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Abstract

Climate change mitigation undoubtedly proves a political matter, thereby stalling efficient energy transition. Hence, a natural question seems to arise: are certain political systems more capable than others of conducting effective climate policy? On the one hand, authoritarian governments possess the necessary apparatus to implement unpopular but effective solutions. Yet, in practice, it appears that these tools are not utilised for environmental goals to a degree comparable with democratic states. This paper aims to establish the theoretical impact of such institutional conditions (i.e. level of democracy) on the economics of climate change mitigation. Thus, we rely on a dynamic adaptation of the seminal model of political economy by McGuire and Olson (1996) and introduce a climate externality. The results suggest that lower democratic accountability is associated with fewer cumulative emissions. This is achieved, however, by reduced economic growth and the ability to constrain societal consumption rather than higher investment in renewables. We show that a positive democracy shock contributes to increased investment in renewables, as well as fewer emissions when expressed as a percentage of output. Moreover, democratic policymakers prove more efficient in limiting emissions in the event of a climate shock.

1 Introduction

Climate change mitigation – despite the scientific consensus regarding the seriousness of the phenomenon – undoubtedly proves a political problem. It probably is not surprising: because agents in society assess policies differently, every policy instrument generates an economic conflict (Persson and Tabellini, 2000). The political aspect of the issue is well illustrated by the referendums in the State of Washington. The proposals for a carbon tax of $15 per ton of CO_2 were rejected twice (in 2016 and 2018). At the same time, it directly points to possible shortcomings of the democratic system in relation to efficient climate policy.

Similarly, it raises the question if nondemocratic systems are perhaps better suited to overcoming political constraints and producing effective solutions. Political regime characteristics, however, were not considered in any of the influential economic models of climate change (e.g. Nordhaus (2008); Golosov et al. (2014)). In this paper, we address this gap and focus on the theoretical impact of democracy's level on the efficiency of climate policy and the ability to limit emissions. Would a rational autocrat be more concerned about prospective climate damages to their source of income? Should countries democratise as far as climate change is concerned?

At the core of the issue is the fact that climate change is a long-horizon problem. At the same time, the costs of its mitigation are immediate. The electoral cycle, however, appears to favour policies with quick positive impacts and minimal costs upon the voters. Budget constraints might give precedence to more urgent (and critical to economic subsistence) matters than environmental care (Midlarsky, 1998). At the same time, officials might indeed make bold climate policy proposals, but delay their implementation so that the budget consequences fall onto their successors (Sinn, 2009).

Furthermore, as von Stein (2022) points out, the fundamental issue that relates democratic quality to environmental outcomes concerns citizens' preferences: electoral accountability implies that policymakers must consider what the public actually wants. Politicians will not risk their next term by implementing unpopular decisions if voters view a climate policy as unacceptable (as was the case e.g. in Washington). Additionally, Barker (2008) stresses the importance of agents' heterogeneity when it comes to practice. Democratic policymaking inherently strives to achieve a compromise between various interest groups, which might halt the efficient development of timely solutions.

On the other hand, authoritarian[1] regimes care about their citizens' preferences and wellbeing only to a limited extent. If rulers deem a policy or an investment worthwhile, they will simply implement it without too much consideration for households' welfare. Undeniably, the "if" is critical here, but specific examples

[1] Throughout this paper, we will use terms like "authoritarian", "autocratic", "dictatorship", etc. interchangeably.

from the world – while not numerous – illustrate the efficiency argument rather vividly.

For instance, in 2023, China began constructing the world's largest plant to generate hydrogen from renewable sources. Kazakhstan commissioned one of its biggest solar plants (100MW) in 2020. Probably the most relevant aspect of the Kazakh undertaking in the context of efficiency is that the entire process (from the bidding and permission, followed by construction and launch of commercial operation) took only two years. Therefore, such examples might explain why the seriousness of the prospective climate crisis and lack of sufficient action in this regard gave rise to the notions of environmental authoritarianism (see e.g. Beeson (2010)) or authoritarian environmentalism (see e.g. Shen and Jiang (2020)).

As we evidence in the literature review in section 2, the literature offers more (often mutually exclusive) arguments regarding the theoretical channels relating the regime type with environmental performance. Moreover, we show that the overall political dimension of environmental performance or policy is studied rather extensively. However, the specific issue of the role of democracy's level in this context is found mostly in empirical papers. Therefore, a clear gap remains in the economic modelling literature. We describe Congleton (1992) and Eriksson and Persson (2003) - two of the very scarce models which attempt to address the matter of our interest - in the literature review, too.

In this paper, we develop a dynamic model of political economy and climate change. The core of our motivation is that carbon emissions accumulate over time and gradually increase the global average temperature. Climate change and associated damages to the economy, therefore, constitute a long-term problem. To address this, we adapt the seminal, static model of political economy by McGuire and Olson (1996) by introducing a climate externality and dynamics: we add the time dimension and reframe the original problem as an intertemporal one. Instead of directly modelling the electoral cycle, we focus on the interplay (channelled by the extent of democratic accountability) between office-holders' and society's objectives to see how respective consumption needs effectively shape policy enactment.

The choice of McGuire and Olson's (1996) design is mainly based on its established position in the literature and the influence it exerted in political economics, particularly in the regime-studies area (see e.g. Papaioannou and van Zanden (2015)). However, an equally important argument concerns the fact of its relative simplicity: the model integrates political and economic considerations into a single dimension. Representing the degree of democracy as a parameter, and thus nesting democracy and autocracy within a single model, is crucial if we are to tractably address questions of how different regime types deal with dynamic policy questions, in particular in the climate change context. Moreover, McGuire and Olson's framework enables valid comparisons *across* the political spectrum. This is essential if we consider the fact that most countries fall into the hybrid regime or flawed democracy category and thus lie on the neither extreme side of the said spectrum. We discuss McGuire and Olson (1996) in more detail in section 2.2.

In accounting for externality, our dynamic model relies on two capital types: green (emission-neutral) capital and brown (more productive but emission-inducing) capital. This way, we show the theoretical impact of the level of democracy on the relative efficiency of limiting emissions, both in the short and long run. Moreover, we visualise the adjustments in the economy over time and demonstrate the impact of climate and regime shocks.

Ultimately, our model predicts that - due to lower economic growth - an autocracy tends to feature lower cumulative emissions. However, a more democratic economy produces fewer emissions when measured as percentage of output. A positive democracy shock contributes to increased emissions, but also to (more than proportionally) higher investment in renewables. In addition, democracies are more efficient in curtailing emissions when faced with a climate shock.

The contribution of this paper is primarily theoretical as it strives to answer the following question: is democracy conducive to efficient climate policy and limiting carbon emissions? Therefore, we extend the existing, very limited, economic modelling literature that analyses the impact of a political regime on environmental regulation. Our study's contribution also touches on methodological grounds. Namely, to our knowledge, we present the first dynamic adaptation of the McGuire and Olson (1996) model, as well as its first climate change variant. Consequently, our paper has the potential to inform climate-related policymaking, with particular consideration of the political regime aspect. Recommendations of this kind could be particularly relevant to international agencies facilitating global climate transition.

The paper is structured as follows. The next section surveys the existing literature and outlines the original model by McGuire and Olson (1996), whereas section 3 introduces our adapted model. Subsequently, we outline the optimisation procedure, and section 5 reports the results of dynamic simulations. The last section concludes.

2 Literature review

2.1 Democracy and environment

Regarding the theoretical channels which relate the regime type with environmental performance or the overall efficiency of policymaking, the literature offers many (often mutually exclusive) arguments. According to Li and Reuveny (2006), free media assured in more democratic countries enable raising public awareness regarding the environment (although the same freedom of speech might as well give a platform for denialist misinformation (von Stein, 2022)). Well-informed citizens might then pressure the government to act or elect suitable officials owing to their civil and political rights. Authoritarian regimes are inherently less sensitive to such pressures (Payne, 1995).

Another argument concerns policy variability. Due to frequent elections and possible government changes, democracies are prone to policy and agenda instability (Rodrik, 1991). A clear example in this context can be found in Donald Trump, who withdrew the US from the Paris Agreement following his appointments in 2017 and 2025. On the other hand, autocracies also exhibit a risk of policy reversals, as well as an overall lack of credibility, thereby possibly deterring investment (Adam and Filippaios, 2007). Mobilising private investment in renewables in such an environment might, therefore, face obvious obstacles.

Lastly, following Tsebelis (2002), democratic policymaking is vulnerable to special-interest groups who can act as veto players. Considering the active role of oil sector lobbyists who oppose pro-climate legislation, this logic seems sensible. Nevertheless, autocratic regimes are not free from the influence of the elites who support or legitimise the reigns of a dictator, either (Bueno de Mesquita et al., 2003). They, too, often possess the control over the nation's natural resources.

Overall, the existing literature studied the impact of democracy on climate performance rather willingly; empirics is especially fruitful in this regard. Despite the political constraints prevalent in democracies, empirical papers mostly give a reassuring view of the positive impact of democratic quality on environmental performance. For instance, Sinha et al. (2023) find that democracies emit less CO_2 for a unit increase in per capita income. According to Lv (2017), democracies indeed curtail carbon emissions. However, this happens only once a country achieves a certain income level. Povitkina (2018), on the other hand, observes that once the influence of corruption is controlled for, the differences between regimes cease to be significant. Nevertheless, while providing us with beneficial insights, empirics – due to its backwards-looking character – does not constitute a sufficient tool for planning the climate transition. Turning to the economic modelling literature, we notice that the topic is much less prevalent.

Admittedly, environmental policy has been studied relatively extensively in political economy models. For instance, the impact of polluting producers' lobbying activity on environmental legislation – in the form of a green tax and three redistribution scenarios – is examined in the probabilistic voting model by Aidt (2010). Borissov et al. (2014), on the other hand, develop a dynamic median voter model with heterogenous households who vote for an environmental tax. Another example can be found in Tol (2020) who developed a model of climate policy with "selfish bureaucrats". However, modelling literature remains largely silent regarding the comparison of environmental policy across the democratic spectrum. Below, we present two scarce examples of such studies.

The most relevant paper is by Congleton (1992) who compares the stringency of pollution regulations between a democracy and an autocracy. In this model, environmental policy is said to follow an individual evaluation of the probability of environmental degradation. Such probability, in turn, decreases due to stricter regulations and increases with national output[2]. Furthermore, environmental standards are assumed to exert a nonlinear impact on national income. Initially, they improve the overall productivity (e.g. health) and increase income. Once a certain threshold is reached, additional regulations decrease national income "as less productive technologies are mandated and inputs are diverted from ordinary economic production to environmental improvement without offsetting productivity increases" (Congleton, 1992, p. 414).

The political component in Congleton's model is reflected chiefly by the share in the economy's income. In this sense, a democracy is governed by preferences of a median voter. Conversely, an authoritarian regime represents the choices of an agent whose share of income is necessarily larger than the median. Moreover, the author assumes the autocrat to have a time-horizon that is shorter than the median voter's. These two differences determine that the authoritarian regime would ultimately enforce a comparably less stringent environmental policy. Firstly, the autocrat would bear higher marginal costs of environmental control (i.e. would suffer "a larger fraction of associated reductions in national income"). Moreover, the costs of environmental policy are assumed to be concentrated in the initial periods, with gains manifesting in the later future. For this reason, a shorter time horizon of the autocrat also disincentivises more significant environmental protection.

The median voter theory is also used by Eriksson and Persson (2003) to examine the interplay between democracy, inequality and pollution. Compared to Congleton (1992), however, they assume the median voter to be decisive in both democracy and nondemocracy. The authors restrict the decision-making in nondemocracies to an exogenously given population subset, i.e. the policy outcome will reflect the preferences of the median voter from the privileged group only. Moreover, the model assumes heterogeneity regarding individual productivity, income and experienced environmental quality (i.e. the privileged group lives in cleaner areas).

Production-wise, the key tradeoff concerns the use of production technology: more productive technology is directly linked to higher emissions. Regarding the preferences, the voter must balance out the marginal utility of consumption with the marginal disutility of pollution. The authors find that a democracy pollutes less than a nondemocracy, assuming both regimes are characterised by a more equal income distribution. Moreover, focusing on environmental inequality,

[2]Regarding the influence of output, however, the author does not appear to assume it to be a source of environmental deterioration (which, in fact, is not specified in the paper at all). Instead, he suggests that the individual perception of risk increases when income is higher. Therefore, environmental regulation plays a role of a social insurance.

they conclude that it affects pollution levels only in nondemocracies. In such a case, higher environmental inequality contributes to greater contamination.

Relative to papers by Congleton (1992) or Eriksson and Persson (2003) which focus on air pollution, our study provides a fully dynamic perspective on the economics of climate change specifically. While the two models, to some extent, do consider the time dimension (i.e. Congleton (1992) refers to an agent's planning horizon; Eriksson and Persson (2003) - in an attempt to mimic the Environmental Kuznets Curve - assume the existence of two phases related to development), they fail to account for accumulation of emissions over time and associated temperature rise. This paper, moreover, shows the impact of climate and democracy shocks on the level of emissions in the short and long run alike.

2.2 Political economy model by McGuire and Olson (1996)

In this section, we introduce the McGuire and Olson (1996) framework (henceforth abbreviated "MOF") which our paper adopts and subsequently adapts. The central argument for MOF's usability concerns the fact that it simplifies and aggregates political and economic interactions into a single objective function. Moreover, the model offers a consistent framework which enables meaningful comparisons across the democratic spectrum. This contrasts with methods traditionally oriented on either the democratic process (e.g. median voter theorem) or a dictatorship (e.g. Wintrobe, 2004).

The framework assumes that, irrespective of the actual regime type, the authorities face only two choices. Firstly, they choose an optimal income tax rate, such that it maximises their prospective revenue. Once the tax rate is set, they decide on the level of public good provision. The society as a whole earns disposable market income, reduced in line with said income tax. In principle, they do not influence the economy.

In MOF, public good expenditure decreases the government's rents (they aim to maximise the difference between the tax revenue and public good spending). However, public good is critical (e.g. through maintenance of social order) to the production of *potential* output, i.e. before deadweight losses are accounted for. Such losses, in turn, are a result of incentive-distorting taxation. Thus, policymakers' decisions regarding the tax rate will incorporate the extent of possible inefficiencies.

An autocrat does not sell labour and does not earn any income in the market. Hence, they only aim to maximise the rents from extraction and face the following objective function:

$$tr(t)Y(G) \; - \; G, \; s.t. \; G < tr(t)Y(G) \qquad \text{(MOF:1)}$$

where

$$
\begin{aligned}
t &= constant\ average\ income\ tax\ rate \\
G &= amount\ of\ the\ pure\ public\ good\ input\ (price = 1) \\
Y(G) &= potential\ output;\ Y'(G) > 0;\ Y''(G) < 0;\ Y(0) = 0 \\
r(t) &= \%\ of\ potential\ Y\ produced\ for\ given\ t;\ r'(t) < 0;\ r(0) = 1 \\
r(t)Y(G) &= I = \ actual\ income
\end{aligned}
$$

Such conceptualisation of autocracy yields interesting theoretical predictions. The critical aspect here is that a dictator, whose self-interest in principle leads them to extract resources from the society, benefits from the productivity of their citizens. Therefore, the rational autocrat would limit the "tax-theft" inclinations because of the incentive-distorting taxation's deadweight losses related to $r(t)$ (which decrease the output level and inherently decrease the tax revenues). In essence, the dictator increases the tax rate until marginal tax revenue equals marginal deadweight costs. A similar logic applies to the public good provision. Although the ruler wants to minimise expenditure on the public good, its provision contributes to the higher income of the society and, therefore, larger tax receipts. To sum up, such "encompassing interest" implicitly limits the predominantly bandit motivations of an absolute ruler[3].

McGuire and Olson extend this theory to reflect on redistributive majoritarian democracies[4]. The authors assume that such a democratic government represents only a part of the wider society and hence leaves out those who do not support it (referred to as a "minority"[5]). In essence, policymakers act in the sole interest of the ruling majority and redistribute income from the minority to themselves through taxes. At the same time, however, they earn market income: MOF introduces a parameter F, which captures the fraction of the ruling interest's stake in market income. The parameter takes values between 0 and 1, where 0 indicates full autocracy (and therefore implies a logic identical to the one described earlier, related to equation (MOF:1)) and 1 suggests a consensual democracy (i.e. the entire society is included in the ruling interest). Thus, the objective function of democratic (or nonautocratic) authorities becomes:

$$(1-t)r(t)FY(G) \ + \ [tr(t)Y(G) \ - \ G],\ s.t.\ G < tr(t)Y(G) \qquad \text{(MOF:2)}$$

The ruling majority will raise taxes for redistribution to itself until "the reduction in its share of market income is exactly as large as what it gains at the margin

[3] MOF assumes that autocrat's planning problem has a "long-horizon". This ensures that autocrats would not simply seize capital goods. The alternative assumption is that there are simply no capital goods.

[4] The authors consider also special cases of consensual and non-redistributive democracies. These are, however, beyond the spectrum of our paper.

[5] Although in the case of oligarchy or other hybrid regimes, the "voiceless" part could constitute a majority of the society.

from redistribution" (McGuire and Olson, 1996, p.86). Put differently, the democratic government's direct stake in the society's income further moderates the tax-related efficiency distortions and, thus, the extent of extraction from the minority. Similarly, a higher degree of encompassing interest in the market income incentivises the policymakers to provide more public good. Hence, compared to autocratic governments, policymakers whose interests are more aligned with the society's perspective (i.e. higher F) set lower taxes, impose smaller deadweight losses, extract less from the society, provide a higher level of public good and, effectively, contribute to a greater production and income.

To conclude, MOF points to the crucial role of F in determining economic outcomes. Namely, higher F means a larger proportion of the society is acknowledged by the government. This leads them to produce policies more aligned with the overall social consensus. In our adaptation, we will proxy this parameter by the "level of democracy".

However, MOF does not feature any intertemporal choices, nor does it exhibit adjustments in the economy over time. Thus, the framework cannot be perceived as dynamic. Therefore, given that our research operates on the premise that most economic policy problems - especially those related to climate change - are processes, we aim to extend the original model in a dynamic direction. Our model thus intends to demonstrate theoretical adjustments in the economy over time, subject to the level of democracy. Moreover, MOF omits the importance of political dynamics: in practice, countries can democratise or move towards authoritarianism. In this context, we also allow for a possibility of a *regime shock*.

3 The model

In the following section, we describe the fundamental features of our model. Essentially, we rely on the objective function characteristics developed by McGuire and Olson (1996). The key aspect of our adaptation, however, is that it allows us to examine how the level of democracy affects the optimal intertemporal decisions of the policymakers.

We merge this baseline model with an adaptation of production and damage functions used in the analytic climate economy model by Golosov et al. (2014). The inclusion of components developed by these authors is motivated predominantly by the fact that it allows us to operate within the same class of models (i.e. analytic integrated assessment models). Moreover, the Golosov et al. (2014) model exhibits useful properties that facilitate its optimisation, such as the existence of analytic solutions and consumption being a constant fraction of output. We simplify the original production function to reduce the amount of interrelated state variables and choices. The simplifying assumptions related to our adaptation of Golosov et al. (2014) are stated in Appendix 8.1.

Overall, our model consists of a passive, price-taking society and policymakers who set a (deadweight loss-inducing) income tax rate and decide on public investment. The extent to which the government acknowledges societal consumption is denoted by the level of democracy. Furthermore, the production of *potential* output (i.e. before the tax-related deadweight loss is accounted for) relies on two inputs: brown and green capital. At the same time, carbon emissions accumulate as a result of brown investment and cause damage to output.

Below, we firstly outline the production function in more detail, as well as specify the climate externality and associated damages. In 3.2, we describe the general political motivations, related economic objectives and constraints which characterise the actions of policymakers. Section 3.3 expands on the political component and how it relates to MOF.

3.1 Production and climate damages

Golosov et al. (2014) specify production as a Cobb-Douglas function of labour, capital and energy, subject to the total factor productivity. In our model, we normalise labour and total factor productivity to 1. Secondly, we alter the original energy composite function. We still adopt the constant elasticity of substitution (CES) form; however, rather than considering energy resources, we implicitly assume that energy is a product of two capital types. This allows to amalgamate the overall energy input (as a CES function of capital) with the production function where capital features directly, so that:

$$Y_t = e^{-\xi P_t} \left(\psi K_{B,t}^{\rho} + K_{G,t}^{\rho} \right)^{\frac{\alpha}{\rho}} \tag{1}$$

Effectively, our production function features two inputs, "brown" capital K_B and "green" capital K_G. α refers to the output elasticity of total capital and ρ refers to the substitution parameter between the capital classes. A value of the latter approaching negative infinity would indicate that the capital classes are perfect complements; in contrast, a value of 1 would imply perfect substitutes. Furthermore, ψ signifies the relative efficiency advantage related to brown capital, which we assume to take values above 1.

Consistent with Golosov et al. (2014), we assume that capital fully depreciates, given that one t reflects a period of approximately 10 years. The amount of capital in the following period, therefore, depends only on respective investment:

$$K_{B,t+1} = I_{B,t} \tag{2}$$

$$K_{G,t+1} = I_{G,t}. \tag{3}$$

Potential output production is additionally affected by the climate externality. Again, drawing from Golosov et al. (2014), we assume that economic damages result from the accumulated stock of carbon emissions. According to production function (1), the proportion of potential output that remains in the economy is captured by $e^{-\xi P_t}$, an exponential function of emissions stock[6]. P_t constitutes the cumulative emission level and ξ denotes the damage parameter that enables scaling the damage function. Furthermore, we assume that emissions accumulate in line with brown investment, such that

$$P_{t+1} = P_t + \theta I_{B,t} \tag{4}$$

where θ represents a multiplier parameter associated with emissions per unit of brown investment (i.e. emission intensity) or simply the “dirtiness” of brown investment.

To sum up, it becomes apparent that production exhibits a trade-off between the input of brown and green capital. On the one hand, brown capital is more productive than its green counterpart. On the other, its stock is inherently linked to brown investment, which contributes to (damaging) emissions.

3.2 Preferences

Policymakers[7] choose tax rates, τ, and make public investment decisions - in this paper disaggregated into I_B and I_G - such that they maximise the sum of their discounted consumption flows, C. Moreover, depending on the weight F, they internalise the impact of their decisions on societal consumption, S. The parameter F is synonymous with the level of democracy, where a value of 0 implies an autocracy and a value of 1 suggests a full democracy. Consumption of both groups is described by logarithmic preferences:

$$\sum_{t=0}^{\infty} \beta^t (lnC_t + FlnS_t) \tag{5}$$

where the authority consumption

$$C_t = \tau_t e^{-\gamma \tau_t} Y_t - I_{B,t} - I_{G,t} \tag{6}$$

and societal consumption

$$S_t = (1 - \tau_t) e^{-\gamma \tau_t} Y_t. \tag{7}$$

β in (5) denotes the discount factor. The $e^{-\gamma \tau_t}$ component present in (6) and (7) represents the proportion of potential output that remains after deadweight losses are accounted for (i.e. agents are interested in so-called *actual* output). Such

[6] According to Golosov et al. (2014), such an exponential function relatively precisely approximates the damage function proposed by Nordhaus (2008).

[7] Throughout this paper, we will use terms like "government", "policymakers", "authorities", "elite", etc. interchangeably.

losses are attributable to incentive-distorting tax, τ_t, and γ parameter allows us to scale said distortions. It also means that we assign a concrete, exponential, form to MOF's function $r(t)$ and ensure the conditions $r' < 0$ and $r(0) = 1$ hold.

Considering specific consumption elements, for each time period, the authorities want to maximise the difference between the collected tax revenue, $\tau_t e^{-\gamma \tau_t} Y_t$, and public investment outlays, I_B and I_G. At the same time, they need to weigh up the impact the tax rate exerts on deadweight losses, actual output and, therefore, taxable income. The society – lacking any impact on the economy's equilibrium – simply consumes the disposable income remaining after the income tax and deadweight loss reductions. Higher taxes always decrease the flow of current societal consumption.

3.3 Political dimension

Consistent with MOF, we assume $F \in \langle 0, 1 \rangle$ to be an exogenous parameter. Values closer to 0 thus imply more autocratic regimes, while values closer to 1 denote more democratic systems. Nevertheless, in our adaptation of MOF, we extend the original idea behind F and simplify the mechanism associated with the ruling interest's redistribution.

First of all, we interpret F as an index related to the level of democracy, rather than a "fraction of the total income produced and earned in the market accruing to the redistributive ruling interest" (McGuire and Olson, 1996, p. 54). Hence, we treat such level of democracy as a degree of policymaker's responsiveness or sensitivity to the society's welfare. Using MOF's logic more directly, F in our specification could be interpreted as a fraction of "the utility derived from societal consumption".

Moreover, we simplify the measurement of relative rents: we explicitly differentiate between the direct interests of the elite, C, and the wider society, S. Our analysis, therefore, is oriented on clear depiction of consumption, utility and associated welfare effects. This contrasts with McGuire and Olson (1996) who focus simply on income (see section 2.3).

According to our specification, an autocrat ($F = 0$) would simply ignore societal consumption when making optimal decisions and focus only on the impact of public investment on future output. However, it does not automatically imply $S_t = 0$ (i.e. there are limits to the extraction). Citizens' consumption needs are just not considered by the dictator and thus are not reflected in optimal choice. Nevertheless – as a byproduct of the autocrat's mutually beneficial decisions – S_t will virtually always be positive.

On the other hand, even full democracies will "suffer" from a positive net extraction (here, thought of as the difference between the tax receipts and public investment back into the economy) to some extent. Technically, it derives from the said separability of interests. Nonetheless, we can relatively safely presume that even the most responsive governments are not free from pursuing the self-interest of the officeholders or their accountability to the elites. This is consistent with the assumption of opportunistic behaviour prevalent in political economy models (see Persson and Tabellini (2000)). Alternatively, we can think of such C_t for $F = 1$ as funds needed to cover costs of running the party (e.g. campaign costs), which are not productive and hence not reflected in public good provision.

4 Optimisation

The following subsection addresses the trade-offs faced by the policymakers, specifies the model's constrained optimisation problem and provides the optimal solution.

The primary tradeoff concerns the optimal tax-setting. In order to maximise tax collections, the policymakers need to balance out the marginal benefits related to a higher tax rate with its offsetting marginal costs. Namely, a higher tax rate always contributes to increased deadweight losses and thus decreases actual output (i.e. income) to be taxed. Therefore, even dictatorships will restrain the appetite for over-extraction from society. The situation is further accentuated if we consider nonautocratic governments (i.e. $F > 0$). Specifically, a higher degree of sensitivity towards society's needs inherently leads policymakers to internalise the additional impact of taxes on societal consumption. Hence, we can expect more democratic states to be associated with lower tax rates and thereby smaller deadweight losses.

The second trade-off is an intertemporal one. In principle, higher investment spending decreases current consumption of the authorities. Nevertheless, being forward-looking (subject to the discount rate), policymakers realise the need to create future output given that it will enable their prospective consumption. This fact once again aligns the interests of the society with the government and is even more pronounced for higher levels of democracy: a more substantial investment is needed to fund future consumption of *both* groups.

The issue of investment inherently brings us to the third key trade-off, which effectively constitutes our model's climate policy. Primarily, policymakers are tempted to invest in brown capital given its productivity advantage over green capital. However, they are aware of the emissions resulting from brown investment and damages to future consumption. Hence, to a certain extent, the government shall mitigate the prospective climate damages by investing in green capital. Whether more democratic governments prove more sensitive to the prospective climate damages constitutes the ultimate research question of this paper.

The above considerations are aggregated numerically in the following dynamic programming problem. Essentially, the policymakers choose series of tax rates, brown investment and green investment to maximise the infinite lifetime objective, (5), subject to the initial states. The Bellman equation is as follows:

$$
\begin{aligned}
V_t(K_{B,t}, K_{G,t}, P_t) = ln\left(\tau_t e^{-\gamma\tau_t} Y_t - I_{B,t} - I_{G,t}\right) + Fln\left((1-\tau_t)e^{-\gamma\tau_t} Y_t\right) \\
+ \beta V_{t+1}(K_{G,t+1}, K_{B,t+1}, P_{t+1})
\end{aligned} \tag{8}
$$

where production is given by (1) and the state variables evolve according to (2), (3) and (4).

The entire solution to our model is described in Appendix 8.2 - 8.8. Differentiation of the objective function yields first-order and envelope theorem conditions which are available in Appendix 8.3. In the subsequent numerical process, we avail ourselves of the features of the Golosov et al. (2014) model. This provides consumption as a constant proportion of output, $C = \lambda Y$. Secondly, the optimality condition equates the marginal products of capital via an implicit carbon tax, such that $MPK_G = MPK_B - T$.

In a similar manner, firstly, we find that the authority consumption is a constant proportion, λ, of tax revenue[8]. Hence, for all periods $t > 1$ we have:

$$
C_t = \lambda \tau_t e^{-\gamma\tau_t} Y_t \tag{9}
$$

Secondly, also following Golosov et al. (2014), we find that the optimal carbon tax, T, is a constant multiplicity $\frac{\theta\xi}{1-\beta}$ of actual output. Therefore, accounting for the emission-inducing impacts of brown investment, the optimality requires that marginal products of capital for all periods $t > 1$ equal:

$$
MPK_G(t) = MPK_B(t) - \frac{\theta\xi}{1-\beta} e^{-\gamma\tau_t} Y_t \tag{10}
$$

Such an implicit carbon tax clearly reflects the importance of θ and ξ. It appears logical that a higher carbon tax would be required to balance out more significant marginal emissions and damages.

4.1 Optimal investment

The two identities established above enable us to obtain consistent investment choices. As before, full details of the solution are available in Appendix 8.5. Nonetheless, the level of green investment for all periods $t > 1$ is obtained from the implicit equation (11)

$$
\begin{aligned}
\alpha I_{G,t}^{\rho-1} = \alpha\psi\left((1-\lambda)\tau_t e^{-\gamma\tau_t} Y_t - I_{G,t}\right)^{\rho-1} \\
- \frac{\theta\xi}{1-\beta}\left(\psi\left((1-\lambda)\tau_t e^{-\gamma\tau_t} Y_t - I_{G,t}\right)^{\rho} + I_{G,t>1}^{\rho}\right)
\end{aligned} \tag{11}
$$

[8]In Appendix 8.8, we describe how optimal λ is calculated.

while the consistent choice of brown investment follows from

$$I_{B,t} = (1-\lambda)\tau_t e^{-\gamma\tau_t} Y_t - I_{G,t} \tag{12}$$

Essentially, it appears clear that investment decisions do not *directly* depend on the level of democracy. However, similarly to the logic established in MOF, we can expect more democratic authorities to impose smaller deadweight losses and consume less. Therefore, this shall leave more resources (otherwise extracted as rents) available for investment. The relative tendency with respect to a specific investment type is less straightforward to establish. Nevertheless, the output of our simulations exhibited in the section 5 will be able to aid the answer.

4.2 Optimal tax rates

As specified in Appendix 8.6, equations characterising the optimal tax rate differ between nonautocratic polity ($F > 0$) and full autocracy ($F = 0$). The former is obtained from

$$\lambda = \frac{1}{F}\left(\frac{1}{\tau(1+\gamma-\gamma\tau)} - 1\right) \tag{13}$$

whereas to consider the particular instance of full autocracy, we rely on a simple formula which depends only on the γ parameter:

$$\tau = \frac{1}{\gamma} \tag{14}$$

In both cases, irrespective of λ's value, tax rate will always be constant over time: it is a function of only parameters. This feature proves consistent with MOF as it confirms that the choice of tax is independent of its prospective impacts on the remaining decisions (i.e. public investment).

Instead, the tax rate will be affected by the democracy level, F, and the deadweight loss parameter, γ. Namely, consistent with McGuire and Olson (1996), lower F leads to a higher tax rate, what is ultimately accentuated in full autocracy. By the same token, higher inefficiency losses captured by γ constitute a limiting factor, decreasing the optimal tax rate.

5 Simulations and results

In this section, we present the output of dynamic simulations and show how our model optimally adjusts over time, focusing predominantly on the impact of the level of democracy. Our analysis concentrates on the most illustrative comparison of the two extreme solutions (full autocracy vs full democracy), although the model is well-equipped to deal with intermediate levels of democracy as well.

Firstly, we describe the calibration strategy. Afterwards, we analyse democracy's influence on the key parts of the modelled economy. Consequently, we address the underlying question posed in this paper: is democracy conducive to combating emissions and limiting temperature rise? Having provided general results, we deliver plausible explanations.

5.1 Calibration

We assume a model period is 10 years, and we are interested in simulating the model from 2020 to 2100. Hence, $t = 1$ would be synonymous with the interval beginning in the year 2020. Secondly, we consider two cases. Both deal with the same initial state of the economy and differ only in terms of the level of democracy, F, i.e. all regimes are initially equally endowed. For possibly the most effective illustration, we contrast the solution linked to $F = 0$ with the one connected to $F = 1$.

To obtain the values of the initial state variables at $t = 1$, we solve an additional model variant, with the same production structure but no environmental externality or political component (refer to Appendix 8.9 for details of the entire procedure). In this variant, policymakers have entire output at their disposal and make choices on brown and green investment, however, not realising any climate consequences. Steady state of this model will be synonymous with $t = 0$ and will determine capital stock in $t = 1$ when politics and emissions are introduced. We choose the substitutability between brown and green capital such that they exist in an 80:20 ratio in the steady state of the additional model. This condition is imposed when $\psi = 4^{(1-\rho)}$. The remaining parameters are chosen arbitrarily and summarised in the table below:

θ	ξ	ρ	ψ	α	β	γ	F
1	0.1	0.8	1.32	0.3	0.82	2	0 vs 1

Table 1: *Parameters*

where the value of β reflects an annual discount rate of 2%.

The last aspect concerns the global temperature growth. As stated in 3.1, we assume the externality is directly mapped to emissions, not temperature. Nonetheless, to aid visualisation, we produce simulations which also reflect the temperature growth. Overall, we depict the incremental changes relative to the base year 2020 where emission stock is zero. In principle, this initial level could reflect 1°C temperature rise since pre-industrial era. The growth that we show thus would reflect the *additional* temperature rise. Then, by referring to the emission stock of a fully democratic economy in 2100, we "translate" this level such that it corresponds to the overall, additional, rise of 2°C (i.e. 3°C pre-industrial). Increments in emissions over time shall then be reflected in proportional increases in temperature, regardless of the regime type. This way, both economies shall pass the goal of the Paris Agreement (2°C above pre-industrial) around 2050/2060.

5.2 Results and discussion

5.2.1 Output and welfare

In $t = 1$ (i.e. 2020), incentive-distorting taxation appears in the economy as the policymakers' tool. The autocrat sets the optimal (fixed) tax rate at 50%, while full democracy does so with 25% [9]. With the taxes, deadweight losses come into existence. Thus, relative to the initial state given by $t = 0$ (where actual output equals potential output), in Figure 1, we observe a sudden fall in actual output[10]. The fall is experienced by both regimes; however, it is more significant for a higher tax rate, i.e. in autocracy.

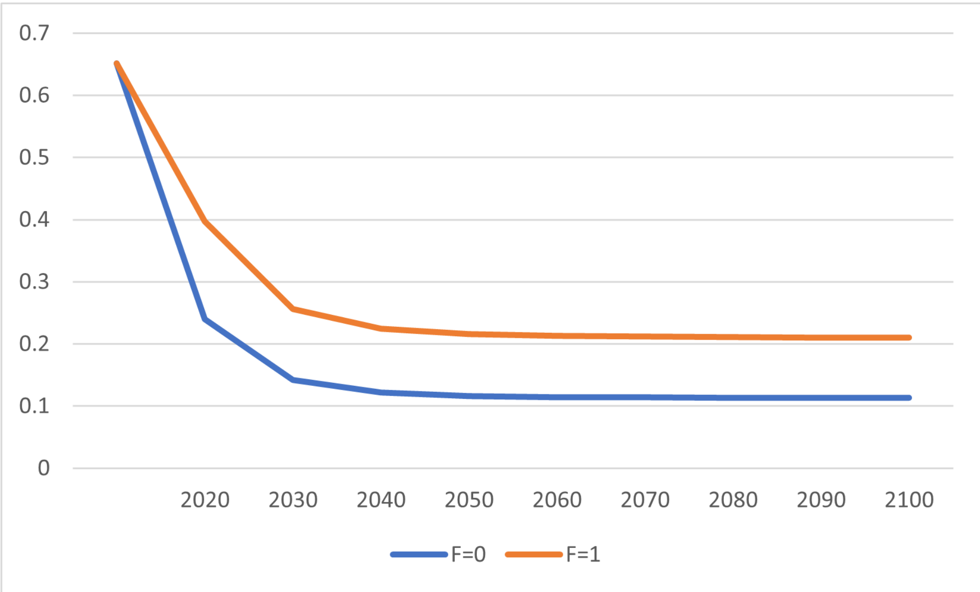

Figure 1: *Actual output over time: full autocracy vs full democracy*

This relative difference in actual output production is maintained up until 2100. By then, democracy would be able to produce 85% more than autocracy[11]. This result is inevitably connected to consistently stronger public investment: in 2100 alone, the democracy's total investment exceeds the autocracy by 46% (investment will be analysed in more detail in 5.2.2).

Furthermore, the society living under the democratic authorities experiences relative welfare gains. Such relative difference (measured as a discounted sum of consumption flows, subject to logarithmic preferences) amounts to as much as 60%. Conversely, the authorities would face a welfare loss of 10%. Consumption paths are depicted in Figures 2 and 3.

[9]Specific values of the tax rates are not important for interpretation of further results. However, we report them to demonstrate the significant difference in motivations and choices of the policymakers on the opposite sides of the political spectrum.

[10]Note that from this point onward, we will exclude $t = 0$ from graphs.

[11]As we will see shortly, democracy achieves higher output level despite higher emissions and thereby more significant climate damages.

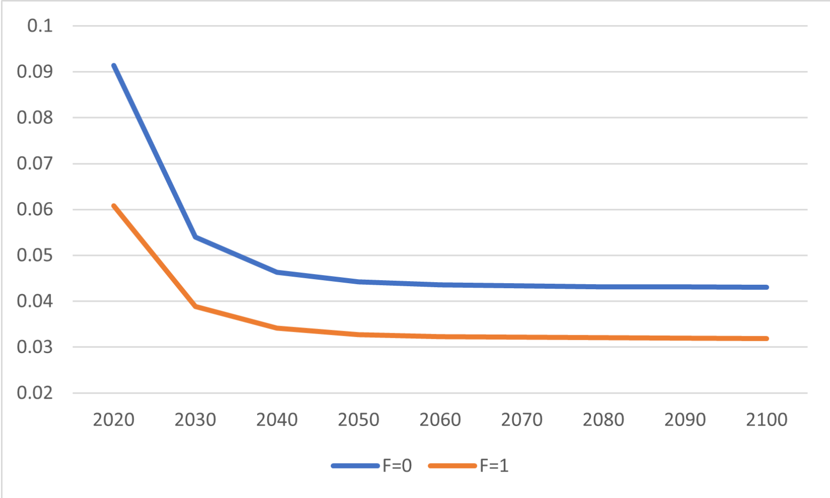

Figure 2: *Elite consumption over time: full autocracy vs full democracy*

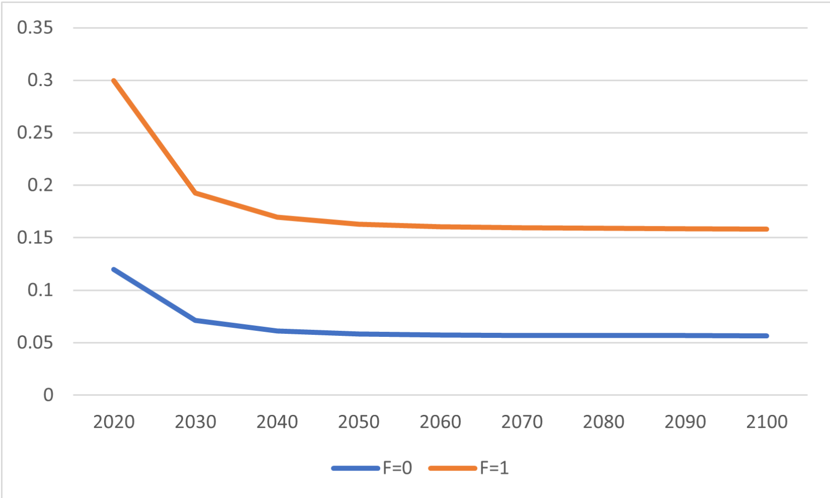

Figure 3: *Societal consumption over time: full autocracy vs full democracy*

The overall logic regarding the democracy's impact can be summarised as follows. Fundamentally, more authoritarian regimes set higher taxes. As a result of their rent-seeking, they impose more significant deadweight losses. This leaves them with even fewer resources available for public investment, considering they still want to maximise the difference between tax revenue and public spending.

In contrast, more democratic governments internalise their voters' welfare to a higher extent. Such a higher degree of the "encompassing interest" effectively translates to lower taxes and deadweight losses. Despite smaller tax collections, lower authority consumption allows for more resources to be dedicated for public investment and future production.

5.2.2 Emissions

Referring to Figures 4 and 5, we can observe that lower democratic accountability is associated with lower (26% by 2050 and 29% by 2100) cumulative emissions and a slower temperature rise. By 2050, the authoritarian regime achieves 0.66°C (0.23°C less than democracy) and 1.43°C by 2100 (0.57°C less than democracy).

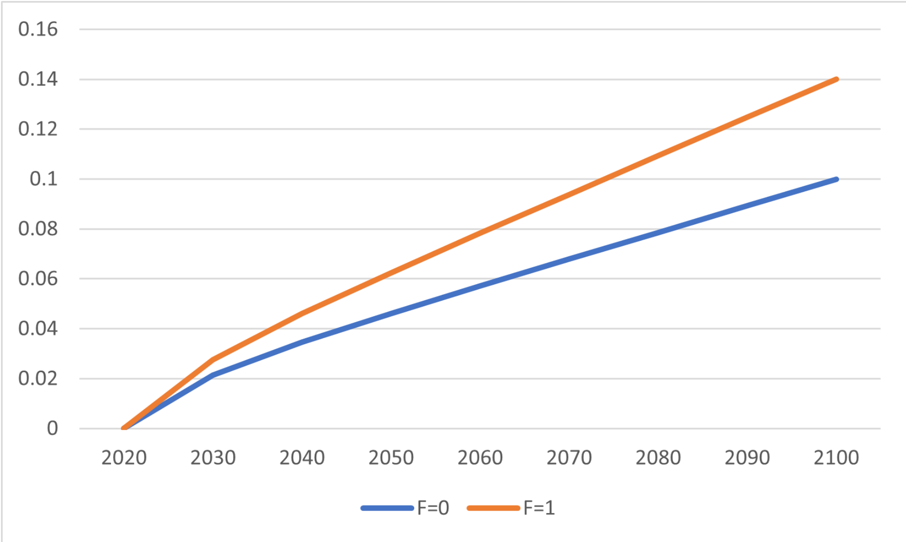

Figure 4: *Cumulative emissions relative to 2020: full autocracy vs full democracy*

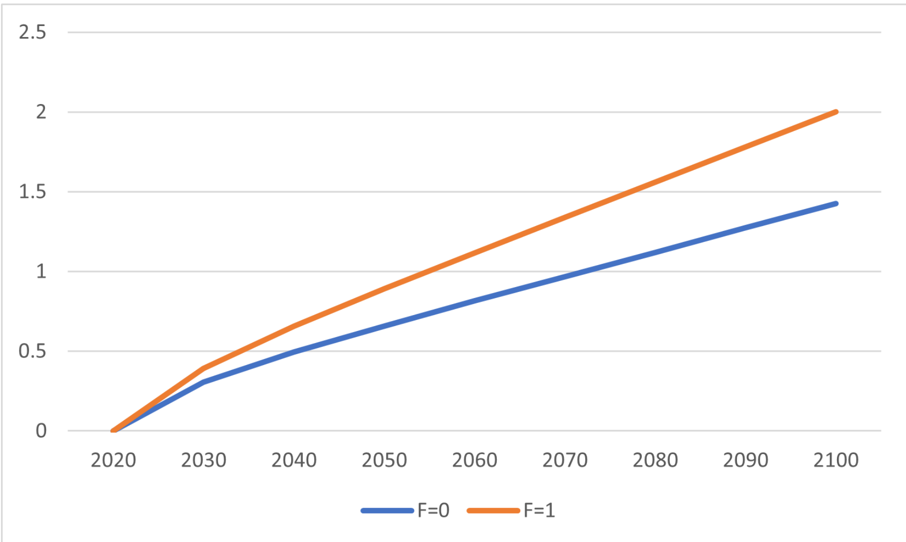

Figure 5: *Temperature rise [°C] relative to 2020: full autocracy vs full democracy*

This is achieved, however, by the ability to constrain societal consumption and reduced output production rather than increased investment in renewables. Namely, following the logic established earlier, the autocracy underprovides public investment. This includes green investment, but also the carbon-intensive brown investment (see Figures 6 and 7). Capital mix, nonetheless, still favours brown capital - although the mean capital mix is only slightly "greener" (1 percentage point difference) under full democracy. Similarly, while the democracy's brown investment in 2100 is 44% higher than the dictator's, green investment is higher by as much as 53%. Crucially for the assessment of the relative "efficiency" of climate policy, the democracy features lower emissions as % of actual output[12]. By 2100, they reach 67%, compared to autocratic 88%.

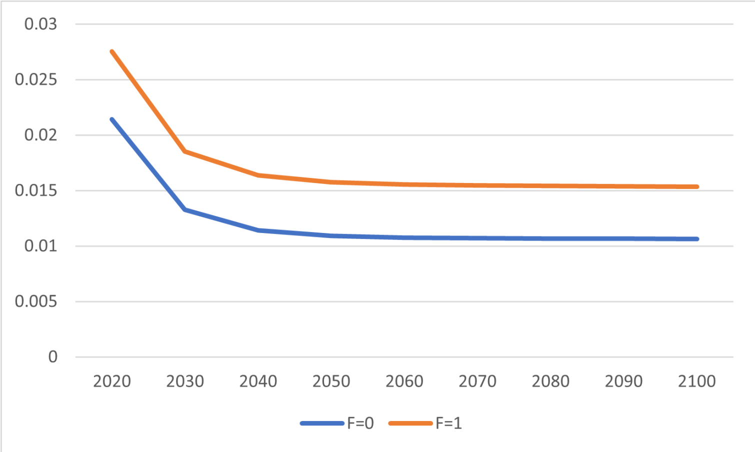

Figure 6: *Brown investment over time: full autocracy vs full democracy*

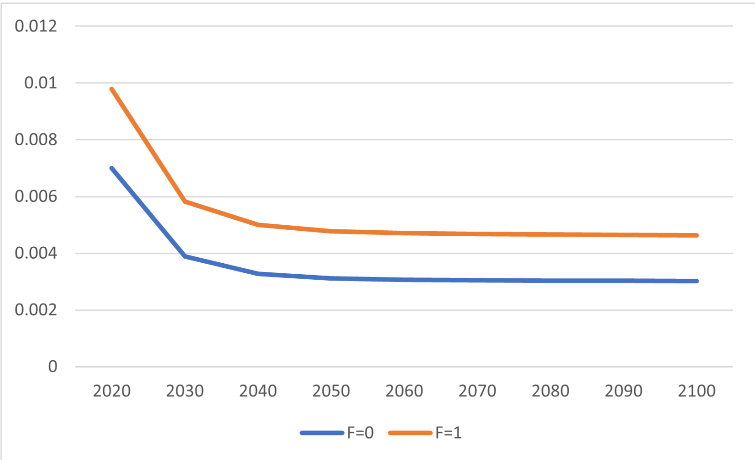

Figure 7: *Green investment over time: full autocracy vs full democracy*

[12]Typically, emission intensity is expressed as CO_2 emissions in kilograms per unit of economic output. However, for the ease of illustration and comparison, we assume emissions are expressed in the same units as output.

Therefore, to sum up, fewer emissions of the autocracy are only a welcome byproduct of lower investment in general. Democracy, in turn, produces higher actual output and invests more despite comparatively larger climate damages (which are greater by 0.4 percentage points in 2100). In the next subsections, we analyse how shocks complete the picture painted above.

5.2.3 Democracy shock

In this subsection we look at a positive democracy shock and its impact on cumulative emissions. Beginning with 2020, we consider a full autocracy what - prior to the shock - implies optimal paths identical to those described in 5.2.2. Then, by 2050 the economy experiences a sudden, moderate democratisation (i.e. $F = 0$ changes to $F = 0.5$). In Figures 8 - 10, we report emission and investment paths: we juxtapose the evolved regime against the counterfactual for a constant $F = 0$.

Following the regime shock, we begin to notice a divergence of emission paths: by 2100, the semi-democratic regime accumulates 15% more emissions. However, this is a result of increased investment overall. After the shock, policymakers reduce the extractions and efficiency losses, thus beginning to invest more. By 2100, the relative difference in brown investment amounts to 31%. The difference in green investment, however, is even higher (37%), what suggests that democratisation improves prospects of a greener capital mix. Similarly, emissions as % of actual output decrease from 88% to only 64%.

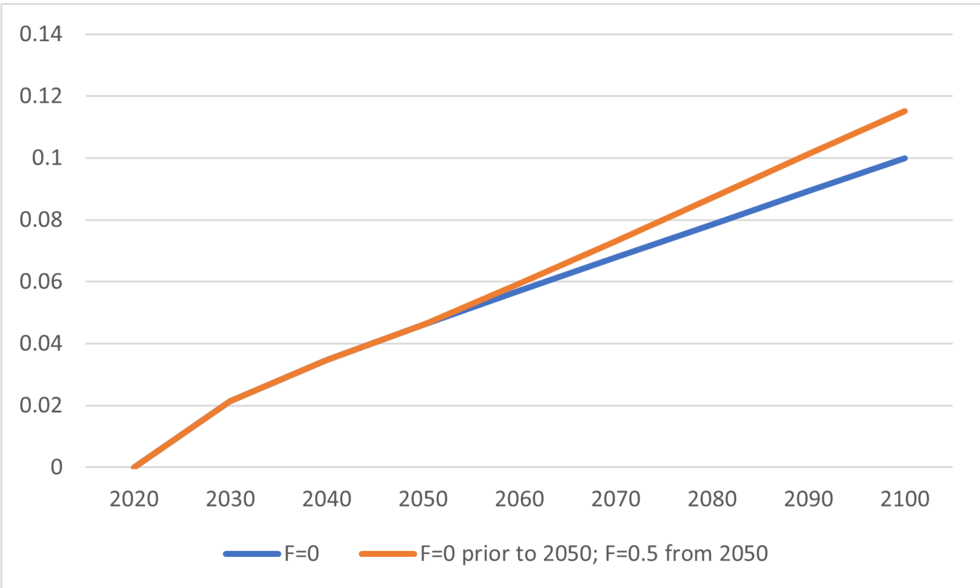

Figure 8: *Cumulative emissions over time: a path where the economy faces a democracy shock by 2050 vs a counterfactual for a constant democracy level*

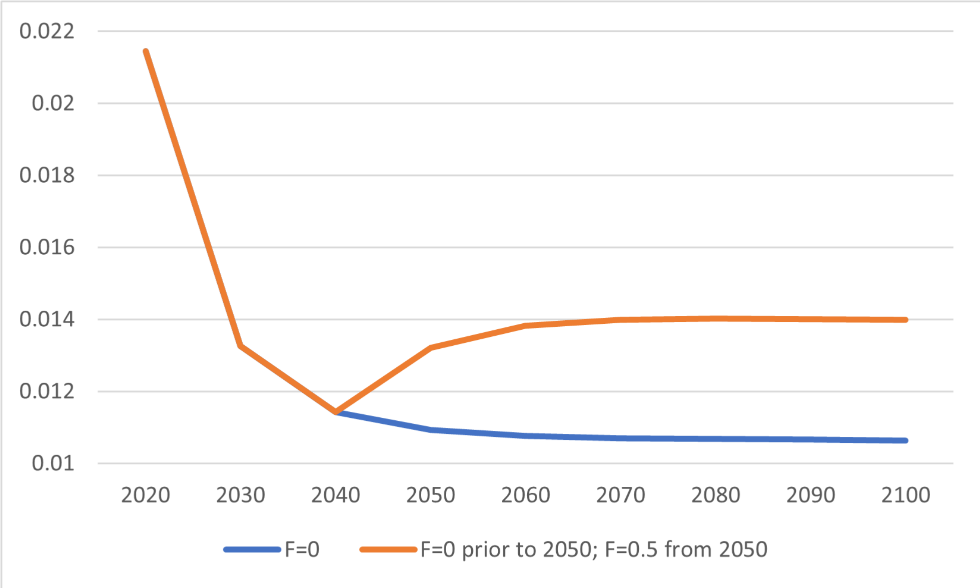

Figure 9: *Brown investment over time: a path where the economy faces a democracy shock by 2050 vs a counterfactual for a constant democracy level*

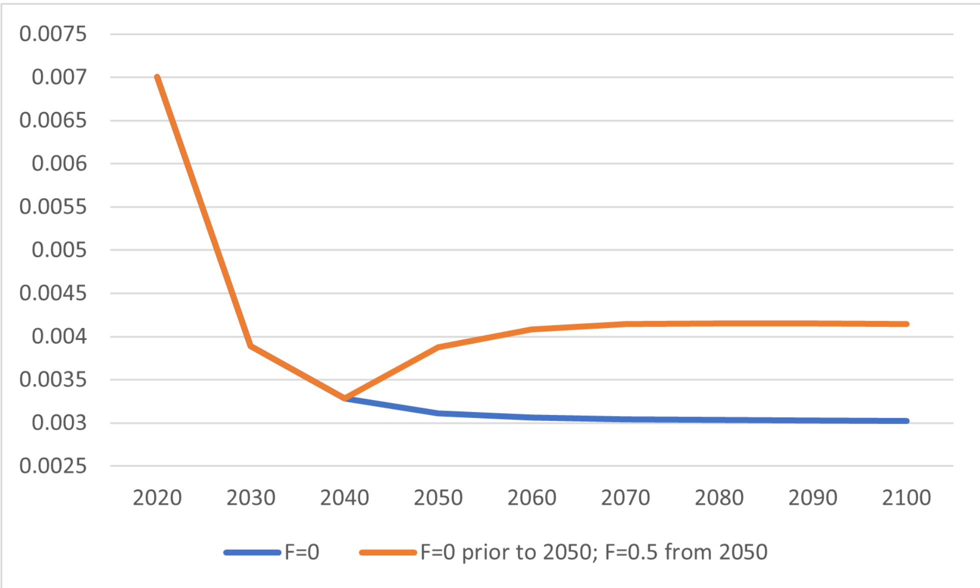

Figure 10: *Green investment over time: a path where the economy faces a democracy shock by 2050 vs a counterfactual for a constant democracy level*

5.2.4 Climate shock

Below we reflect on the relative capability of regimes to cope with a climate shock. As in 5.2.2, we compare two extreme polity cases. Both regimes initially begin with the emission intensity and the damage factor parameters assumed as earlier, i.e. $\theta = 1$ and $\xi = 0.1$. By 2050, however, they realise (we assume a new scientific evidence is available) that the climate repercussions become more significant. This is reflected by the change of said parameters to $\theta = 1.5$ and $\xi = 1.5$.

Following the shock, the pace of emissions growth noticeably decreases in both regimes (see Figure 11). Moreover, compared to the solution in 5.2.2 where we observed a continuously increasing divergence in emission levels, here we notice that the two paths (insignificantly) converge. Put differently, compared to the solution in 5.2.2, the relative difference in 2100 cumulative emissions diminishes. Ultimately, although the democracy still emits more (18%), it also proves more efficient in curtailing emissions: compared to cumulative emissions reported in 5.2.2, the democracy reduces its emissions by 19% and the autocracy by 14%.

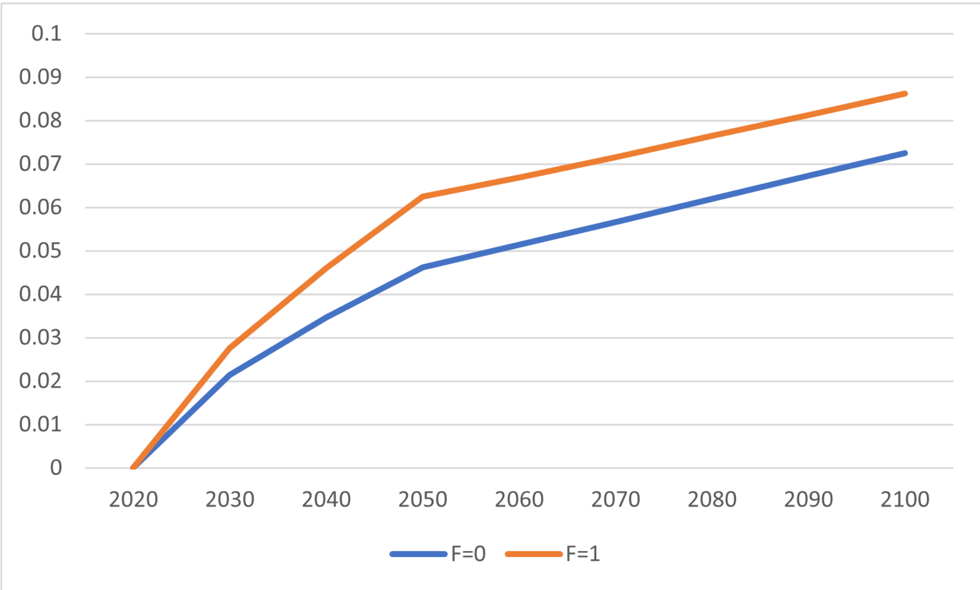

Figure 11: *Cumulative emissions relative to 2020 with a climate shock occurring in 2050: full autocracy vs full democracy*

Turning attention to investment (Figures 12 and 13), we observe that both regimes swiftly adjust to the shock. They, already in 2050, significantly increase green investment; the democracy features a higher increase and maintains the relative difference in the long run (76% by 2100). Similarly, both economies substantially decrease brown investment; the democracy exhibits a greater fall, such that the comparative levels remain negligible over the long run. By 2100, capital mix in both economies favours renewables: 25:75 in the democracy and 36:64 in the autocracy. These results, together with the significant difference in emissions as % of actual output (53% under democracy and 81% under autocracy), suggest that democracy is better equipped to transition to a low-carbon economy.

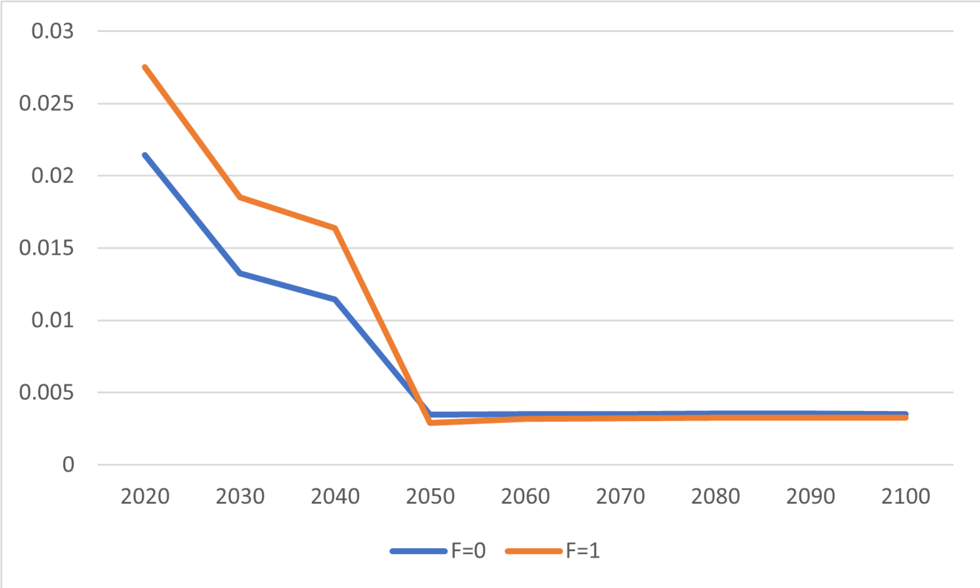

Figure 12: *Brown investment over time with a climate shock occurring in 2050: full autocracy vs full democracy*

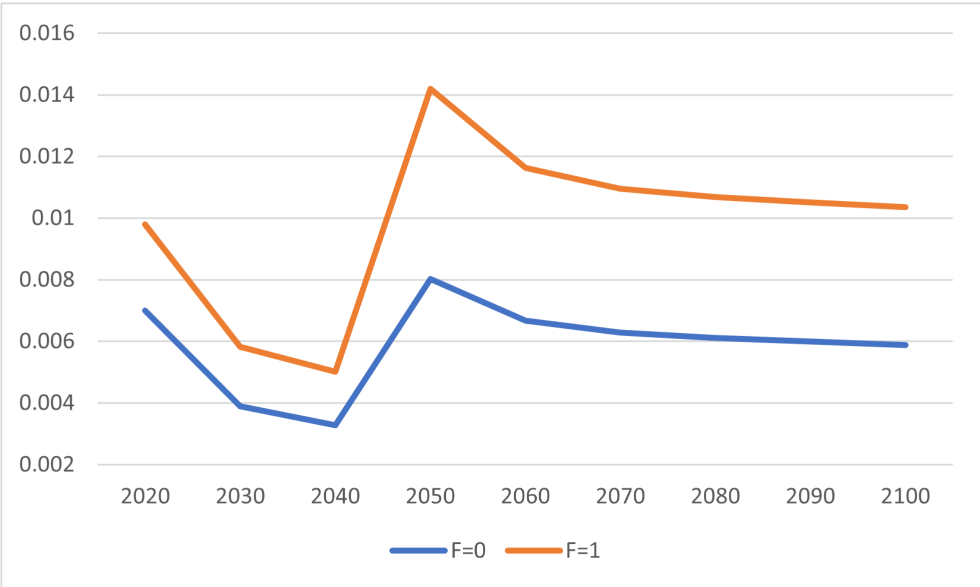

Figure 13: *Green investment over time with a climate shock occurring in 2050: full autocracy vs full democracy*

5.2.5 Emissions for inflated values of θ and ξ

To complete the picture, we show an additional case where we assume that both regimes realise higher climate consequences already in 2020. This analysis highlights the utmost importance of time and early action in climate change mitigation. In 5.2.4, the democracy demonstrated a better efficiency of investment adjustments, but still ended up with higher cumulative emissions.

By inflating the climate consequences already in 2020, we obtain a more meaningful image of policymakers' actions. If rational authorities are aware of higher environmental and economic implications related to brown investment, it becomes clear that democracies internalise such an externality to a greater extent. Namely, their cumulative emissions by 2100 amount to 16% less than under an autocrat (see Figure 14). This further highlights the relative inability of autocracies to combat climate change when emission intensity is stronger. Assessment of the paths of investment (to follow on the next page) provides an intuition for this development.

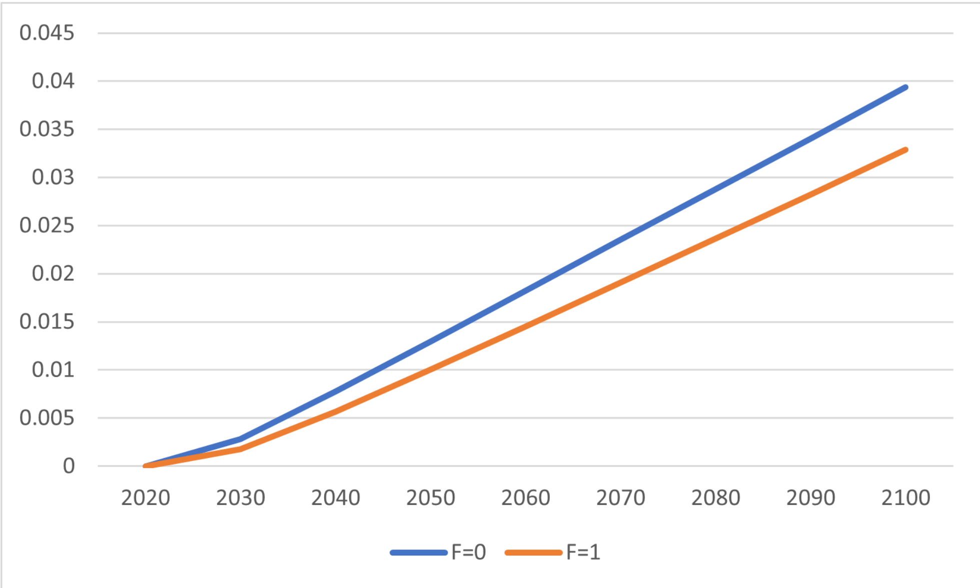

Figure 14: *Cumulative emissions relative to 2020 for* $\theta = 1.5$ *and* $\xi = 1.5$*: full autocracy vs full democracy*

Initially, both regimes react quickly to the perspective of serious environmental impacts and adjust their investment accordingly: green investment significantly exceeds brown investment. The democracy, from the start, invests comparably even more in green capital. Interestingly, however, both regimes gradually decrease green investment over time and increase accompanying brown investment (see Figures 15 and 16 on the next page). While both economies follow a similar trend, the initial difference in magnitudes is maintained over time. Specifically, by 2100, the complete democracy invests 88% more into green sources when juxtaposed with the autocracy. At the same time, it constrains its brown investment: compared to the authoritarian policymakers, it invests 12% less. Relative differences in capital mix also become more apparent. While the average ratio of brown to green capital is now 29:71 in the autocracy, the democracy achieves a ratio of 17:83. Lastly, by 2100, the democracy features the figure of emissions as % of actual output of only 18%, compared to 41% under the dictatorship.

To explain the overall logic behind our results, we suggest two complementary arguments. Firstly, more authoritarian governments are simply inefficient in the deadweight losses sense. This leaves them with fewer resources available for investment in general. To fund their future consumption, they would then rely on more productive (brown) investment to a higher degree, compared to democracies. Secondly, a higher level of democracy strengthens the encompassing interest. Namely, not only do policymakers care about their own consumption, but also about future societal consumption. Therefore, they will internalise the long-term damaging impacts of emissions on *both* groups and try to limit them more substantially.

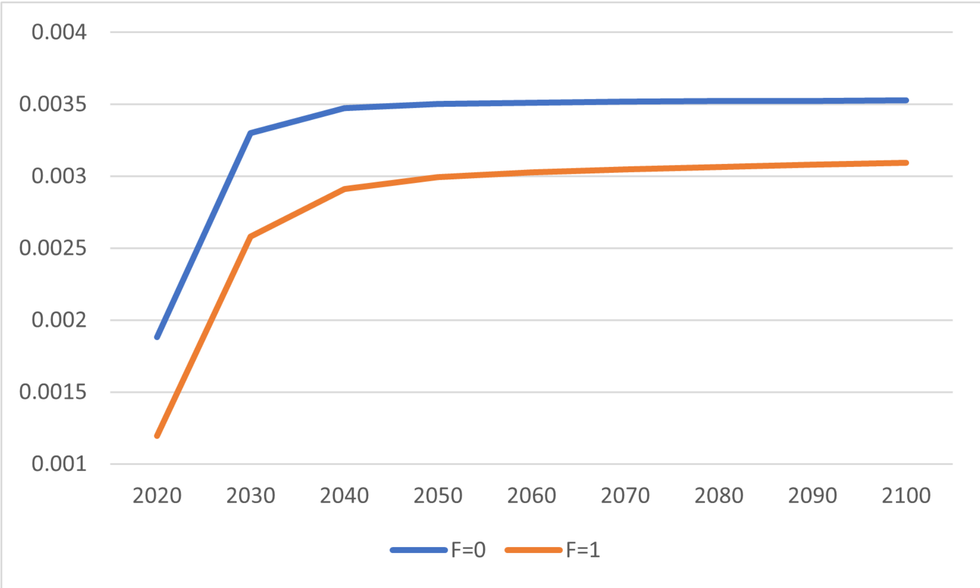

Figure 15: *Brown investment over time for $\theta = 1.5$ and $\xi = 1.5$: full autocracy vs full democracy*

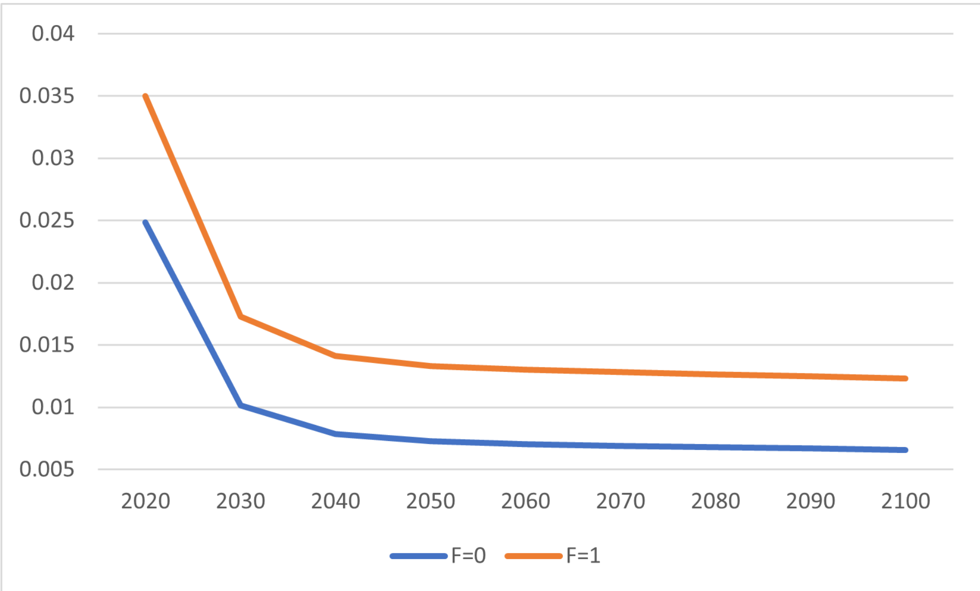

Figure 16: *Green investment over time for $\theta = 1.5$ and $\xi = 1.5$: full autocracy vs full democracy*

6 Conclusion

In this paper, we provided a positive view of the regime type's (denoted by the level of democracy) influence on the policymakers' willingness to limit carbon emissions. The literature offers various, but often contradictory, theoretical channels for the potential relationship between democratic quality and environmental performance. Nevertheless, economic models of climate change very rarely deal with political issues of this kind. We fill this gap by adding a climate externality to the dynamic variant of the McGuire and Olson (1996) model of political economy.

We find that less democratic economies are associated with lower cumulative emissions. However, this can be perceived as a byproduct of lower economic growth. Autocrats extract a large proportion of income from the society to themselves, thereby imposing higher deadweight losses. Such inefficiency losses leave the policymakers with fewer resources available for investment regardless of its "dirtiness".

Conversely, more democratic economies push for higher societal consumption. This results in smaller extractions from the society and lower deadweight losses. Therefore, democratic regimes possess more resources that are used for investment. This logic concerns both the emission-heavy investment and investment in renewables: compared to autocracies, democracies would invest more in both capital types. Considering the ratio of emissions to output, however, higher levels of democracy are characterised by a less emission-intensive production.

We also analyse the impact of democracy and climate shocks. Considering the former, a positive regime shock contributes to more emissions. However, the associated increase in brown investment is smaller than the increase in green investment. Thus, democratisation stimulates a slightly greener capital mix. Regarding the climate shock, we find that democratic economies are better equipped to limiting emissions (although, cumulatively, they still emit more). Specifically, they decrease brown investment to levels comparable with autocracies and increase investment in renewables significantly more. Therefore, democracies maintain higher economic growth while featuring a greener capital mix in the long run.

Lastly, we show that timing is essential to the effectiveness of limiting emissions. If policymakers are aware of more significant climate consequences early on, it becomes clear that democracies produce fewer cumulative emissions by switching to renewables more swiftly. Overall, because autocracies are inefficient in the deadweight loss sense, such governments prefer more productive (i.e. brown) investment. Moreover, democratic policymakers - by caring about their citizens' future consumption - internalise prospective climate damages to a greater extent.

Our results offer some political insights into the wider climate change debate and associated policymaking. While it might seem that political transition to a less democratic system could save climate, one might object to such a view on ethical grounds (i.e. we show that social welfare is radically worse under an authoritarian system). Moreover, we show that democracies are nevertheless more apt and efficient in *adjusting* their climate policy and limiting emissions.

7 References

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8 Appendix

8.1 Simplifying assumptions

To simplify the energy inputs used by Golosov et al. (2014) so that output is a product of capital, we rely on the following assumptions:

$$Y_t = F_0(\underline{E}_{0,t}, P_t) = e^{-\xi P_t}\tilde{F}_0(\underline{E}_{0,t}) = e^{-\xi P_t}\left(\frac{\psi}{\theta^\rho}\right)^{\frac{\alpha}{\rho}}\left(E^\rho_{0,B,t} + E^\rho_{0,G,t}\right)^{\frac{\alpha}{\rho}}$$

$$\underline{E}_{0,t} = \left(E_{0,B,t}, E_{0,G,t}\right)$$

$$E_{0,B,t} = E_{B,t} = F_1(K_{B,t}) = \theta K_{B,t}$$

$$E_{0,G,t} = E_{G,t} = F_2(K_{G,t}) = \left(\frac{\theta}{\psi^{\frac{1}{\rho}}}\right)K_{G,t}$$

$$K_t = K_{B,t} + K_{G,t}$$

Moreover, emissions evolve according to:

$$P_t = \tilde{P}\left(\sum_{s=0}^{t-1} E_{1,t-s}\right) = \sum_{s=0}^{t-1} E_{B,t-s} = E_{B,t-1} + \sum_{s=1}^{t-1} E_{B,t-s} = E_{B,t} + P_{t-1}$$

i.e.

$$P_t - \overline{P} = \sum_{s=0}^{t+T}(1-d_s)E_{B,t-s} \quad \textit{with } \overline{P} = 0,\ T = -1, (1-d_s) = 1\ \forall s$$

i.e.

$$1 - d_s = \phi_L + (1-\phi_L)\phi_0(1-\phi)^s = 1\ \forall s \ \Rightarrow \phi = 0, \phi_0 = 1$$

which means there is no depreciation of the emissions stock.

8.2 Marginal products of capital

Differentiating the production function (1) with respect to capital yields the following marginal products of capital:

$$
\begin{aligned}
MPK_B &= \frac{Y_t}{\partial K_{B,t}} \left[e^{-\gamma\tau_t} e^{-\xi P_t} \left(\psi K_{B,t}^{\rho} + K_{G,t}{}^{\rho} \right)^{\frac{\alpha}{\rho}} \right] \\
&= e^{-\gamma\tau_t} Y_t \frac{\alpha\psi K_{B,t}^{\rho-1}}{\psi K_{B,t}^{\rho} + K_{G,t}{}^{\rho}}
\end{aligned} \tag{15}
$$

$$
\begin{aligned}
MPK_G &= \frac{Y_t}{\partial K_{G,t}} \left[e^{-\gamma\tau_t} e^{-\xi P_t} \left(\psi K_{B,t}^{\rho} + K_{G,t}{}^{\rho} \right)^{\frac{\alpha}{\rho}} \right] \\
&= e^{-\gamma\tau_t} Y_t \frac{\alpha K_{G,t}^{\rho-1}}{\psi K_{B,t}^{\rho} + K_{G,t}{}^{\rho}}
\end{aligned} \tag{16}
$$

8.3 Optimisation

Optimisation of the Bellman equation (8) subject to (2)-(4) yields the following first order (i.e. taken with respect to the control variables τ_t, $I_{B,t}$ and $I_{G,t}$) and envelope theorem (i.e. taken with respect to the state variables $K_{B,t}$, $K_{G,t}$ and P_t) conditions:

F.O.C.s

$$
w.r.t.\ \ \tau_t,\ \ for\ F > 0 \qquad C_t = \frac{(1-\tau_t)(1-\gamma\tau_t)e^{-\gamma\tau_t}Y_t}{F(1+\gamma(1-\tau_t))} \tag{17}
$$

$$
w.r.t.\ \ \tau_t,\ \ for\ F = 0 \qquad \tau_t = \frac{1}{\gamma} \tag{18}
$$

$$
w.r.t.\ \ I_{B,t}, \qquad \frac{1}{C_t} = \beta \left[\frac{\partial V_{t+1}}{\partial K_{B,t+1}} + \theta \frac{\partial V_{t+1}}{\partial P_{t+1}} \right] \tag{19}
$$

$$
w.r.t.\ \ I_{G,t}, \qquad \frac{1}{C_t} = \beta \frac{\partial V_{t+1}}{\partial K_{G,t+1}} \tag{20}
$$

E.T.s

$$
w.r.t.\ \ K_{B,t}, \qquad \frac{\partial V_t}{\partial K_{B,t}} = \frac{\tau_t}{C_t} MPK_B(t) + \frac{F}{e^{-\gamma\tau_t}Y_t} MPK_B(t) \tag{21}
$$

$$
w.r.t.\ \ K_{G,t}, \qquad \frac{\partial V_t}{\partial K_{G,t}} = \frac{\tau_t}{C_t} MPK_G(t) + \frac{F}{e^{-\gamma\tau_t}Y_t} MPK_G(t) \tag{22}
$$

$$
w.r.t.\ \ P_t, \qquad \frac{\partial V_t}{\partial P_t} = \beta \frac{\partial V_{t+1}}{\partial P_{t+1}} - \xi \frac{\tau_t e^{-\gamma\tau_t} Y_t}{C_t} - F\xi \tag{23}
$$

8.4 Carbon tax

Merging and rearranging conditions (20) and (22) yields the following Euler equation:

$$\frac{1}{C_t} = MPK_G(t+1)\left[\beta\frac{\tau_{t+1}}{C_{t+1}} + \beta\frac{F}{e^{-\gamma\tau_{t+1}}Y_{t+1}}\right] \tag{24}$$

Moreover, merging and rearranging conditions (19) and (21) gives:

$$\frac{1}{C_t} = \beta\left[\frac{\tau_{t+1}}{C_{t+1}}MPK_B(t+1) + \frac{F}{e^{-\gamma\tau_{t+1}}Y_{t+1}}MPK_B(t+1) + \theta\frac{\partial V_{t+1}}{\partial P_{t+1}}\right] \tag{25}$$

Combining (24) with (25) then yields

$$MPK_G(t+1) = MPK_B(t+1) + \frac{\theta}{\frac{\tau_{t+1}}{C_{t+1}} + \frac{F}{e^{-\gamma\tau_{t+1}}Y_{t+1}}}\frac{\partial V_{t+1}}{\partial P_{t+1}} \tag{26}$$

This must mean that the carbon tax that equalises the marginal products of capital is given by

$$\frac{\theta}{\frac{\tau_{t+1}}{C_{t+1}} + \frac{F}{e^{-\gamma\tau_{t+1}}Y_{t+1}}}\frac{\partial V_{t+1}}{\partial P_{t+1}} = -Te^{-\gamma\tau_{t+1}}Y_{t+1} \tag{27}$$

i.e. carbon tax is a constant proportion of actual output.

Subsequently, we plug condition (23) to (27) and obtain:

$$\frac{\xi\theta}{(1-\beta)} = T \tag{28}$$

i.e.

$$MPK_G(t+1) = MPK_B(t+1) - \frac{\theta\xi}{1-\beta}e^{-\gamma\tau_{t+1}}Y_{t+1} \tag{29}$$

8.5 Optimal investment for $t > 1$

Assuming $C_{t>1} = \lambda\tau_{t>1}e^{-\gamma\tau_{t>1}}Y_{t>1}$, it must mean that $I_{B,t>1} + I_{G,t>1} = (1-\lambda)\tau_{t>1}e^{-\gamma\tau_{t>1}}Y_{t>1}$. Thus:

$$I_{B,t>1} = (1-\lambda)\tau_{t>1}e^{-\gamma\tau_{t>1}}Y_{t>1} - I_{G,t>1} \tag{30}$$

Expressing (29) in terms of investment allows us to use (30) and rearrange the equation so that:

$$\begin{aligned}\alpha I_{G,t>1}^{\rho-1} &= \alpha\psi\left((1-\lambda)\tau_{t>1}e^{-\gamma\tau_{t>1}}Y_{t>1} - I_{G,t>1}\right)^{\rho-1} \\ &\quad - \frac{\theta\xi}{1-\beta}\left(\psi\left((1-\lambda)\tau_{t>1}e^{-\gamma\tau_{t>1}}Y_{t>1} - I_{G,t>1}\right)^{\rho} + I_{G,t>1}^{\rho}\right)\end{aligned} \tag{31}$$

from which we can implicitly obtain $I_{G,t>1}$. Once $I_{G,t>1}$ is obtained, we refer back to (30) to get the consistent choice of $I_{B,t>1}$.

8.6 Optimal tax rates for $t > 1$

To obtain the optimal tax rates, we rely on condition (17) and (9) such that

$$\lambda\tau_{t>1}e^{-\gamma\tau_{t>1}}Y_{t>1} = \frac{(1-\tau_{t>1})(1-\gamma\tau_{t>1})e^{-\gamma\tau_t}Y_{t>1}}{F(1+\gamma(1-\tau_{t>1}))} \tag{32}$$

i.e.

$$\lambda = \frac{1}{F}\left(\frac{1}{\tau_{t>1}(1+\gamma-\gamma\tau_{t>1})} - 1\right) \tag{33}$$

where $F > 0$.

The full autocracy case, $F = 0$, relies on condition (18), i.e.

$$\tau_{t>1} = \frac{1}{\gamma} \tag{34}$$

8.7 Optimal choices at $t = 1$

At $t = 1$ we are still choosing optimally such that

$$MPK_G(2) = MPK_B(2) - \frac{\theta\xi}{1-\beta} e^{-\gamma\tau_2} Y_2 \tag{35}$$

i.e.

$$\alpha I_{G,1}^{\rho-1} = \alpha\psi I_{B,1}^{\rho-1} - \frac{\theta\xi}{1-\beta} \left(\psi I_{B,1}^{\rho} + I_{G,1}^{\rho} \right) \tag{36}$$

Using the budget constraint (i.e. $\tau_t e^{-\gamma\tau_t} Y_t - I_{B,t} - I_{G,t} = C$), we can express the above as

$$\begin{aligned} \alpha I_{G,1}^{\rho-1} &= \alpha\psi \left(\tau_1 e^{-\gamma\tau_1} Y_1 - C_1 - I_{G,1} \right)^{\rho-1} \\ &\quad - \frac{\theta\xi}{1-\beta} \left(\psi \left(\tau_1 e^{-\gamma\tau_1} Y_1 - C_1 - I_{G,1} \right)^{\rho} + I_{G,1}^{\rho} \right) \end{aligned} \tag{37}$$

to solve for $I_{G,1}$. Consistent $I_{B,1}$ is then taken from the budget constraint.

Furthermore, the optimal initial tax rate for $F > 0$ is given by condition (17) so that

$$C_1 = \frac{(1-\tau_1)(1-\gamma\tau_1) e^{-\gamma\tau_1} Y_1}{F(1+\gamma(1-\tau_1))} \tag{38}$$

and for $F = 0$ by condition (18):

$$\tau_1 = \frac{1}{\gamma} \tag{39}$$

Lastly, C_1 is chosen such that the equations (37) and (38) or (39) hold and that the Euler equation (24) implies:

$$\frac{1}{C_1} = \beta \frac{\tau_2}{C_2} MPK_G(2) + \beta \frac{F}{e^{-\gamma\tau_2} Y_2} MPK_G(2) \tag{40}$$

i.e.

$$\frac{1}{C_1} = \frac{\beta}{\lambda} \frac{\alpha I_{G,1}^{\rho-1}}{\psi I_{B,1}^{\rho} + I_{G,1}^{\rho}} + \beta F \frac{\alpha I_{G,1}^{\rho-1}}{\psi I_{B,1}^{\rho} + I_{G,1}^{\rho}} \tag{41}$$

8.8 Optimal λ

Having specified how all control variables of the model are optimally chosen assuming the validity of (9), the only remaining matter is to solve for a value of λ that would indeed guarantee the above conditions are met. Given the optimal choices at $t = 1$, we specify the entire optimised system for any $t > 1$ relying on the control variables given by (11)-(14) and evolution of the state variables given by (2)-(4). Ultimately, we solve for the value of λ that ensures the Euler equation (24) holds for every $t > 1$, subject to tolerance error.

8.9 Initial state variables

Assume our model starts from the no-externality, no-politics steady state where production is given by:

$$Y_t = \left(\psi K_{B,t}^{\rho} + K_{G,t}^{\rho}\right)^{\frac{\alpha}{\rho}} \tag{42}$$

The Bellman Equation is specified as:

$$\begin{aligned} V_t(K_{B,t}, K_{G,t}) = ln\left(\left(\psi K_{B,t}^{\rho} + K_{G,t}^{\rho}\right)^{\frac{\alpha}{\rho}} - I_{B,t} - I_{G,t}\right) \\ + \beta V_{t+1}(K_{B,t+1}, K_{G,t+1}) \end{aligned} \tag{43}$$

where:

$K_{B,t+1} = I_{B,t}$

$K_{G,t+1} = I_{G,t}$

Optimisation of the Bellman equation (43) yields the following first order (i.e. taken with respect to the control variables $I_{B,t}$ and $I_{G,t}$) and envelope theorem (i.e. taken with respect to the state variables $K_{B,t}$ and $K_{G,t}$) conditions:

F.O.C.s

$$w.r.t.\ \ I_{B,t}, \qquad \frac{1}{C_t} = \beta\frac{\partial V_{t+1}}{\partial K_{B,t+1}} \tag{44}$$

$$w.r.t.\ \ I_{G,t}, \qquad \frac{1}{C_t} = \beta\frac{\partial V_{t+1}}{\partial K_{G,t+1}} \tag{45}$$

E.T.s

$$w.r.t.\ \ K_{B,t}, \qquad \frac{\partial V_t}{\partial K_{B,t}} = \frac{1}{C_t}MPK_B(t) \tag{46}$$

$$w.r.t.\ \ K_{G,t}, \qquad \frac{\partial V_t}{\partial K_{G,t}} = \frac{1}{C_t}MPK_G(t) \tag{47}$$

Rearranging the conditions yields the Euler equation

$$\frac{C_{t+1}}{C_t} = \beta MPK_G(t+1) \tag{48}$$

and the identity

$$MPK_G(t+1) = MPK_B(t+1) \tag{49}$$

i.e.

$$K_{G,t+1}^{\rho-1} = \psi K_{B,t+1}^{\rho-1} \tag{50}$$

Using (48) we guess that $C_t = \lambda Y_t$. Then:

$$\frac{1}{Y_t} = \frac{\alpha\beta K_{G,t+1}^{\rho-1}}{\psi K_{B,t+1}^{\rho} + K_{G,t+1}^{\rho}} \tag{51}$$

i.e.

$$K_{B,t+1} + K_{G,t+1} = \alpha\beta Y_t \tag{52}$$

This means that

$$Y_t - C_t = (1-\lambda)Y_t = \alpha\beta Y_t \tag{53}$$

i.e. validating our guess.

Finally, we assume the steady state reflects $\dfrac{K_{G,1}}{K_{B,1} + K_{G,1}} = 20\%$, which implies $K_{B,1} = 4K_{G,1}$.

However, we need to ensure $MPK_B = MPK_G$, from which follows:

$$K_{B,1}^{\rho-1} = \psi(4K_{G,1})^{\rho-1} \Rightarrow \psi = 4^{1-\rho} \tag{54}$$

and

$$K_{G,1} = \left[\alpha\beta\left(\psi 4^{\rho} + 1\right)^{\frac{\alpha-\rho}{\rho}}\right]^{\frac{1}{1-\alpha}} \tag{55}$$