[\frac{2m\beta+\gamma\theta_t}{2m+\gamma} - \frac{\gamma m Q_t}{2m+\gamma}\right]$ to get the first line of (34). If the black capacity constraint binds, $\frac{dp_t}{d\theta_t} = \frac{db_t^s}{d\theta_t} = 0$ and $b_t^s = Z_t$, so that $\frac{dW^{oO}}{d\theta_t} = -\frac{Z_t}{2} < 0$ implying $\theta_t^o = 0$.

Differentiating (33) with respect to θ_t yields

$$\frac{\partial W^{yY}}{\partial \theta_t} = \frac{b_t^s}{2} + \frac{\theta_t}{2}\frac{db_t^s}{d\theta_t} - [b_t^y + g_t^y]\frac{dp_t}{d\theta_t} - [1+\rho\delta]h\frac{db_t^s}{d\theta_t}.$$

If the black capacity constraint does not bind, we set $\frac{\partial W^{yY}}{\partial \theta_t} = 0$ and substitute $\frac{dp_t}{d\theta_t} = \frac{\gamma}{2m+\gamma}$, $\frac{db_t^s}{d\theta_t} = -\frac{2}{2m+\gamma}$, $b_t^s = \frac{2\beta - 2\theta_t - \gamma Q_t}{2m+\gamma}$, and $b_t^y + g_t^y = \frac{\beta}{\gamma} - \frac{1}{\gamma}\left[\frac{2m\beta+\gamma\theta_t}{2m+\gamma} - \frac{\gamma m Q_t}{2m+\gamma}\right]$ to get the first line of (35). If the black capacity constraint binds, $\frac{dp_t}{d\theta_t} = \frac{db_t^s}{d\theta_t} = 0$ and $b_t^s = Z_t$, so that $\frac{dW^{yY}}{d\theta_t} = \frac{Z_t}{2} > 0$. Thus, the preferred tax rate is set to its maximal level ensuring $b_t^s = Z_t$. According to (14) and (24), θ_t^y is set such that $\lambda_b(t) = 0$ just holds implying $\theta_t^y = -\frac{\gamma}{2}Q_t - \frac{2m+\gamma}{2}Z_t + \beta$.

A.2. Perfect foresight

Suppose that party O wins the elections and implements the tax rate for the non-binding capacity constraint $\theta_t = \theta_t^{ob} = \frac{4m+\gamma}{2}Q_t + \frac{4m+2\gamma}{\gamma}h - \frac{2m\beta}{\gamma}$. Substituting into (21) yields

$$Z_t = \frac{\alpha - \sigma_{t-1} - 1}{\rho m} - \frac{4m+\gamma}{2m}Q_t - \frac{4m+2\gamma}{m\gamma}h + \frac{2}{\gamma}\beta. \tag{A.1}$$

From (20), (24), (25), and (34) we get

$$Q_t = \frac{2}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho} - \frac{4}{\gamma}h, \tag{A.2}$$

$$b_t^s = \frac{2}{\gamma}\beta - 2Q_t - \frac{4}{\gamma}h. \tag{A.3}$$

Solving (A.1) - (A.3) yields

$$Z_t = \frac{2}{\gamma}\beta + \frac{4}{\gamma}h - \frac{4m[\alpha - \sigma_{t-1} + \gamma}{\rho m \gamma}, \tag{A.4}$$

$$b_t^s = \frac{2}{\gamma}\beta + \frac{4}{\gamma}h - \frac{4}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho}, \tag{A.5}$$

so that $Z_t - b_t^s < 0$. Because the representative young individual of period $t-1$ has perfect foresight, she anticipates that the capacity constraint will bind in the next period ruling out $\theta_t^{ob} = \frac{4m+\gamma}{2}Q_t + \frac{4m+2\gamma}{\gamma}h - \frac{2m\beta}{\gamma}$. Consequently, $\theta_t = \theta_t^{oZ} = 0$ implying

$$Z_t = \frac{\alpha - \sigma_{t-1} - 1}{\rho m}, \tag{A.6}$$

$$Q_t = \frac{2}{\gamma}\beta + \frac{1}{\rho m} - \frac{2m+\gamma}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho m}. \tag{A.7}$$

Suppose that party Y wins the elections and implements the tax rate for the non-binding capacity constraint $\theta_t = \theta_t^y = -\frac{\gamma}{2}Q_t + \frac{4m+2\gamma}{4m+\gamma}[1+\rho\delta]h + \frac{2m\beta}{4m+\gamma}$. Substituting into (21) yields

$$Z_t = \frac{\alpha - 1}{\rho m} + \frac{\gamma}{2m}Q_t - \frac{4m+2\gamma}{4m+\gamma}\frac{1+\rho\delta}{m}h - \frac{2}{4m+\gamma}\beta. \tag{A.8}$$

From (20), (24), (25), and (34) we get

$$Q_t = \frac{2}{\gamma}\frac{4m}{4m+\gamma}\beta + \frac{4}{4m+\gamma}[1+\rho\delta]h - \frac{2}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho}, \tag{A.9}$$

$$b_t^s = \frac{2}{4m+\gamma}\beta - \frac{4}{4m+\gamma}[1+\rho\delta]h. \tag{A.10}$$

Solving (A.8) - (A.10) yields

$$Z_t = -\frac{1}{\rho m} + \frac{2}{4m+\gamma}\beta - \frac{4}{4m+\gamma}[1+\rho\delta]h, \tag{A.11}$$

so that $Z_t - b_t^s < 0$. Because the representative young individual of period $t-1$ has perfect foresight, she anticipates that the capacity constraint will bind in the next period ruling out $\theta_t^{yb} = -\frac{\gamma}{2}Q_t + \frac{4m+2\gamma}{4m+\gamma}[1+\rho\delta]h + \frac{2m\beta}{4m+\gamma}$. Consequently, $\theta_t = \theta_t^{yZ} = \beta - \frac{\gamma}{2}[Q_t + Z_t] - mZ_t$. Substituting into (19) shows that the marginal profits from black capacity investments are nil and, therefore, $Z_t = 0$. Consequently, (20) and (24) imply

$$Q_t = \frac{2}{\gamma}\left[\beta - \frac{\alpha - \sigma_{t-1}}{\rho}\right].$$

□

A.3. Imperfect foresight

The tax rate is either θ_t^{ob} or θ_t^{oZ} if party O wins and either θ_t^{yb} or θ_t^{yZ} if party Y wins. Thus, the expected tax rate is given by one of the four combinations of Tab. 1.

Consider combination (I). Then, either $\theta_t = \theta_t^{ob}$ or $\theta_t = \theta_t^{yb}$ and $\Theta_t = \pi_t \theta_t^{ob} + [1-\pi_t]\theta_t^{yb}$. Suppose $\theta_t^{ob} > \theta_t^{yb}$. Then, the young generation invests less than in case of party Y's certain election but more than in case of party O's certain election. From Proposition 2 we known that with perfect foresight the young generation's black capacity investments are too small to ensure $b_t^s < Z_t$. Consequently, if party Y wins, the black capacity will not be large enough to allow party Y to implement θ_t^{yb}, so that $\theta_t = \theta_t^{yZ}$ and $b_t^s = Z_t$. For the case $\theta_t^{ob} < \theta_t^{yb}$, an analogous argument implies that party O implements θ_t^{oZ} if it wins. Thus, combination (I) can be ruled out.

Consider combination (III). The expected tax rate is given by

$$\Theta_t = \pi_t \left[\frac{4m+\gamma}{2} Q_t + \frac{2(2m+\gamma)}{\gamma} h - \frac{2m}{\gamma} \beta \right] + [1-\pi_t] \left[\beta - \frac{\gamma}{2} Q_t - \frac{2m+\gamma}{2} Z_t \right], \quad \text{(A.12)}$$

while the expected price at time t reads

$$P_t = \pi_t \left[\frac{\gamma}{2} Q_t + 2h \right] + [1-\pi_t] \left[\beta - \frac{\gamma}{2} Q_t - \frac{\gamma}{2} Z_t \right]. \quad \text{(A.13)}$$

Substituting into (20) and (21) yields $Z_t = \frac{2}{\gamma}\beta - \frac{1-2\pi_t}{1-\pi_t} Q_t + \frac{4}{\gamma}\frac{\pi_t}{1-\pi_t} h - \frac{2}{[1-\pi_t]\gamma}\frac{\alpha-\sigma_{t-1}}{\rho}$ and $Z_t = \frac{1}{2\pi_t m - \gamma[1-\pi_t]} \left\{ \frac{2}{\rho}[\alpha - \sigma_{t-1} - 1] - [4\pi_t m + 2\pi_t \gamma - \gamma] Q_t - 4\frac{\pi_t}{\gamma}[2m+\gamma] h + \frac{2\pi_t[2m+\gamma] - 2\gamma}{\gamma} \beta \right\}$, and therefore

$$Q_t = \frac{2\pi_t m \left[\alpha - \sigma_{t-1}\right] - [1-\pi_t]\gamma}{\rho \gamma \pi_t m} - \frac{4}{\gamma} h, \quad \text{(A.14)}$$

$$Z_t = \frac{2}{\gamma}\beta - \frac{4}{\gamma}\frac{\alpha - \sigma_{t-1}}{\rho} + \frac{1-2\pi_t}{\rho \pi_t m} + \frac{4}{\gamma} h. \quad \text{(A.15)}$$

Combination (III) implies $\theta_t^{Ob} > \theta_t^{YZ}$, because the black capacity constraint should not bind if party O wins but should be binding if party Y wins. Substituting (34), (35), (A.14) and (A.15) yields $-1 > 0$, which obviously never holds. Consequently, combination (III) is ruled out. In the remaining combinations (II) and (IV), party O implements $\theta_t^{OZ} = 0$ if it wins the elections at time t implying a binding black capacity constraint. □

A.4. Case (II) vs. Case (IV)

Suppose that the capacities Z_t^{II} and Q_t^{II} are given by (36) and (37), and that party Y holds office. To determine the welfare of the young generation at time t if party Y

implements the case (II) tax rate θ_t^{Yb}, we need $W_{t+1}^{oO,II}$ and $W_{t+1}^{oY,II}$, which can be written as[17]

$$\begin{aligned}
W_{t+1}^{oO,II} = & \beta\frac{Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}-\frac{\gamma}{2}\frac{[Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})]^2}{4}\\
& -p_{t+1}^O(\sigma_t,\pi_{t+1})\frac{[Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})]}{2}+p_{t+1}^O(\sigma_t,\pi_{t+1})Z_{t+1}(\sigma_t,\pi_{t+1})\\
& -\frac{m}{2}\left[Z_{t+1}(\sigma_t,\pi_{t+1})\right]^2+p_{t+1}^O(\sigma_t,\pi_{t+1})Q_{t+1}(\sigma_t,\pi_{t+1})\\
& -h\left[Z_{t+1}(\sigma_t,\pi_{t+1})+\delta b_t^{s,II}(\sigma_{t-1},\pi_t)+\delta^2E_{t-1}\right],\\
W_{t+1}^{oY,II} = & \beta\frac{b_{t+1}^s(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}-\frac{\gamma}{2}\frac{\left[b_{t+1}^s(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})\right]^2}{4}\\
& -p_{t+1}^Y(\sigma_t,\pi_{t+1})\frac{b_{t+1}^s(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}+p_{t+1}^Y(\sigma_t,\pi_{t+1})b_{t+1}^s(\sigma_t,\pi_{t+1})\\
& -\frac{m}{2}\left[b_{t+1}^s(\sigma_t,\pi_{t+1})\right]^2-\theta_{t+1}^Y(\sigma_t,\pi_{t+1})b_{t+1}^s(\sigma_t,\pi_{t+1})+p_{t+1}^Y(\sigma_t,\pi_{t+1})Q_{t+1}(\sigma_t,\pi_{t+1})\\
& +\frac{\theta_{t+1}^Y(\sigma_t,\pi_{t+1})b_{t+1}^s(\sigma_t,\pi_{t+1})-\sigma_{t+1}Q_{t+2}(\sigma_{t+1},\pi_{t+2})}{2}\\
& -h\left[b_{t+1}^s(\sigma_t,\pi_{t+1})+\delta b_t^{s,II}(\sigma_{t-1},\pi_t)+\delta^2E_{t-1}\right],
\end{aligned}$$

where $b_t^{s,II}$ is given by (40). Consequently, welfare at time t under case (II) policy reads

$$\begin{aligned}
W_t^{yY,II} = & \beta\frac{b_t^{s,II}(\sigma_{t-1},\pi_t)+Q_t^{II}(\sigma_{t-1},\pi_t)}{2}-\frac{\gamma}{2}\frac{\left[b_t^{s,II}(\sigma_{t-1},\pi_t)+Q_t^{II}(\sigma_{t-1},\pi_t)\right]^2}{4}\\
& -p_t^{II}(\sigma_{t-1},\pi_t)\frac{\left[b_t^{s,II}(\sigma_{t-1},\pi_t)+Q_t^{II}(\sigma_{t-1},\pi_t)\right]}{2}+L-[\alpha-\sigma_t]Q_{t+1}(\sigma_t,\pi_{t+1})\\
& -Z_{t+1}(\sigma_t,\pi_{t+1})+\frac{\theta_t^{Yb}(\sigma_{t-1},\pi_t)b_t^{s,II}(\sigma_{t-1},\pi_t)-\sigma_tQ_{t+1}(\sigma_t,\pi_{t+1})}{2}\\
& -h\left[b_t^{s,II}(\sigma_{t-1},\pi_t)+\delta E_{t-1}\right]+\rho\left\{\pi_{t+1}W_{t+1}^{oO,II}+[1-\pi_{t+1}]W_{t+1}^{oY,II}\right\},
\end{aligned}$$

where p_t^{II} is given by (41).

If party Y implements the tax rate θ_t^{YZ}, i.e. the case (IV) type policy, the welfare functions for period $t+1$ read

$$\begin{aligned}
W_{t+1}^{oO,IV,II} = & \beta\frac{Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}-\frac{\gamma}{2}\frac{[Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})]^2}{4}\\
& -p_{t+1}^O(\sigma_t,\pi_{t+1})\frac{[Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})]}{2}+p_{t+1}^O(\sigma_t,\pi_{t+1})Z_{t+1}(\sigma_t,\pi_{t+1})\\
& -\frac{m}{2}\left[Z_{t+1}(\sigma_t,\pi_{t+1})\right]^2+p_{t+1}^O(\sigma_t,\pi_{t+1})Q_{t+1}(\sigma_t,\pi_{t+1})\\
& -h\left[Z_{t+1}(\sigma_t,\pi_{t+1})+\delta Z_t^{II}(\sigma_{t-1},\pi_t)+\delta^2E_{t-1}\right],
\end{aligned}$$

[17]To ease notation, we take account of (52).

$$
\begin{aligned}
W_{t+1}^{oY,IV,II} &= \beta \frac{b_{t+1}^s(\sigma_t,\pi_{t+1}) + Q_{t+1}(\sigma_t,\pi_{t+1})}{2} - \frac{\gamma}{2} \frac{\left[b_{t+1}^s(\sigma_t,\pi_{t+1}) + Q_{t+1}(\sigma_t,\pi_{t+1})\right]^2}{4} \\
&- p_{t+1}^Y(\sigma_t,\pi_{t+1}) \frac{b_{t+1}^s(\sigma_t,\pi_{t+1}) + Q_{t+1}(\sigma_t,\pi_{t+1})}{2} + p_{t+1}^Y(\sigma_t,\pi_{t+1}) b_{t+1}^s(\sigma_t,\pi_{t+1}) \\
&- \frac{m}{2} \left[b_{t+1}^s(\sigma_t,\pi_{t+1})\right]^2 - \theta_{t+1}^Y(\sigma_t,\pi_{t+1}) b_{t+1}^s(\sigma_t,\pi_{t+1}) + p_{t+1}^Y(\sigma_t,\pi_{t+1}) Q_{t+1}(\sigma_t,\pi_{t+1}) \\
&+ \frac{\theta_{t+1}^Y(\sigma_t,\pi_{t+1}) b_{t+1}^s(\sigma_t,\pi_{t+1}) - \sigma_{t+1} Q_{t+2}(\sigma_{t+1},\pi_{t+2})}{2} \\
&- h\left[b_{t+1}^s(\sigma_t,\pi_{t+1}) + \delta Z_t^{II}(\sigma_{t-1},\pi_t) + \delta^2 E_{t-1}\right].
\end{aligned}
$$

Thus, welfare of the young generation in period t is given by

$$
\begin{aligned}
W_t^{yY,IV,II} &= \beta \frac{Z_t^{II}(\sigma_{t-1},\pi_t) + Q_t^{II}(\sigma_{t-1},\pi_t)}{2} - \frac{\gamma}{2} \frac{\left[Z_t^{II}(\sigma_{t-1},\pi_t) + Q_t^{II}(\sigma_{t-1},\pi_t)\right]^2}{4} \\
&- p_t^{IV,II}(\sigma_{t-1},\pi_t) \frac{\left[Z_t^{II}(\sigma_{t-1},\pi_t) + Q_t^{II}(\sigma_{t-1},\pi_t)\right]}{2} + L - [\alpha - \sigma_t] Q_{t+1}(\sigma_t,\pi_{t+1}) \\
&- Z_{t+1}(\sigma_t,\pi_{t+1}) + \frac{\theta_t^{YZ,II}(\sigma_{t-1},\pi_t) Z_t^{II}(\sigma_{t-1},\pi_t) - \sigma_t Q_{t+1}(\sigma_t,\pi_{t+1})}{2} \\
&- h\left[Z_t^{II}(\sigma_{t-1},\pi_t) + \delta E_{t-1}\right] + \rho\left\{\pi_{t+1} W_{t+1}^{oO,IV,II} + [1-\pi_{t+1}] W_{t+1}^{oY,IV,II}\right\},
\end{aligned}
$$

where the tax rate $\theta_t^{YZ,II}(\sigma_{t-1},\pi_t)$ and the price $p_t^{IV,II}(\sigma_{t-1},\pi_t)$ read

$$
\begin{aligned}
\theta_t^{YZ,II}(\sigma_{t-1},\pi_t) &= \beta - \frac{\gamma}{2} Q_t^{II}(\sigma_{t-1},\pi_t) - \frac{2m+\gamma}{2} Z_t^{II}(\sigma_{t-1},\pi_t), \\
p_t^{IV,II}(\sigma_{t-1},\pi_t) &= \beta - \frac{\gamma}{2}\left[Z_t^{II}(\sigma_{t-1},\pi_t) + Q_t^{II}(\sigma_{t-1},\pi_t)\right].
\end{aligned}
$$

The welfare difference is given by

$$
\begin{aligned}
\Delta^{II} &= W_t^{yY,II} - W_t^{yY,IV,II} \\
&= \frac{\{[4m+\gamma][\pi[\alpha-\sigma_{t-1}]-1] - 2\rho m \pi_t[\beta - 2[1+\rho\delta]h]\}^2}{2[4m+\gamma][2m+\gamma\pi_t\{1-\pi_t\}]^2\rho^2}. \qquad \text{(A.16)}
\end{aligned}
$$

Suppose now that the capacities Z_t^{IV} and Q_t^{IV} are given by (43) and (44). If the Y-government at time t implements the tax rate θ_t^{YZ}, the welfare functions for period $t+1$ read

$$
\begin{aligned}
W_{t+1}^{oO,IV} &= \beta \frac{Z_{t+1}(\sigma_t,\pi_{t+1}) + Q_{t+1}(\sigma_t,\pi_{t+1})}{2} - \frac{\gamma}{2} \frac{[Z_{t+1}(\sigma_t,\pi_{t+1}) + Q_{t+1}(\sigma_t,\pi_{t+1})]^2}{4} \\
&- p_{t+1}^O(\sigma_t,\pi_{t+1}) \frac{[Z_{t+1}(\sigma_t,\pi_{t+1}) + Q_{t+1}(\sigma_t,\pi_{t+1})]}{2} + p_{t+1}^O(\sigma_t,\pi_{t+1}) Z_{t+1}(\sigma_t,\pi_{t+1}) \\
&- \frac{m}{2} [Z_{t+1}(\sigma_t,\pi_{t+1})]^2 + p_{t+1}^O(\sigma_t,\pi_{t+1}) Q_{t+1}(\sigma_t,\pi_{t+1}) \\
&- h\left[Z_{t+1}(\sigma_t,\pi_{t+1}) + \delta Z_t^{IV}(\sigma_{t-1},\pi_t) + \delta^2 E_{t-1}\right],
\end{aligned}
$$

$$
\begin{aligned}
W_{t+1}^{oY,IV} &= \beta\frac{b_{t+1}^{s}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}-\frac{\gamma}{2}\frac{\left[b_{t+1}^{s}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})\right]^2}{4}\\
&-p_{t+1}^{Y}(\sigma_t,\pi_{t+1})\frac{b_{t+1}^{s}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}+p_{t+1}^{Y}(\sigma_t,\pi_{t+1})b_{t+1}^{s}(\sigma_t,\pi_{t+1})\\
&-\frac{m}{2}\left[b_{t+1}^{s}(\sigma_t,\pi_{t+1})\right]^2-\theta_{t+1}^{Y}(\sigma_t,\pi_{t+1})b_{t+1}^{s}(\sigma_t,\pi_{t+1})+p_{t+1}^{Y}(\sigma_t,\pi_{t+1})Q_{t+1}(\sigma_t,\pi_{t+1})\\
&+\frac{\theta_{t+1}^{Y}(\sigma_t,\pi_{t+1})b_{t+1}^{s}(\sigma_t,\pi_{t+1})-\sigma_{t+1}Q_{t+2}(\sigma_{t+1},\pi_{t+2})}{2}\\
&-h\left[b_{t+1}^{s}(\sigma_t,\pi_{t+1})+\delta Z_t^{IV}(\sigma_{t-1},\pi_t)+\delta^2E_{t-1}\right].
\end{aligned}
$$

Consequently, welfare of the young generation at time t is given by

$$
\begin{aligned}
W_t^{yY,IV} &= \beta\frac{Z_t^{IV}(\sigma_{t-1},\pi_t)+Q_t^{IV}(\sigma_{t-1},\pi_t)}{2}-\frac{\gamma}{2}\frac{\left[Z_t^{IV}(\sigma_{t-1},\pi_t)+Q_t^{IV}(\sigma_{t-1},\pi_t)\right]^2}{4}\\
&-p_t^{IV}(\sigma_{t-1},\pi_t)\frac{\left[Z_t^{IV}(\sigma_{t-1},\pi_t)+Q_t^{IV}(\sigma_{t-1},\pi_t)\right]}{2}+L-[\alpha-\sigma_t]Q_{t+1}(\sigma_t,\pi_{t+1})\\
&-Z_{t+1}(\sigma_t,\pi_{t+1})+\frac{\theta_t^{Yb}(\sigma_{t-1},\pi_t)Z_t^{IV}(\sigma_{t-1},\pi_t)-\sigma_tQ_{t+1}(\sigma_t,\pi_{t+1})}{2}\\
&-h\left[Z_t^{IV}(\sigma_{t-1},\pi_t)+\delta E_{t-1}\right]+\rho\left\{\pi_{t+1}W_{t+1}^{oO,IV}+[1-\pi_{t+1}]W_{t+1}^{oY,IV}\right\},
\end{aligned}
$$

where p_t^{IV} is determined by (45).

If the Y-government implements the case (II) policy, i.e. the tax rate θ_t^{Yb}, the welfare functions for period $t+1$ read

$$
\begin{aligned}
W_{t+1}^{oO,II,IV} &= \beta\frac{Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}-\frac{\gamma}{2}\frac{\left[Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})\right]^2}{4}\\
&-p_{t+1}^{O}(\sigma_t,\pi_{t+1})\frac{\left[Z_{t+1}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})\right]}{2}+p_{t+1}^{O}(\sigma_t,\pi_{t+1})Z_{t+1}(\sigma_t,\pi_{t+1})\\
&-\frac{m}{2}\left[Z_{t+1}(\sigma_t,\pi_{t+1})\right]^2+p_{t+1}^{O}(\sigma_t,\pi_{t+1})Q_{t+1}(\sigma_t,\pi_{t+1})\\
&-h\left[Z_{t+1}(\sigma_t,\pi_{t+1})+\delta b_t^{s,II,IV}(\sigma_{t-1},\pi_t)+\delta^2E_{t-1}\right],\\
W_{t+1}^{oY,II,IV} &= \beta\frac{b_{t+1}^{s}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}-\frac{\gamma}{2}\frac{\left[b_{t+1}^{s}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})\right]^2}{4}\\
&-p_{t+1}^{Y}(\sigma_t,\pi_{t+1})\frac{b_{t+1}^{s}(\sigma_t,\pi_{t+1})+Q_{t+1}(\sigma_t,\pi_{t+1})}{2}+p_{t+1}^{Y}(\sigma_t,\pi_{t+1})b_{t+1}^{s}(\sigma_t,\pi_{t+1})\\
&-\frac{m}{2}\left[b_{t+1}^{s}(\sigma_t,\pi_{t+1})\right]^2-\theta_{t+1}^{Y}(\sigma_t,\pi_{t+1})b_{t+1}^{s}(\sigma_t,\pi_{t+1})+p_{t+1}^{Y}(\sigma_t,\pi_{t+1})Q_{t+1}(\sigma_t,\pi_{t+1})\\
&+\frac{\theta_{t+1}^{Y}(\sigma_t,\pi_{t+1})b_{t+1}^{s}(\sigma_t,\pi_{t+1})-\sigma_{t+1}Q_{t+2}(\sigma_{t+1},\pi_{t+2})}{2}\\
&-h\left[b_{t+1}^{s}(\sigma_t,\pi_{t+1})+\delta b_t^{s,II,IV}(\sigma_{t-1},\pi_t)+\delta^2E_{t-1}\right].
\end{aligned}
$$

To determine

$$
b_t^{s,II,IV}=\frac{2\beta-2\theta_t^{Yb,IV}(\sigma_{t-1},\pi_t)-\gamma Q_t^{IV}(\sigma_{t-1},\pi_t)}{2m\gamma},
$$

we have to take account of

$$\theta_t^{Yb,IV} = -\frac{\gamma}{2}Q_t^{IV}(\sigma_{t-1},\pi_t) + \frac{4m+2\gamma}{4m+\gamma}[1+\rho\delta]h + \frac{2m}{4m+\gamma}\beta.$$

The welfare of the young generation of period t reads

$$\begin{aligned}
W_t^{yY,II,IV} &= \beta\frac{b_t^{s,II,IV}(\sigma_{t-1},\pi_t) + Q_t^{IV}(\sigma_{t-1},\pi_t)}{2} - \frac{\gamma}{2}\frac{\left[b_t^{s,II,IV}(\sigma_{t-1},\pi_t) + Q_t^{IV}(\sigma_{t-1},\pi_t)\right]^2}{4} \\
&\quad - p_t^{II,IV}(\sigma_{t-1},\pi_t)\frac{\left[b_t^{s,II,IV}(\sigma_{t-1},\pi_t) + Q_t^{IV}(\sigma_{t-1},\pi_t)\right]}{2} + L - [\alpha-\sigma_t]Q_{t+1}(\sigma_t,\pi_{t+1}) \\
&\quad - Z_{t+1}(\sigma_t,\pi_{t+1}) + \frac{\theta_t^{Yb,IV}(\sigma_{t-1},\pi_t)b_t^{s,II,IV}(\sigma_{t-1},\pi_t) - \sigma_t Q_{t+1}(\sigma_t,\pi_{t+1})}{2} \\
&\quad - h\left[b_t^{s,II,IV}(\sigma_{t-1},\pi_t) + \delta E_{t-1}\right] + \rho\left\{\pi_{t+1}W_{t+1}^{oO,II,IV} + [1-\pi_{t+1}]W_{t+1}^{oY,II,IV}\right\},
\end{aligned}$$

with

$$p_t^{II,IV} = \frac{2m\beta + \gamma\theta_t^{Yb,IV}(\sigma_{t-1},\pi_t)}{2m+\gamma} - \frac{m\gamma Q_t^{IV}(\sigma_{t-1},\pi_t)}{2m+\gamma}.$$

The welfare difference reads

$$\begin{aligned}
\Delta^{IV} &= W_t^{yY,II,IV} - W_t^{yY,IV} \\
&= \frac{\{[4m+\gamma][\pi[\alpha-\sigma_{t-1}]-1] - 2\rho m\pi_t[\beta - 2[1+\rho\delta]h]\}^2}{8m^2[4m+\gamma]\pi_t^2\rho^2}.
\end{aligned} \tag{A.17}$$

Both (A.16) and (A.17) describe a parabola with a zero at $\sigma_{t-1} = \tilde{\sigma}_{t-1}$ and positive values for all $\sigma_{t-1} \neq \tilde{\sigma}_{t-1}$. □

A.5. Proof of Proposition 5

The subsidy rate of case (II) can be only set if $\sigma_{t-1}^{II} \in [0, \tilde{\sigma}_{t_1}]$. The upper limit implies that $\sigma_{t-1}^{\Delta II} = \tilde{\sigma}_{t_1} - \sigma_{t-1}^{II} \geq 0$ has to hold. The interval $[0, \tilde{\sigma}_{t_1}]$ only exists if $\tilde{\sigma}_{t-1} \geq 0$. Because $\frac{d\sigma_{t-1}^{II}}{d\alpha} < 0$, $\frac{d\sigma_{t-1}^{\Delta II}}{d\alpha} > 0$, $\frac{d\tilde{\sigma}_{t-1}}{d\alpha} > 0$, and $\frac{d^2\sigma_{t-1}^{II}}{d\alpha^2} = \frac{d^2\sigma_{t-1}^{\Delta II}}{d\alpha^2} = \frac{d^2\tilde{\sigma}_{t-1}}{d\alpha^2} = 0$, σ_{t-1}^{II} linearly decreases in α, while both $\sigma_{t-1}^{\Delta II}$ and $\tilde{\sigma}_{t-1}$ linearly increase in α. The zeros are given by α^{II}, $\alpha^{\Delta II}$ and $\alpha^{\min II}$, which proves proposition 5(i).

The subsidy of case (IV) can be only set if $\sigma_{t-1}^{IV} \in [\tilde{\sigma}_{t_1}, \alpha-1]$ and $\sigma_{t-1}^{IV} \geq 0$. The former lower limit implies that $\sigma_{t-1}^{\Delta IV} = \tilde{\sigma}_{t_1} - \sigma_{t-1}^{IV} \leq 0$ has to hold. The latter lower limit implies that $\Delta^{\min} = \alpha - 1 - \sigma_{t-1}^{\Delta IV} \geq 0$ has to hold. Because $\frac{d\sigma_{t-1}^{IV}}{d\alpha} < 0$, $\frac{d\sigma_{t-1}^{\Delta IV}}{d\alpha} > 0$, $\frac{d\Delta^{\min}}{d\alpha} > 0$, and $\frac{d^2\sigma_{t-1}^{IV}}{d\alpha^2} = \frac{d^2\sigma_{t-1}^{\Delta IV}}{d\alpha^2} = \frac{d^2\Delta^{\min}}{d\alpha^2} = 0$, σ_{t-1}^{IV} linearly decreases in α, while both $\sigma_{t-1}^{\Delta IV}$ and $\Delta^{\min}$ linearly increase in α. The zeros are given by α^{IV}, $\alpha^{\Delta IV}$ and $\alpha^{\min IV}$, which proves proposition 5(ii).

Suppose that both σ_{t-1}^{II} and σ_{t-1}^{IV} are feasible for some α. Then, a Y-government will set the subsidy rate σ_{t-1}^{II} at time $t-1$ if $\Delta W_{t-1} = W_{t-1}^{yY}(\sigma_{t-1}^{II}) - W_{t-1}^{yY}(\sigma_{t-1}^{IV})$. By differentiating ΔW_{t-1}, we find

$$\frac{d^2 \Delta W_{t-1}}{d\alpha^2} = \frac{-[1-\pi_t]}{8\rho m^2[4m+\gamma]^2\pi_t\Big\{4m^2+4m\gamma[1-\pi_t]^2\pi_t+\gamma^2\pi_t^2[1-\pi_t]\Big\}}$$
$$\Bigg\{2\gamma^5\pi_t^3 + 8m\gamma^4\pi_t^2[1+2\pi_t] + 32m^3\gamma^2\pi_t\Big[3+[15-7\pi_t]\pi_t\Big]$$
$$+ 128m^4\gamma\pi_t\Big[3+[7-5\pi_t]\pi_t\Big] + 512m^5\pi_t\Big[1+[1-\pi_t]\pi_t\Big]$$
$$+ 8m^2\gamma^3\pi_t\Big[1+\pi_t[13+\pi_t]\Big]\Bigg\} < 0.$$

Consequently, the extremum of ΔW_{t-1} at

$$\alpha^{\max} = \frac{1}{\pi_t\Big\{4m^2[4m+\gamma]^2+4m[m+\gamma][4m+\gamma]^2\pi_t-[2m+\gamma]^2[16m^2-\gamma^2]\pi_t^2\Big\}}$$
$$\Bigg\{\gamma^4\pi_t^3[1+2h\rho] + 2m\gamma^3\pi_t^2\Big[3+\pi_t+2h[2+\pi_t]\rho\Big]$$
$$+ 16m^4\Big[2+\pi_t\Big[4-4\pi_t+[2h+\beta]\rho+2\pi_t\rho[\beta[1-\pi_t]+2h\pi_t]-2h\delta[1+2[1-\pi_t]\pi_t]\rho^2\Big]\Big]$$
$$+ 4m^2\gamma^2\pi_t\Big[3+2h\rho+7\pi_t[1+2h\rho]-\pi_t^2\Big[4-\beta\rho+2h\rho[4+\delta\rho]\Big]\Big]$$
$$+ 8m^3\gamma\Big[1+\pi_t\Big[8+6h\rho-\pi_t[4\pi_t-2h[5-\pi_t]\rho+\beta[2-\pi_t]\rho-2h\delta[2-\pi_t]\rho^2]\Big]\Big]\Bigg\}$$

is a maximum. The zeros are given by $\alpha = \pm\tilde{\alpha}$, so that the government chooses σ_{t-1}^{II} if $\alpha < \tilde{\alpha}$. □

The relations of $\alpha^{\min II}$, $\alpha^{\min IV}$, α^{II}, $\alpha^{\Delta II}$, α^{IV} and $\alpha^{\Delta IV}$ used for Fig. 3 are given by

$$\alpha^{IV} - \alpha^{\min IV} = \frac{4\rho m h}{2m+\gamma} > 0,$$
$$\alpha^{\Delta IV} - \alpha^{IV} = \frac{2m}{[2m+\gamma]\pi_t} + \frac{4\rho m^2\{\beta-2[1+\rho\delta]h\}}{[2m+\gamma][4m+\gamma]} - \frac{2m[1+2\rho h]}{2m+\gamma},$$
$$\alpha^{\min II} - \alpha^{\Delta IV} = \frac{\gamma[1-\pi_t-2\rho\pi_t h]}{[2m+\gamma]\pi_t} + \frac{2\rho m\gamma\{\beta-2[1+\rho\delta]h\}}{[2m+\gamma][4m+\gamma]},$$
$$\alpha^{\Delta II} - \alpha^{\min II} = \frac{2\gamma\rho\pi_t\{h\pi_t[4m+\gamma]-m[\beta-2[1+\rho\delta]h]\}}{[4m+\gamma][2m+\gamma\pi_t]},$$
$$\alpha^{II} - \alpha^{\Delta II} = \rho\frac{\{4m^2+4m\pi_t\gamma[1-\pi_t]^2+\gamma^2\pi_t^2[1-\pi_t]\}\{h\pi_t[4m+\gamma]-m[\beta-2[1+\rho\delta]h]\}}{m[4m+\gamma]\pi_t[3-2\pi_t][2m+\gamma\pi_t]}.$$

If both π_t and $\beta-2[1+\rho\delta]h$ are sufficiently small, all stated differences are positive.

A.6. Changing the election probability by setting subsidies

In case (II) we can derive a closed form expression for $\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}}$ using (60):

$$
\begin{aligned}
\frac{\mathrm{d}\pi_t}{\mathrm{d}\sigma_{t-1}} = \Bigg\{ & \frac{1}{(4m+\gamma)\nu(2m-\gamma(\pi_t-1)\pi_t)} \\
& \frac{1}{(4(\pi_t(2\alpha(\pi_t-2)-\beta\rho(\pi_t-2)+2h\rho(\pi_t+\delta(\pi_t-1)\rho)-2\pi_t\sigma_{t-1}+4\sigma_{t-1}-2)+2)m^2+2\gamma\left(\pi_t\left(-2h\rho(\delta\rho+2)\pi_t^2+(2h\rho+\beta\rho+\sigma_{t-1}+2)\pi_t-\alpha(\pi_t+2)+h\rho(\delta\rho+2)+2\sigma_{t-1}-1\right)+1\right)m+\gamma^2\pi_t^2(-\alpha-h(\pi_t-1)\rho(\delta\rho+2)+\sigma_{t-1}+1))} \\
& \Big[128\rho^2m^5+16\Big(4\nu(\pi_t-1)\alpha^2-4\nu(\beta(\pi_t-1)\rho+h(\delta\rho-2(\delta\rho\pi_t+\pi_t))\rho+2(\pi_t-1)\sigma_{t-1}+1)\alpha+4\nu(\pi_t-1)\sigma_{t-1}^2 \\
& +\rho\left(4\nu\rho(\delta\rho+1)(\delta\rho\pi_t+\pi_t+1)h^2-2\nu(2\beta\pi_t\rho+\delta(\beta(2\pi_t-1)\rho+2)\rho+2)h+2\beta\nu+4\gamma\rho+(\pi_t-1)\left(\beta^2\nu-12\gamma\pi_t\right)\rho\right)+4\nu(\beta(\pi_t-1)\rho+h(\delta\rho-2(\delta\rho\pi_t+\pi_t))\rho+1)\sigma_{t-1}\Big)m^4 \\
& +8\gamma(\gamma\left(12\left(\pi_t^4-2\pi_t^3+\pi_t\right)+1\right)\rho^2 \\
& +\nu((\beta\rho-2h(\delta\rho+1)\rho+2\sigma_{t-1})^2\pi_t^3-3(-\beta\rho+2h(\delta\rho+1)\rho-2\sigma_{t-1})(-\beta\rho+2h(\delta\rho+1)\rho-2\sigma_{t-1}+2)\pi_t^2+2\left(2h^2(\delta\rho+1)(\delta\rho+2)\rho^2+\beta(\sigma_{t-1}-7)\rho-h(-10\delta\rho+\beta(\delta\rho+2)\rho+4\delta\sigma_{t-1}\rho+6\sigma_{t-1}-6)\rho+2(\sigma_{t-1}-7)\sigma_{t-1}+4\right)\pi_t \\
& -4\sigma_{t-1}^2+4\alpha^2\left(\pi_t^3-3\pi_t^2+\pi_t-1\right)+5\beta\rho+h\rho(-6\delta\rho-\beta(\delta\rho+2)\rho+2h(\delta\rho+1)(\delta\rho+2)\rho-2)-2(2h+\beta)\rho\sigma_{t-1}+12\sigma_{t-1} \\
& +2\alpha\left(2h\rho+\beta\rho+4\sigma_{t-1}+\pi_t\left((-2\beta\rho+4h(\delta\rho+1)\rho-4\sigma_{t-1})\pi_t^2-6(-\beta\rho+2h(\delta\rho+1)\rho-2\sigma_{t-1}+1)\pi_t-\beta\rho+2h\rho(2\delta\rho+3)-4\sigma_{t-1}+14\right)-6\right)-8))m^3 \\
& -4\gamma^2(\gamma(\pi_t-1)\pi_t(2(\pi_t-2)\pi_t-1)\left(2\pi_t^2-3\right)\rho^2 \\
& +\nu(2h\rho(\delta\rho+2)(-\beta\rho+2h(\delta\rho+1)\rho-2\sigma_{t-1})\pi_t^4+\left(8\sigma_{t-1}+\rho\left(-4\rho(\delta\rho+1)h^2-2\delta\rho(\beta\rho+8)h+4(\sigma_{t-1}-6)h+\beta(\beta\rho+2\sigma_{t-1}+4)\right)\right)\pi_t^3 \\
& -3(-4(\sigma_{t-1}-1)\sigma_{t-1}+\beta(\rho-2\rho\sigma_{t-1})+2h\rho(2\sigma_{t-1}+\delta\rho(2\sigma_{t-1}-3)-5)-4)\pi_t^2-\left(\sigma_{t-1}^2-4h\rho(\delta\rho+2)\sigma_{t-1}-28\sigma_{t-1}-7\beta\rho+h\rho(10\delta\rho-\beta(\delta\rho+2)\rho+2h(\delta\rho+1)(\delta\rho+2)\rho+6)+20\right)\pi_t \\
& +\sigma_{t-1}^2+\alpha^2(\pi_t(12\pi_t-1)+1)-2(2h+\beta)\rho+h\rho(\delta\rho+2)\sigma_{t-1}-9\sigma_{t-1}+\alpha\left(4h\rho(\delta\rho+2)\pi_t^4-2(2h\rho+\beta\rho+4)\pi_t^3+6(-\beta\rho+2h(\delta\rho+1)\rho-4\sigma_{t-1}+2)\pi_t^2+2(-2h\rho(\delta\rho+2)+\sigma_{t-1}-14)\pi_t-h\rho(\delta\rho+2)-2\sigma_{t-1}+9\right)+12))m^2 \\
& -2\gamma^3(\gamma(\pi_t-1)^2\pi_t^2(2\pi_t-3)(2\pi_t+1)\rho^2+\nu(h\rho(\delta\rho+2)(-\beta\rho+2h(\delta\rho+1)\rho-4\sigma_{t-1})\pi_t^4+\left(-2h^2(\delta\rho+1)(\delta\rho+2)\rho^2+2\beta(\sigma_{t-1}+1)\rho+h(\beta\rho(\delta\rho+2)+4(-3\delta\rho+\sigma_{t-1}-5))\rho+\sigma_{t-1}(3\sigma_{t-1}+8)\right)\pi_t^3 \\
& +3\alpha^2(\pi_t+1)\pi_t^2+3(4h\rho(\delta\rho+2)+(\sigma_{t-1}-1)\sigma_{t-1}+4)\pi_t^2+(h\rho(\delta\rho+2)+7)(\sigma_{t-1}-2)\pi_t-h\rho(\delta\rho+2)-2\sigma_{t-1}+\alpha\left(\pi_t\left(4h\rho(\delta\rho+2)\pi_t^3-2(2h\rho+\beta\rho+3\sigma_{t-1}+4)\pi_t^2+(3-6\sigma_{t-1})\pi_t-h\rho(\delta\rho+2)-7\right)+2\right)+6))m \\
& -\gamma^4\left(\gamma(\pi_t-1)^3\rho^2\pi_t^3+\nu\left(h\rho(\delta\rho+2)(\alpha-\sigma_{t-1})\pi_t^3+\left(\alpha^2-(h\rho(\delta\rho+2)+2(\sigma_{t-1}+1))\alpha+h\rho(\delta\rho+2)(\sigma_{t-1}-2)+\sigma_{t-1}(\sigma_{t-1}+2)\right)\pi_t^2+3(h\rho(\delta\rho+2)+1)\pi_t-h\rho(\delta\rho+2)-3\right)\pi_t+\nu\right)\Big]\Bigg\}^{-1}. \qquad \text{(A.18)}
\end{aligned}
$$

A.7. Parameters of the numerical example

We assume that one period equals 40 years. With an annual discount-rate of 3%, we get $\rho = \frac{1}{1.03^{40}} \approx 0.3066$. For the natural regeneration rate $1 - \delta$, we make use of Joos et al. (2013, pp.2801). According to their calculations, the fraction of one CO_2 unit emitted at time t that remains in the atmosphere after $\tilde{t} \in [0, 1000]$ years is given by $0.2173 + 0.224e^{-0.0025\tilde{t}} + 0.2824e^{-0.0274\tilde{t}} + 0.2763e^{-0.2323\tilde{t}}$. For $\tilde{t} = 40$ we get $\delta \approx 0.5144$. To get numbers for the marginal extraction costs m, the marginal climate damages h, and the marginal capacity costs of green investments α, we use IWG (2016), IEA (2022), IEA (2023a), and IRENA (2023). For α, we calculate the average capacity costs of fossil fuel fired (coal and gas) power plants per kWh in the USA, EU, China and India, and the average capacity costs of renewables (PV, Wind, Nuclear) per kWh.[18] The data of IEA (2022) give the calculations summarized in Tab. A.3 - A.6, where the share of onshore and offshore wind are taken from IRENA (2023). According to IEA (2023a), on average, 40% of annual investments into renewable energies and grids are used for grid investment between 2021 and 2050. Therefore, we multiply the capacity costs of wind and solar energy with $1\frac{2}{3}$.

	Costs	Capacity Factor	Lifetime Capacity Costs	Energy Production
Coal	2100 $/kW	35%	150 $/kWh	914 TWh
Gas	1000 $/kW	55%	45.45 $/kWh	1747 TWh
Nuclear	5000 $/kW	90%	138.89 $/kWh	804 TWh
PV	1866.67 $/kW	21%	222.22 $/kWh	185 TWh
Onshore Wind	2033.33 $/kW	42%	121.03 $/kWh	441.83 TWh
Offshore Wind	6766,67 $/kW	42%	402.78 $/kWh	0.17 TWh

Table A.3: Capacity costs in the USA

For the USA, we get average capacity costs in USD per kWh of 81.36 for fossil fuels and of 144.18 for renewables. In case of the EU, the numbers are 144.56 and 252.19. For China, we get 40.30 and 171.23. For India, we get 46.86 and 139.12. By using the regions' relative share of fuel production and green energy production, respectively, as

[18] We consider nuclear power as a renewable energy, because it is carbon free.

	Costs	Capacity Factor	Lifetime Capacity Costs	Energy Production
Coal	2000 \$/kW	30%	166.67 \$/kWh	484 TWh
Gas	1000 \$/kW	20%	125 \$/kWh	547 TWh
Nuclear	6600 \$/kW	70%	235.71 \$/kWh	607 TWh
PV	1650 \$/kW	14%	294.64 \$/kWh	202 TWh
Onshore Wind	2916.67 \$/kW	29%	251.44 \$/kWh	386.12 TWh
Offshore Wind	5700 \$/kW	50%	285 \$/kWh	51.88 TWh

Table A.4: Capacity costs in the EU

	Costs	Capacity Factor	Lifetime Capacity Costs	Energy Production
Coal	800 \$/kW	50%	40 \$/kWh	5536 TWh
Gas	560 \$/kW	30%	46.67 \$/kWh	257 TWh
Nuclear	2800 \$/kW	80%	87.50 \$/kWh	418 TWh
PV	1200 \$/kW	13%	230.77 \$/kWh	327 TWh
Onshore Wind	1833.33 \$/kW	26%	176.28 \$/kWh	700.84 TWh
Offshore Wind	4700 \$/kW	32%	367.19 \$/kWh	61.16 TWh

Table A.5: Capacity costs in China

weights, the average capacity costs are 67.53 for fossil fuels and 172.72 for renewables. Finally, we take into account that more solar and wind energy requires storage capacities. According to IEA (2022), the world-wide battery capacity amounted to 45GW in 2022. By assuming that the regions' share of battery capacity is equal to the regions' share of world-wide solar and wind capacity and that the productivity of batteries is equal to the one of solar and wind capacity, we get a production of 57.68TWh. The costs per kWh are 315\$, as stated by IEA (2022). This increases the average costs of renewables to 174.52, which yields $\alpha \approx 2.5844$.

According to IWG (2016, p.5), the social costs of carbon increase from 51\$ per ton of CO_2 in 2020 to 85\$ per ton of CO_2 in 2050. On average, we get 67.57\$ per ton of CO_2 or 67,571,428.57\$ per Mt CO_2. We multiply this with an average emission intensity factor of 0.3183Mt CO_2 per TWh, which calculated as stated in Tab. A.7. Thus, we set

	Costs	Capacity Factor	Lifetime Capacity Costs	Energy Production
Coal	1200 \$/kW	65%	46.15 \$/kWh	1270 TWh
Gas	700 \$/kW	25%	70 \$/kWh	39 TWh
Nuclear	2800 \$/kW	80%	87.50 \$/kWh	50 TWh
PV	1066.67 \$/kW	20%	133.33 \$/kWh	105 TWh
Onshore Wind	1866.67 \$/kW	26%	179.49 \$/kWh	79 TWh
Offshore Wind	5100 \$/kW	33%	386.36 \$/kWh	0 TWh

Table A.6: Capacity costs in India

$h = 21508.5222\$$ per GWh.

	World CO_2 Emissions	World Energy Supply	Emission Factor in Mt CO_2/TWh
Coal	10876Mt	30558 TWh	0.3559
Gas	3201Mt	15834.6 TWh	0.2022

Table A.7: Average Emission Factor, Data from IEA (2022)

We set the marginal extraction costs m, such that they solve (14) for $\theta_t = \lambda_b = 0$. As energy price, we use the average energy price of the USA, EU, China and India in 2022. According to data from the International Energy Agency, the consumer price of electricity was 151.2\$/MWh in the USA and 82.3\$/MWh in China.[19] For the EU, eurostat reportes 0.2168€/kWh and for India statista reports 6.29INR/kWh.[20] With average exchange rates of 1.053\$/€ and 78.611INR/\$, we get 228.24\$/MWh and 80.01\$/MWh, respectively. Thus, the average energy price is 122634.5488\$/GWh, which yields $m \approx 0.0116$. The remaining parameter β, γ, ν and L are chosen such that we get an interior solution with respect to the subsidy rate σ_{t-1} and the election probability π_t in case of an endogenous probability. Finally, we assume that the emission stock E_0 is normalized to zero.

[19] Cf. IEA (2023b).
[20] Cf. eurostat (2023) and Statista (2023).

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