Inefficient Policies in the Green Transition

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Abstract

Countries have used a wide range of policy instruments to mitigate climate change. These policies have followed a common pattern in many cases: inefficient policies that rely on subsidies and command-and-control regulations have given way to carbon pricing. This paper analyzes a simple dynamic model of climate policymaking that can explain this pattern. Even though carbon taxes alone are optimal, in equilibrium a climate-concerned policymaker uses subsidies to induce investments in emissions-abatement technologies and, thus, obtain support for efficient policies in the future. The model provides additional insights: First, a policy package that satisfies the political constraints and passes a cost-benefit analysis only exists if neither the costs of decarbonization nor the discount rate of political actors are too large, and the social cost of carbon is intermediate. Second, if the policymaker is sufficiently ambitious, there are multiple equilibria: self-fulfilling expectations of future policy can lead to more stringent policy in the present. Finally, while a future climate-skeptic proposer might impede climate policy progress, that possibility relaxes political constraints in the present, and can paradoxically help initiate the policy sequence. The paper introduces a novel approach to modeling policy feedback and the influence of special interests in policymaking that may have further applications.

1. Introduction

Motivation. Countries representing 80.7% of global greenhouse gasses (GHG) emissions have communicated a target of net-zero emissions, most of them by 2050 (Climate Watch). There are two policies that, according to leading economists, can achieve these climate objectives at minimal cost: carbon pricing and R&D subsidies (e.g., Acemoglu et al., 2016; Metcalf, 2019; Blanchard et al., 2023). However, in practice, a wide variety of policies are used, which differ substantially in how efficient they are in terms of the cost per ton of CO_2 abated (Mealy et al., 2024; Hahn et al., 2024). Moreover, different kinds of policies are sequenced in predictable patterns: less efficient policies such as command-and-control regulations, feed-in tariffs (FITs) and renewable portfolio standards (RTSs), which involve explicit or implicit subsidies for emissions abatement investments and renewable energy production, are eventually replaced by carbon pricing as the main policy tool (Linsenmeier et al., 2022).

The following examples illustrate this pattern. Germany relied on FITs to support the expansion of renewable energy production since the 1990s (von Hirschhausen et al., eds, 2019), but replaced the FITs with auctions in 2014 (Clean Energy Wire). Despite initially being reluctant to participate in the EU Emissions Trading System (ETS) (Ellerman et al., eds, 2010), Germany implemented a carbon price for the heating and transport sectors in 2021 (IEA). The EU followed a similar path. It enacted in 2001 the Renewable Energy Directive mandating member states to set national targets for renewable energy production; in 2009, the targets became legally binding, and their scope was expanded (Leipprand et al., 2020).[1] The ETS was introduced in 2003, and it imposed a low carbon price until its 2018 reform, which took effect in 2021; prices have been above 80€ per ton of CO_2 most of the time since 2022 (van den Bergh and Botzen, 2024). The Canadian federal government implemented a series of inefficient regulations and subsidies in its unsuccessful attempt to comply with the Kyoto Protocol (Jaccard et al., 2006; Samson and Stamler, 2009; Harrison, 2010b); in 2018, it enacted an ambitious national carbon price (Harrison, 2023).

In a series of papers, Meckling et al. (2015, 2017) and Pahle et al. (2018) have proposed an explanation for the sequencing of policy instruments based on the idea of policy feedback: technology mandates and renewable energy support policies, for example, can be used to build a coalition in support for more efficient and stringent policies in the future. Policies that create concentrated benefits, while protecting powerful opponents from immediate costs, can induce economic agents to make investments tied to the long-term decarbonization of the economy, which disrupts the power of incumbent carbon-intensive industries in the future without leading to an immediate veto.

This argument raises a number of theoretical questions. First, how large is the distortion from first-best policies required to pursue this strategy? Second, under what conditions is it possible for policymakers to design a policy package that attracts pivotal opponents without alienating existing members of the coalition? Third, how is the strategy affected by the possibility that future policymakers may not be willing to continue the intended policy sequence?

This paper. To address these questions, I develop a dynamic model of climate policymaking. The main ingredients are the following. First, policies emerge from legislative bargaining, and the legislature is heterogeneous—some legislators represent districts that are more invested in "brown" (i.e., high emissions intensity) technologies, and some districts face lower costs of decarbonization than others. Both present climate policy and the expectation of future policy affect the investments

[1] In the top six European countries, "[t]he cost to society implied by the deployment of wind and solar technologies [in 2010] represented €48,300 million" (Dechezleprêtre and Popp, 2017).

that economic actors make, which, in turn, affects their preferences in the future. Today's policy outcome is therefore constrained by today's legislature, but also shapes the legislative constraints a policymaker faces in the future.

Second, policymakers face the threat of turnover. The current policymaker may be replaced by another whose preferences differ in how they prioritize environmental concerns versus aggregate economic welfare.[2] This creates uncertainty, which affects incentives to invest in mitigation technologies.

In the baseline model I consider two policy instruments: a carbon tax, and a subsidy for investments in green capital (e.g., renewable energy, clean manufacturing technologies, carbon capture, energy efficiency, or electric vehicles). The carbon tax is a form of carbon pricing and is equivalent to an emissions trading scheme with auctioned allowances. I assume that the revenues are recycled as uniform lump-sum transfers. Later, I extend the model to consider other types of policies, including targeted transfers (e.g., free allowances in the context of cap-and-trade systems), output subsidies, tradable standards, and feed-in tariffs.

The first-best policy in the model is simply a Pigouvian carbon tax that equates the price of carbon emissions to the social cost of carbon. The investment subsidy is not needed, because the expectation of an optimal carbon price is enough to induce socially optimal investment decisions.

Results. The main findings of the paper concern the scenario in which a climate-concerned policymaker has agenda-setting power, the status quo is business-as-usual (BAU), and a majority of the members in the legislature represent carbon-intensive constituencies. In this scenario polluting interests have effectively veto power over climate policy, and in a static model they would block any change over the status quo. However, under some conditions the policymaker is able to implement a climate policy package that eventually leads to first-best policy. This holds even if legislators care about the economic interests of their constituents and not about environmental outcomes.

The equilibrium climate policy in the first period consists of an investment subsidy and a carbon tax that is below the Pigouvian level, and can be zero. The subsidy is set at the level that leaves the median legislator (ordered by the productivity of the green alternative technology in their district) indifferent between paying the proposed carbon tax, taking the subsidy, and investing in abatement, on the one hand, and keeping their polluting capital under business-as-usual for both periods, on the other hand. All the brown districts with better decarbonization opportunities than the median strictly prefer the policy package over the status quo, and decide to invest in abatement. Therefore, in the second period the green districts form a majority, and thus the green policymaker (if still in

[2] Most economic models express environmental damages in terms of a decrease in production (e.g., Golosov et al., 2014), so it's not obvious how to separate conceptually concerns for climate and for the economy. There are at least two ways. The first is to think that the two parties differ in their beliefs about the causal link between greenhouse gas emissions and climate change. The second is that the concern for GHG emissions expresses an attitude about the country's responsibility to reduce emissions, possibly induced by international cooperation.

power) implements the first-best policy. If, instead, the brown party is in power, they are forced to keep the carbon tax at the new status quo level. Thus, the green proposer uses policy in the first period to reduce the power of the brown interests, and to build a coalition in support of efficient policy in the future.

The need to build a coalition in the legislature that contains both green and brown interests imposes two political constraints on policy. The brown districts want a low carbon tax today and a generous investment subsidy. This creates a trade-off: an ambitious carbon tax in the first period requires a larger subsidy to compensate. The green districts support a carbon tax because they enjoy the increased government revenue, but oppose a raise in taxes to cover the green subsidies, so they impose a dynamic budget surplus constraint: the subsidy must pay itself with the current plus the future carbon tax revenue. If both constraints can be satisfied simultaneously, the proposer can start the climate policy sequence.

I show that these constraints cannot always be jointly satisfied: the alternative clean technology must be sufficiently productive, investment costs sufficiently low, the discount factor sufficiently large, and the social cost of carbon cannot be too large. The last condition is perhaps counterintuitive; the reason is that if the green policymaker is too ambitious, brown producers expect large losses if they do not invest in abatement; this, in turn, leads to large fiscal costs due to the subsidy, which clashes with the budget surplus constraint.

The fact that a climate policy sequence can be started, i.e., the political constraints can be jointly satisfied, does not imply that a climate-concerned policymaker will pursue it. Satisfying the demands of the pivotal brown industries increases the social costs of climate policy due to inefficient investments and low levels of abatement. If these costs are large enough, the green policymaker will prefer to keep the status quo, unless their climate concerns are sufficiently serious. Thus, the model can explain not only how the policy sequencing strategy works, but also why in many cases it fails or is not pursued, even if politicians in power are concerned about the climate.

The dynamic linkage of policies raises a novel implication: under some conditions, the model has multiple equilibria.[3] There is always an equilibrium in which polluting interests expect that failure of climate policy in the present preserves their political power in the future. But, if the policymaker is sufficiently concerned about the climate, a self-fulfilling prophecy is possible in which, expecting a carbon price in the future, enough economic agents make abatement investments, which reduces the political influence of polluters in the future, leaving the policymaker room to enact the carbon pricing policy. The fact that polluters are expected to lose their political power in the future regardless of the policies implemented in the present reduces their bargaining power, which enables the policymaker to enact more ambitious policies than in the baseline equilibrium. However,

[3] Biais and Landier (2022) and Smulders and Zhou (2024) also study models where climate policy creates multiple equilibria.

even though first-best policy is possible under some circumstances, in general the equilibrium features the same policy sequencing pattern: a green technology subsidy combined with a low carbon price, eventually replaced with a Pigouvian carbon tax.

The possibility that the policymaker is not in power in the future to continue the policy sequence may paradoxically help start it. Suppose that with some probability the future policymaker is not concerned about the environment. In that case the carbon tax will stay low, and brown constituencies will be more reluctant to make investments in green capital despite the subsidy. This reluctance has a benefit: it reduces the fiscal cost of the subsidy as fewer districts utilize it, leaving the current policymaker with more fiscal resources for transfers. As a result, the political constraints are relaxed, enabling the implementation of more ambitious policies.

This finding challenges the intuitive notion that low polarization on climate issues is necessary for policy progress. Instead, a polarized party system—where one major party is more committed to climate change mitigation than the median voter, while another opposes stringent climate policy—may be more conducive to initial policy progress when polluting interests still wield significant political power. Such polarization can create windows of opportunity for initiating ambitious climate policy sequences, even though it increases the likelihood of these sequences being interrupted. The passage of the Inflation Reduction Act of 2022 in the US suggests the plausibility of this result.

Finally, the model can be extended to study other policy instruments such as renewable energy production subsidies, clean technology standards, and feed-in tariffs. The qualitative results are robust: if green technologies are sufficiently advanced, capital costs low, and discount factors high, these policies are used in equilibrium in a first stage to disrupt the power of polluting interests, build a green coalition, and create the ground for optimal carbon taxes in the future.

Literature. The paper contributes to the literature on the domestic political economy of climate policy (besides the work already cited, relevant papers include Harrison, 2010a; Breetz et al., 2018; Dolphin et al., 2020; Battaglini and Harstad, 2020; Besley and Persson, 2023). The first contribution is methodological—I provide a new way to model policymaking under political constraints that are dynamic and microfounded. There are two main approaches in the literature to study policy distortions by special interests: ad-hoc constraints, and common agency models. Two examples of the first approach are Tornell (1991), who models the political pressure by a protected industry as a constraint that policy must keep the employment level of the industry above a certain baseline, and Rozenberg et al. (2020), who models the political pressure by fossil fuel energy producers as a "no stranded assets" constraint on policy. Two examples of the second approach are Grossman and Helpman (1994) and Gerlagh and Liski (2023), who assume that a subset of producers can offer transfers to the policymaker contingent on policies.[4] The drawback of both approaches is that they

[4]Other papers using the ad-hoc constraints approach to study climate policy include Bovenberg et al. (2005, 2008); Kalkuhl et al. (2013); Kalk and Sorger (2023); Acharya et al. (2024). Others using the common agency approach

cannot account for the ability of policy to change the power of special interests, because that power is assumed to be exogenous.

Second, the paper contributes specifically to the literature on policy feedback in climate policy (Aklin and Urpelainen, 2013; Meckling et al., 2015, 2017; Pahle et al., 2018; Stokes, 2020) by analyzing a stylized but microfounded model of the feedback mechanism. More broadly, the paper contributes to the theoretical literature that studies how the dynamic political effects of policies impact their choice (Alesina and Tabellini, 1990; Persson and Svensson, 1989; Besley and Coate, 1998; Prato, 2017) by showing how dynamic strategic considerations can explain puzzling patterns of climate policy. Baldursson and von der Fehr (2007) follow a similar approach, but they study a different question, viz, why "brown" governments may sell long-lived allowances instead of pursuing a carbon tax, given that the latter is more efficient. This paper also provides further implications of dynamic policymaking with an endogenous status quo (Buisseret and Bernhardt, 2017; Dziuda and Loeper, 2018; Austen-Smith et al., 2019).

Third, I contribute to a related literature that studies the effects of partisan turnover on climate policy (Ulph and Ulph, 2013; Schmitt, 2014; Harstad, 2020; Hochman and Zilberman, 2021; Behmer, 2023). A common result is that the possibility of a "brown" policymaker in the future distorts policy in the present by increasing carbon taxes and clean technology subsidies relative to the first-best. Although the same forces are present in this paper, I reconcile the effect of turnover with the empirical observation that green subsidies coexist with low or zero carbon prices.

Fourth, the analysis in this paper contribute to the literature on the politics of climate policy instrument choice (Buchanan and Tullock, 1975; Aidt and Dutta, 2004; Hughes and Urpelainen, 2015; Meckling and Jenner, 2016; Cullenward and Victor, 2020; Konisky, 2024) by showing how policies that offer benefits conditional on investments in emissions-cutting technologies can be used in political equilibrium even though they increase social cost relative to other available policies. Aidt and Dutta (2004) explain the transition from command-and-control policies to carbon pricing, but they need to assume that there is an exogenous tightening in emissions-reduction objectives; in contrast, the increase in policy ambition emerges endogenously in my model. In addition, the model provides a political economy rationale for the use of green industrial policy (Rodrik, 2014; Meckling, 2021; Allan and Nahm, 2024; Juhász and Lane, 2024).

The paper also speaks to the research on the political acceptability of climate policy (Gaikwad et al., 2022; Meckling and Nahm, 2022; Meckling and Strecker, 2023; Bolet et al., 2023; Gazmararian and Tingley, 2023) and lobbying (Grumbach, 2015; Kim et al., 2016, 2021; Brulle, 2018; Meng and Rode, 2019; Goldberg et al., 2020; Kennard, 2020) by showing how they shape both the ambition

include Fredriksson (1997); Damania (2001); Fredriksson and Svensson (2003); Damania and Fredriksson (2003); Fredriksson and Sterner (2005); Fredriksson and Wollscheid (2008); Habla and Winkler (2013); Aidt (1998); Aidt and Dutta (2004); Aidt (2010); Lai (2007, 2008); Hanoteau (2014); Grey (2018); Kalkuhl et al. (2020); Winkler (2022).

of policy objectives and the instruments used to achieve them.

Structure of the paper. In Section 2 I introduce the model and discuss its assumptions. In Section 3 I determine optimal policy without political constraints in first-best and second-best scenarios, and with political turnover. In Section 4 I analyze the full model and provide the main results. In Section 5 I show that the main qualitative findings are not affected by considering other policy instruments such as targeted rebates and subsidies, output subsidies, standards and feed-in-tariffs. Section 6 concludes.

2. The model

The economy. There is a set of districts indexed by $i \in I = [0, 1]$. Each district has a unit of specific capital that cannot be traded.[5] Capital can be "green" or "brown", and we denote $\chi_{it} = 1$ if the capital of i is brown at time t, and $\chi_{it} = 0$ if it is green. Brown districts can "upgrade" or "transition" their capital to the green kind by paying a cost $c > 0$. The decision to upgrade at time t is denoted $\iota_{it} = 1$; absent a transition, $\iota_{it} = 0$.

There is one good in the economy, which is used for production and consumption, and will serve as the numéraire. A brown district produces y units of the good at cost $\frac{1}{2}y^2$, and emits y units of carbon by doing so. A green district produces y units at cost $\frac{1}{2A_i}y^2$, where $A_i > 0$ is the productivity of green technology in district i.[6] For simplicity, I will assume that $A_i = Ai$ for all $i \in I$, where $A > 1$ is a parameter. This captures in reduced form the assumption that decarbonization entails different changes in productivity in some districts than others—green technology is more productive than brown technology in some districts, but less productive in others.

Policy. There are three policies. First, a carbon tax $\tau \in [0, 1]$. Second, there is a green investment subsidy $s \geqslant 0$ that is transferred to any brown district that decides to upgrade its capital. Finally, there is a uniform lump-sum transfer (or tax) $T \in \mathbb{R}$. A climate policy bundle is defined a tuple (τ, s, T) of a carbon tax, a green investment subsidy, and a uniform transfer.

Policy process. The districts are represented in a legislature. There are two parties, G and B, and an initial policy bundle $p_0 = 0$. In each period $t \in \{1, 2\}$ the timing of events is:

1. The proposer $P_t \in \{G, B\}$ is drawn, with $\Pr(P_t = P_{t-1} | P_{t-1}) = \rho \in [0, 1]$.
2. P_t chooses a policy proposal $p'_t = (\tau'_t, s'_t, T'_t)$.
3. If a majority of districts i prefer p'_t over p_{t-1}, then $p_t = p'_t$, and otherwise $p_t = p_{t-1}$.

[5] This is a composite of the district's human capital and investments that are location-specific in the short run (e.g., energy production capacity and infrastructure).

[6] This is equivalent to assuming that there are firms with production function $f_i(x) = x_B^{\frac{1}{2}} k_B^{\frac{1}{2}} + A_i x_G^{\frac{1}{2}} k_G^{\frac{1}{2}}$, where x_B, x_G denote units of the numéraire used for production, k_B denotes units of i's brown specific capital, and k_G denotes units of i's green specific capital.

4. Districts make production and investment decisions, $y_i \geqslant 0$ and $\iota_{it} \in \{0, 1\}$.

In the last period T is not a choice, and is set so that the budget is intertemporally balanced:

$$\sum_{t=1}^{2} \delta^t \left[\tau_t e_t - T_t - \int_0^1 \iota_{it} s_t \, di \right] = 0,$$

where $e_t = \int_0^1 e_{it} \, di$ is the aggregate quantity of emissions. I assume that agents can take on debt for free subject to the same budget constraint, viz, $\sum_{t=1}^{2} \delta^t B_t = 0$ if B_t is the net debt taken/paid in period t.

Preferences. The agents maximize expected discounted payoffs, with a common discount factor $\delta \in (0, 1]$. In each period t, districts' payoff is given by their income

$$\pi_{it} = \begin{cases} (1 - \tau_t) y_{it} - \frac{1}{2} y_{it}^2 - \iota_{it}(c - s_t) + T_t & \text{if } i \text{ is brown,} \\ y_{it} - \frac{1}{2Ai} y_i^2 + T_t & \text{if } i \text{ is green,} \end{cases}$$

which is given by the returns of their capital endowment net of taxes and transfers, and investment costs net of subsidies if they decide to transition.

The payoff of a proposer of type $P \in \{G, B\}$ in period t is given by

$$W_t = \int_0^1 \pi_{it} \, di - \alpha_P D_t(E_t),$$

where $E_t = e_1 + \cdots + e_t$ is the stock of local carbon emissions, D_t measures environmental damage at time t, with $D_t' > 0$ and $D_t'' \geqslant 0$, and $\alpha_P \in [0, 1]$ measures how each proposer trades off consumption for environmental damage. I will assume that $\alpha_G = 1$ and $\alpha_B = 0$, and that environmental damage is linear in emissions, $\sum_{s \geqslant t} \delta^{s-t} (D_s(E) - D_s(0)) = \lambda E$ for all $t \geqslant 1$ and $E \geqslant 0$, where $\lambda \in (0, \frac{1}{2})$ measures the social cost of carbon.

Equilibrium Concept. Subgame perfect equilibrium, with a Markov refinement that excludes strategies that condition on past production levels.[7]

Comments on the Assumptions. The model of the economy is highly stylized in order to focus on the political mechanism, but the simplifications are not uncommon in the literature. For example, Acharya et al. (2024) also assume that there is only one good in the economy and there is no market power, and Coate and Morris (1999) also assume that firms upgrade their technology by making a binary investment decision. Colmer et al. (2024) provide empirical justification for the

[7] The reason for this assumption is to avoid implausible equilibria in which a green government induces abatement "for free" by promising to take away carbon tax rebates from districts in the second period if they do not reduce emissions or invest in the first period.

latter assumption: in their study of the EU ETS the conclude that "[o]ur findings are consistent with firms paying an up-front fixed cost to invest in alternative 'clean' production technologies that reduce marginal variable costs". Ramadorai and Zeni (2024) show that firms react to beliefs about future carbon prices by investing in carbon abatement technology, which justifies the assumption that firms anticipate future climate policies. The assumption that the productivity of clean technology is heterogeneous across constituencies can be defended in two ways: the cost-competitiveness of renewable energy depends on location (Davis et al., 2023), and the advances in decarbonization technology depend on industry (Victor et al., 2019).

The assumption that different proposers may differ in their concerns for climate may be explained by differences in partisanship. Cadoret and Padovano (2016) find that left-wing governments promote the development of renewable energy more than right-wing parties in Europe. Lundquist (2024) finds that the degree of environmentalism expressed in parties' manifestos predicts the level of policy stringency they implement when in power. Knill et al. (2010), Jensen and Spoon (2011) and Jahn (2022) obtain similar results. Fankhauser et al. (2015) and Dolphin et al. (2020), however, do not find an effect of party ideology on climate legislation or the carbon price. In any case, the main results of this paper do not depend on this assumption. What is crucial is that carbon-intensive interests hold political power (because of their representation in the legislature) regardless of which party controls the agenda. Mildenberger (2020)'s logic of the double representation of these interests (with labor being represented via left-wing parties and business via right-wing parties) provides an empirically grounded justification for this assumption.

An important feature of the model is that investments in emissions-substituting capital in the present change the policy preferences of the constituencies where those investments take place. I offer two pieces of evidence to support this assumption. First, Urpelainen and Zhang (2022) show that wind turbine installations increased vote shares of climate-concerned Democratic candidates in US House elections, and led to an increase in pro-climate votes in Congress, even though they may have created an electoral backlash among voters located close to the turbines. Second, Vormedal and Meckling (2023) provide evidence that the shale gas revolution led oil and gas industries to sincerely support carbon pricing (during the Trump administration, Exxon lobbied against withdrawal from the Paris Agreement, and a Republican-backed coalition involving Exxon and other oil companies promoted legislation for a federal carbon tax starting at $40 per ton), and the fuel-efficiency regulations on the car industry imposed by the Obama administration led some car manufacturers to resist Trump's decision to roll back those regulations, due to their investments in clean technologies.

There are many important issues involved in climate policy from which the model abstracts, such as innovation, learning-by-doing and network externalities (Stock, 2020; Fischer et al., 2021; Bistline et al., 2023; Hahn et al., 2024), imperfect competition (Kennard, 2020), regulation of energy markets (Reguant, 2019; Davis et al., 2023), land use regulation (Sud et al., 2023), other tax distortions (Barrage, 2020), international trade (Clausing and Wolfram, 2023; Kotchen and Maggi, 2024), conservation (Harstad, 2023a), international cooperation (Battaglini and Harstad, 2016; Harstad, 2023b), private politics (Egorov and Harstad, 2017), consumer preferences (Besley and Persson, 2023), behavioral distortions of energy-efficiency investments (Allcott et al., 2014), and the possibility of fiscal illusion (Abbott and Jones, 2023).

3. Benchmarks

Optimal Policy. Suppose that a green policymaker is unconstrained by the legislature, and does not face the threat of turnover. What is the optimal policy choice? To answer this question, I will characterize first how policies affect production and investment decisions.

Given a tax τ_t, firms in brown districts i choose the level of production y_{it} to maximize profits $(1-\tau_t)y_{it} - \frac{1}{2}y_{it}^2$. Thus, $y_{it} = 1-\tau_t$, and profits are $\frac{1}{2}(1-\tau_t)^2$. Similarly, firms in green districts i choose $y_{it} = A_i$, and their profit is $\frac{1}{2}A_i$.

Let $b_t = \int_0^1 \chi_{it}\, di$ be the share of brown firms at time t. If a firm in district i decides to invest in green capital in the first period, they pay the cost of capital, $-c$, and receive the investment subsidy, s. Their discounted second-period profit is $\delta\frac{1}{2}A_i$. If the firm does not invest, its expected profit in the second period is $\delta\frac{1}{2}(1-\tau_2)^2$. Therefore, the firm invests in green capital if and only if $s - c + \frac{\delta A_i}{2} \geqslant \frac{\delta}{2}(1-\tau_2)^2$. Using the assumption that $A_i = Ai$, we obtain that the set of brown firms that transition is $[b_2, b_1)$, where b_2 is given by

$$s - c + \frac{\delta A}{2}b_2 = \frac{\delta}{2}(1-\tau_2)^2. \tag{1}$$

Thus, the policy instruments have the following effects on the economy. Carbon taxes reduce emissions by reducing production in the brown districts. The second-period carbon tax also induces investment in green capital, since, if correctly anticipated, it reduces the expected returns from using brown capital. The subsidy s increases investment in the first period directly.

Observation 1. *The optimal policy consists of Pigouvian carbon taxes and no subsidies. Moreover, it implements the optimal allocation.*

Proof. All proofs are in Appendix B. ∎

There are two kinds of economic decisions, production and investment, and both have externalities—production creates carbon emissions, and investment reduces carbon emissions in the future. The carbon tax induces producers to internalize the first externality; thus the optimal tax is equal to the marginal environmental damage (this the Pigouvian level). The subsidy can induce producers to internalize the second externality, viz, to give them incentives to invest in green capital and thus reduce future emissions. However, in equilibrium the policymaker does not use the subsidy, because once the first externality is corrected, the second one disappears. If the subsidy was used along with Pigouvian carbon taxes, it would lead to inefficient investments, i.e., investments in technologies that reduce emissions at an economic cost larger than the environmental cost of pollution.

Political Turnover. Suppose now that there is a probability $1 - \rho$ that the policymaker in the second period is not concerned about environmental damages. Such policymaker would impose no carbon taxes. Thus, from a first-period perspective, the expected future profit in the brown sector is greater than if turnover was not possible, because with probability ρ the future carbon tax is zero. As a result, fewer firms decide to transition.

How should the green policymaker respond? As I show in Appendix B.2, the Pigouvian carbon tax is still optimal, but the optimal subsidy is now $s = \delta(1 - \rho)\lambda$. The reason why the subsidy is required in this case is that political turnover reduces investment below the optimal level, and the subsidy is the appropriate instrument to correct this distortion. It is noteworthy and intuitive that the optimal subsidy increases with the probability of turnover and with the social cost of carbon.

The result that the equilibrium carbon tax is not affected by political turnover depends on the assumption that the environmental damage is linear. If the environmental damage is a strictly convex function of the stock of carbon emissions, the effect of an increase in the probability of turnover on the first-period carbon tax is ambiguous. There are two effects. First, given that the second-period carbon tax is likely to be repealed, emissions are likely to be larger than optimal; with a convex cost, this implies that the cost of additional first-period emissions is larger, which pushes first-period carbon taxes above the first-best level. However, a second effect is that turnover leads to the use of the subsidy, which increases investment, and hence brings emissions down, which decreases the cost of additional first-period emissions. See Appendix B.2 for details.

In sum, government turnover can explain the use of subsidies, but under this mechanism subsidies arise as a complement to carbon pricing, not as a substitute. To explain why subsidies are enacted with low or zero carbon taxes, we need to incorporate political constraints to the model.

4. Legislative Bargaining

I study now the full model, incorporating the legislative bargaining game to the analysis. An initial observation is that if green districts form a majority in the first period then they are at least as willing to implement ambitious climate policy as the green policymaker, since they benefit from the fiscal revenue and do not suffer the economic costs of the policies. Therefore, in this case the green policymaker is effectively unconstrained, and we are back to the scenario in the previous section. From now on, I will focus on the interesting case in which brown districts form a majority initially.

Assumption 1. The initial set of brown districts are exactly the districts that do not have an incentive to transition if no climate policy in either period is expected, and are a majority. Formally, districts $i \in [0, b_1)$ are brown in the first period, and $i \in [b_1, 1]$ are green, where b_1 is given by $-c + \frac{\delta A}{2} b_1 = \frac{\delta}{2}$ and satisfies $\frac{1}{2} < b_1 < 1$.

If brown districts are still a majority in the second period, the legislature will block any proposal to raise carbon taxes. In the first period, the legislature only accepts a carbon tax if it is bundled with a subsidy that is generous enough to compensate for the cost imposed by the tax. A crucial observation is that in order for a district to benefit from the subsidy, it needs to invest in the clean technology, which turns them into a green district in the second period. Therefore, a legislative victory in the first period occurs only if there is a green majority in the second period. In that case, the future green majority accepts any increase in carbon taxes and blocks any proposal to lower them, because they do not suffer the economic costs but enjoy the fiscal benefits. Thus, if the green policymaker stays in power in the second period, they set the carbon tax at the Pigouvian level, and, if a brown policymaker takes over, they keep the carbon tax at the level inherited from the first period.

Legislators anticipate that approving a subsidy in the first period can lead to a raise in the future carbon tax. They understand that even if the government runs a deficit in the present to pay for the subsidy, this may not lead to new taxes, because the future carbon tax is a source of revenue. Hence subsidies can be attractive even for green districts, who do not benefit directly from them. Brown districts that do not plan to take the subsidy, on the other hand, realize that even if the first-period carbon tax is low or even zero, it can lead to a large tax in the future, and hence they oppose it.

To change he status quo policy, the policymaker needs to create a winning coalition that includes the green districts and enough brown districts to form a majority. The pivotal brown districts demand a subsidy that is large enough to compensate them for the losses from the carbon tax in the present and the costs from the investment in green capital. The green districts demand a subsidy that is not so large that exceeds the expected revenue from the carbon tax, because they are not willing to pay taxes.

When casting their vote, legislators compare the policy that is proposed, in conjunction with the future policy they expect to follow, against the status quo plus the policy they expect to be enacted in the future if the status quo is preserved. There are two possibilities in the second case. If there is a brown majority in the future, the future carbon tax is zero. However, if there is a green majority in the future and the green policymaker stays in power, they enact a Pigouvian carbon tax. The first possibility is always an equilibrium of the subgame in which the proposal fails in the first period. I consider the second possibility in the next section. The following Lemma characterizes the two political constraints, assuming that if the proposal is rejected in the present then the status quo persists.

Lemma 1. *A carbon tax τ_1 and a subsidy s are accepted by the legislature if and only if*

$$\frac{1}{2}(1-\tau_1)^2 + s - c + \frac{\delta A}{4} + T \geqslant \frac{1}{2} + \frac{\delta}{2} \tag{PC$_B$}$$

and

$$T = b_1\tau_1(1-\tau_1) + \delta b_2 \mathrm{E}[\tau_2(1-\tau_2)] - s(b_1 - b_2) \geqslant 0, \tag{PC$_G$}$$

hold, where $\tau_2 = \max\{\tau_1, \lambda\}$ with probability ρ and $\tau_2 = \tau_1$ with probability $1-\rho$, and b_2 is given by

$$s - c + \frac{\delta A}{2} b_2 = \frac{\delta}{2}\mathrm{E}\big[(1-\tau_2)^2\big]. \tag{2}$$

Proof. See Appendix B.3. ■

What do equilibrium policies look like? If the policymaker can satisfy the political constraints, the carbon tax is less than optimal, and it can be zero in equilibrium, while the subsidy is positive and can even be larger than the cost of green capital.

Proposition 1. *In equilibrium $\tau_1 = s = 0$ or $\tau_1 < \lambda$ and $s > 0$.*

To understand this result, we can focus on the case in which there is no turnover for simplicity. Notice first that in equilibrium either the political constraint imposed by pivotal brown districts, PC_B, binds, or the subsidy is zero. This is because, given the first-period tax, both the policymaker and the green districts prefer to reduce the subsidy, so the policymaker chooses the subsidy to be as low as possible. Brown districts are not willing to accept a carbon tax with no subsidies. Thus, if the policymaker decides to impose a carbon tax, the higher the tax, the greater the subsidy needs to be in order to compensate the pivotal brown districts. There is a tradeoff: a larger carbon tax brings it closer to the Pigouvian level, but increases the size of the subsidy, whose efficient level is zero. The equilibrium carbon tax is below the efficient level, because, starting from the Pigouvian level, a small decrease in the tax has a negative effect on the objective of the policymaker that is of second order, but makes possible a reduction in the subsidy that has a first order positive effect. For the same reason, the subsidy must be positive, because an increase from 0 is second order, but makes possible an increase in the carbon tax that has a positive first order effect.

This result can explain the phenomenon of policy sequences: the green policymaker initially obtains a partial political victory by enacting a low carbon tax and an inefficiently large subsidy, and this leads over time to efficient policies. The initial policies are designed to expand the green coalition by inducing pivotal brown districts to transition. Germany's experience with the Renewable Energy Sources Act (EEG) of 2000 offers an illustration of this mechanism. The EEG, enacted by the Social Democrat-Green coalition, provided generous feed-in tariffs for renewable energy, which effectively acted as an investment subsidy. While these tariffs were inefficient as policies designed to reduce carbon emissions (Marcantonini and Ellerman, 2015), they served to rapidly expand the renewable energy sector. This expansion created a growing constituency of firms, workers, and communities with vested interests in green policies. Over time, as the renewable energy industry matured and costs decreased, Germany was able to gradually reduce the subsidies and implement more market-based mechanisms: the 2017 revision of the EEG introduced competitive auctions for most renewable energy sources. Furthermore, despite initially being reluctant to participate in the EU Emissions Trading System (Ellerman et al., eds, 2010), Germany implemented a carbon price for the heating and transport sectors in 2021 (IEA). This progression exemplifies how an initially inefficient policy paved the way for more comprehensive and efficient climate measures by altering the balance of power between green and brown economic interests over time.

Proposition 1, however, raises the following question: under what conditions does the policy sequence start? Two key conditions must be met. First, there must be a policy package that is acceptable to both the green districts and the pivotal brown districts. In other words, the two political constraints must be feasible. These constraints are in conflict: brown districts close to the green frontier demand low carbon taxes and large subsidies, while green districts advocate for high carbon taxes and low subsidies. Second, there must exist a feasible policy that the policymaker prefers over the status quo. The policymaker, while concerned about environmental damages, also prioritizes aggregate economic performance. Political feasibility introduces distortions that conflict with the objective of improving economic outcomes. Consequently, for the policy sequence to initiate, a policy bundle must not only be politically feasible but also pass a cost-benefit analysis: the expected environmental benefits must outweigh the aggregate losses in consumption.

A simple characterization of the conditions under which the political constraints are feasible is not possible. However, the analysis (technical details in Appendix B.5) reveals the following insights. First, the constraints are feasible if and only if green technology is sufficiently advanced (i.e., A is sufficiently large, given the other parameters), the cost of green capital c is sufficiently low, and the discount factor δ is large enough. In other words, as the economic incentive to switch to carbon-abating technologies improves, the political challenge of implementing climate policies is reduced. There are two reasons for this result. First, high productivity of carbon abatement and low capital costs imply that more districts should have already transitioned, resulting in a lower initial share of brown districts. Consequently, the fiscal costs of the subsidy are smaller. Second, lower private costs of decarbonization reduce the required level of compensation, thus decreasing the fiscal cost of securing support from the marginal district.

An additional result is that, if the initial political opposition is not too large, the political constraints are feasible if and only if the social cost of carbon is not too large. The reason is that if the social cost of carbon is large, brown districts expect the carbon tax in the second period to be large; as a result, they invest in green capital in larger numbers. Therefore, as the carbon tax rate increases, the base of the tax, i.e., the number of economic agents that pay the tax, decreases; the second effect dominates for large tax rates. At the same time, the fiscal cost of the subsidy rises, because the marginal districts that invest receive the subsidy. This, in turn, implies that the subsidy needed to compensate the pivotal brown districts has to increase, because the expectation of lower fiscal surpluses reduces the attractiveness of the policy proposal to these districts, since fiscal surpluses are transferred back to the districts. This effects, in turn, further exacerbates the problem, because a larger subsidy induces even more districts to transition, reduces the carbon tax base, and increases the fiscal costs.

This last result is somewhat paradoxical at first glance: the more the green party desires to reduce carbon emissions, the harder it is for them to implement *any* reduction. This is because of time inconsistency. The only way to reduce carbon emissions is to obtain a green majority in the future. But once the green majority is achieved, a very progressive green party will ask it to implement very ambitious policy. This, in turn, makes building the majority harder, because the subsidy needed to compensate the pivotal districts creates a fiscal cost can alienate the existing members of the coalition. If the policymaker could commit to a second-period carbon tax, they would not choose a Pigouvian tax, because the direct effect of reducing the second-period tax on the objective is second order, and, thus, the indirect effect on the first-period tax dominates. This is because a smaller second-period carbon tax reduces the share of districts that transition, which reduces the distortion caused by the subsidy; this, in turn, lets the policymaker increase the subsidy, and increase the first-period carbon tax, which has a first order positive effect on the objective. Another way of thinking about this intuition is that commitment would make it possible to produce tax smoothing: instead of a very low τ_1 followed by an optimal τ_2, it is preferable to have a larger τ_1 and a smaller τ_2.

The fact that the political constraints are feasible, and there is a policy (τ_1, s) that the legislature is willing to approve, does not imply that the policymaker will choose the best such policy, because the distortions may be so large that inaction is preferable. In other words, the best politically feasible climate policy may not pass a cost-benefit analysis. Let $\Delta W(\tau_1, s) = W(\tau_1, s) - W^{\mathrm{BAU}}$, so that the green policymaker prefers (τ_1, s) over BAU if and only if $\Delta W(\tau_1, s) \geqslant 0$. We have the following result.

Observation 2. *There is $\underline{\lambda} > 0$, which depends on A, c, δ, ρ, such that PC_B, PC_G and $\Delta W \geqslant 0$ hold only if $\lambda \geqslant \underline{\lambda}$.*

Proof. See Appendix B.6. ∎

The reason for this result is simple: if the cost of carbon is very small then the policymaker does not prioritize environmental damages, and, therefore, is not willing to implement substantial climate policy. However, the political constraint for brown districts requires that the pivotal districts

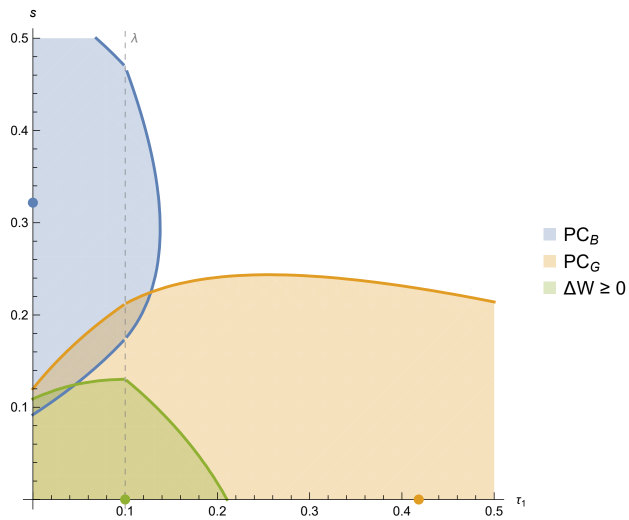

Figure 1: Political constraints when $A = 1.8$, $c = 0.06$, $\delta = 0.9$, $\lambda = 0.1$ and $\rho = 1$. The blue dot is the ideal policy of the pivotal brown districts; the orange dot is the ideal policy of the green districts, and the green dot is the ideal policy of the green party.

invest in green capital, which requires a subsidy that does not vanish as λ goes to zero. Therefore, as $\lambda \to 0$, the policymaker is eventually not willing to provide the required subsidy by the brown districts, and prefers to keep the status quo, even though climate policy may be feasible. This result is important because it shows that if the policymaker believes that the social cost of carbon is low, climate policy in general is politically feasible, but it is not enacted in equilibrium, because the economic cost created by the political constraints outweighs the environmental benefits of the policy.

See Figure 1 for an illustration of the political constraints. The pivotal brown districts benefit from the subsidy and prefer low carbon taxes. The ideal level of the subsidy for the brown districts is finite, because a larger subsidy induces more districts to take it, which increases its fiscal cost and decreases fiscal revenue in the second period; at some point this effect dominates the direct benefit of the subsidy. The green districts prefer the subsidy to be as small as possible, and prefer a large carbon tax because they receive the rebates. The ideal level of the carbon tax is not confiscatory (the maximum of the Laffer curve is at $\tau_1 = \frac{1}{2}$), because, when $\tau_1 > \lambda$, the second period carbon tax is expected to stay at the level τ_1; therefore, increasing τ_1 decreases the expected future profits from the brown capital, which induces the marginal district to transition, and reduces the fiscal revenue from the carbon tax in the second period. The set of feasible policies is the intersection of the regions defined by PC_B and PC_G. The set of feasible policies that the proposer is willing to implement is the intersection of the three regions.

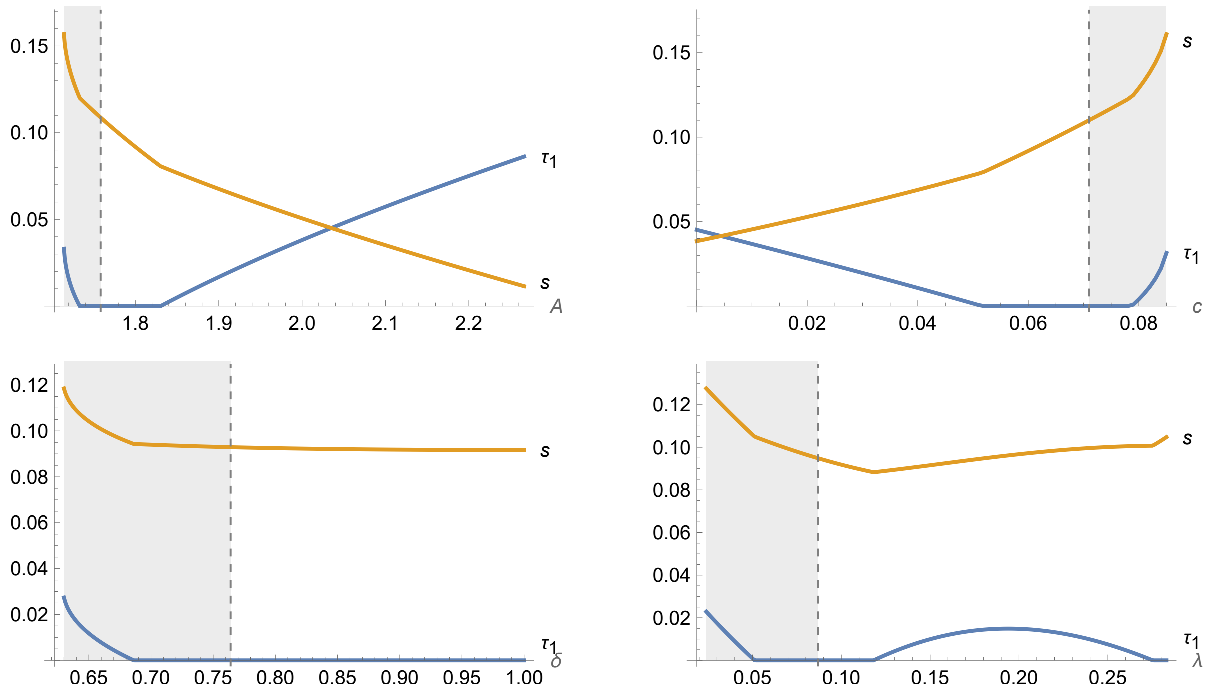

Figure 2: Equilibrium policy when $A = 1.8$, $c = 0.06$, $\delta = 0.9$, $\lambda = 0.1$ and $\rho = 1$, as each parameter changes. In the gray regions the optimal feasible policy is no better than BAU, and in equilibrium no policy is enacted.

Figure 2 shows how the equilibrium policy depends on parameters. Increasing the productivity of green technology A, decreasing the cost of transition c or increasing the discount factor δ relaxes the political constraints, so policy is closer to optimal: τ_1 increases, and s decreases. This holds as long as the green districts' political constraint does not bind. For low enough A, or large enough c, τ_1 is so small and s is so large that the fiscal constraint PC_G binds: the carbon tax is not enough to pay for the subsidies. This requires increasing taxes or decreasing spending in the future, which the green districts do not support. To compensate, the policymaker can increase τ_1, which requires an increase in s. This works until the constraints cannot be jointly satisfied. However, as we see in the Figure, the policy does no longer pass a cost-benefit analysis for the policymaker before PC_G binds.

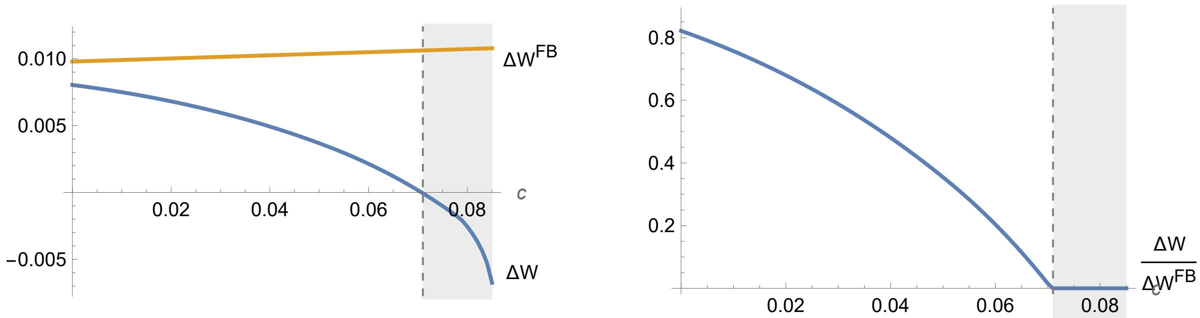

Figure 3: Equilibrium policy when $A = 1.8$, $\delta = 0.9$, $\lambda = 0.1$ and $\rho = 1$ as c changes. In the gray regions the optimal feasible policy is no better than BAU, and in equilibrium no policy is enacted.

Figure 3 shows how the objective of the policymaker compares to the first best, relative to business as usual. As c grows, and the political constraints become harder to satisfy, the improvement of equilibrium climate policy over the status quo BAU decreases, and diverges from the first best policy more, until it is no longer better than BAU. The welfare loss relative to the first best can vary enormously depending on parameters; for the parameters illustrated in the Figure, equilibrium policy goes from achieving more than 80% of the welfare gains produced by optimal policy if $c = 0$ to being no better than the status quo when $c \approx 0.07$.

4.1. *Political Turnover*

The probability that a brown policymaker replaces the proposer in the second period, $1 - \rho$, reduces the expected carbon tax in the future. This, in turn, reduces the share of brown districts who transition given by (2), because it increases the value of brown capital. A smaller level of investment has a positive effect on the fiscal balance, which is apparent in (PC_G): it reduces the cost of the subsidy, and raises the base of the carbon tax in the second period. This effect relaxes both political constraints, and can dominate the negative effect given by the reduction in the expected future carbon tax.

For this reason the possibility of turnover can paradoxically help a green policymaker start a policy sequence that leads to an efficient carbon tax in the future. This is despite the fact that turnover means that the sequence is likely to be interrupted, and green investments fall as a result of policy uncertainty.

A theoretical implication of the analysis is that the effect of political turnover is very different once we incorporate political constraints into the model. In Section 3, turnover meant that the economic outcomes were no longer optimal, and the policymaker had to use the subsidy to fix the suboptimal level of investment. The picture fundamentally changes with political constraints, because they force the policymaker to use subsidies even without turnover. In political equilibrium the level of investment is inefficiently large. Introducing turnover attenuates this distortion, and partially aligns the objective of the green proposer with that of the pivotal brown districts. The former now sees subsidies as a tool to curb the negative environmental effects of a future brown policymaker, and the latter demand the subsidy as a form of compensation for the present and expected future carbon tax.

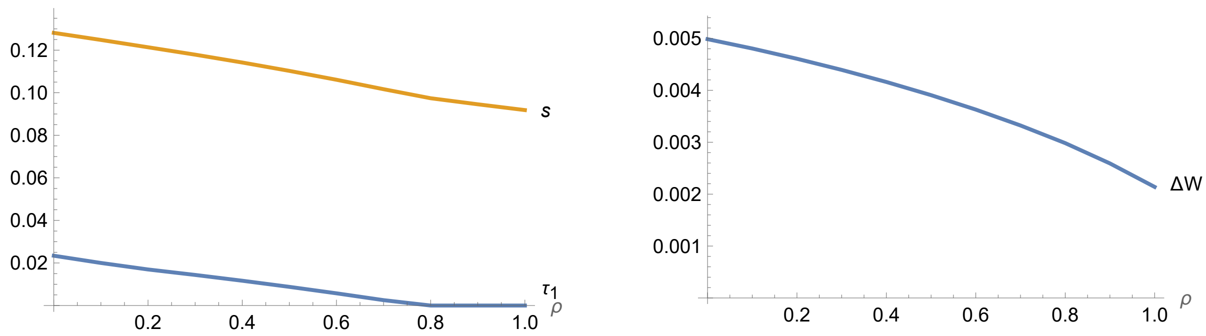

Figure 4: Equilibrium policy and payoff for the green party when $A = 1.8$, $c = 0.06$, $\delta = 0.9$ and $\lambda = 0.1$, as the probability of turnover changes.

Figure 4 shows how the probability of turnover affects equilibrium policies and the welfare of the green policymaker. More likely turnover (lower ρ) leads to an increase in the carbon tax and the subsidy, and it increases the welfare of the green policymaker in equilibrium. Consistent with previous literature (Schmitt, 2014; Harstad, 2020), the probability of turnover increases the equilibrium subsidy, but in this model the carbon tax is significantly lower than the social cost of carbon, which is consistent with empirical observation.

4.2. *Green Expectations and Soft Commitments*

Under Assumption 1, the expectation of a second-period carbon tax induces some districts to transition even in the absence of an investment subsidy. This is because a future carbon tax decreases the value of the brown capital in the future, and convinces a district that is indifferent between upgrading its capital or not to do it. In the previous section, I studied the equilibrium in which, absent policy in the first period, brown districts expect no climate policy in the second period, which leads them to stay brown. In this section, I consider an alternative equilibrium, the *green expectations* equilibrium, in which brown districts expect a carbon tax in the second period, which leads some of them to decarbonize in the first period. This is possible only if the share of districts that transition is enough to create a green majority in the second period that allows the green policymaker to implement the carbon tax. In that case, the expectation of climate policy in the first period is confirmed, which makes it an equilibrium.

In terms of the model, this is an equilibrium if the second-period brown districts do not form a majority, i.e., if $b_2 \leqslant \frac{1}{2}$, where the marginal district that transitions, b_2, is such that $-c + \frac{\delta A}{2} b_2 = \frac{\delta}{2}\left[\rho(1-\lambda)^2 + 1 - \rho\right]$. Using Assumption 1, this is equivalent to

$$b_1 \leqslant \frac{1}{2} + \frac{\rho\lambda(2-\lambda)}{A}. \tag{3}$$

In words, for the green expectations equilibrium to exist, the initial share of brown districts cannot be too large. A greater Pigouvian carbon tax λ and a smaller probability of turnover $1-\rho$ increase the upper bound, and make this equilibrium more likely to hold, because they lead more districts to transition if they expect a carbon tax in the future.

The fact that brown districts expect a future carbon tax in the future absent any policy in the first period changes the political calculation for the green policymaker, because resisting a climate policy bundle (τ_1, s) is less attractive in this equilibrium than in the equilibrium considered in the previous section. The new political constraints are as follows:

$$\frac{1}{2}(1-\tau_1)^2 + s - c + \frac{\delta A}{4} + T \geqslant \frac{1}{2} \underbrace{- c + \frac{\delta A}{4}}_{\substack{\text{transition}\\ \text{without subsidy}}} + \tilde{T} \tag{PC$'_B$}$$

and

$$T = b_1\tau_1(1-\tau_1) + \delta b_2\tau_2(1-\tau_2) - s(b_1 - b_2) \geqslant \tilde{T} = \delta\tilde{b}_2\rho\lambda(1-\lambda), \tag{PC$'_G$}$$

where $\tau_2 = \max\{\tau_1, \lambda\}$ with probability ρ and $\tau_2 = \tau_1$ with probability $1-\rho$, and $\tilde{b}_2$ is given by $-c + \frac{\delta A}{2}\tilde{b}_2 = \frac{\delta}{2}\left[\rho(1-\lambda)^2 + 1 - \rho\right]$.

We have the following.

Proposition 2. *In the green expectations equilibrium* $\tau_1 = s = 0$ *or* $\tau_1 < \lambda$ *and* $s > 0$.

Proof. See Appendix B.7. ∎

Therefore, a feasible policy (τ_1, s) is either laissez-faire, $\tau_1 = s = 0$, or it involves a positive subsidy, $s > 0$, and a less than Pigouvian first-period carbon tax $\tau_1 < \lambda$, because of the same tradeoff as in the previous section. In either case, it is distorted relative to the first best, even though expectations help the policymaker.

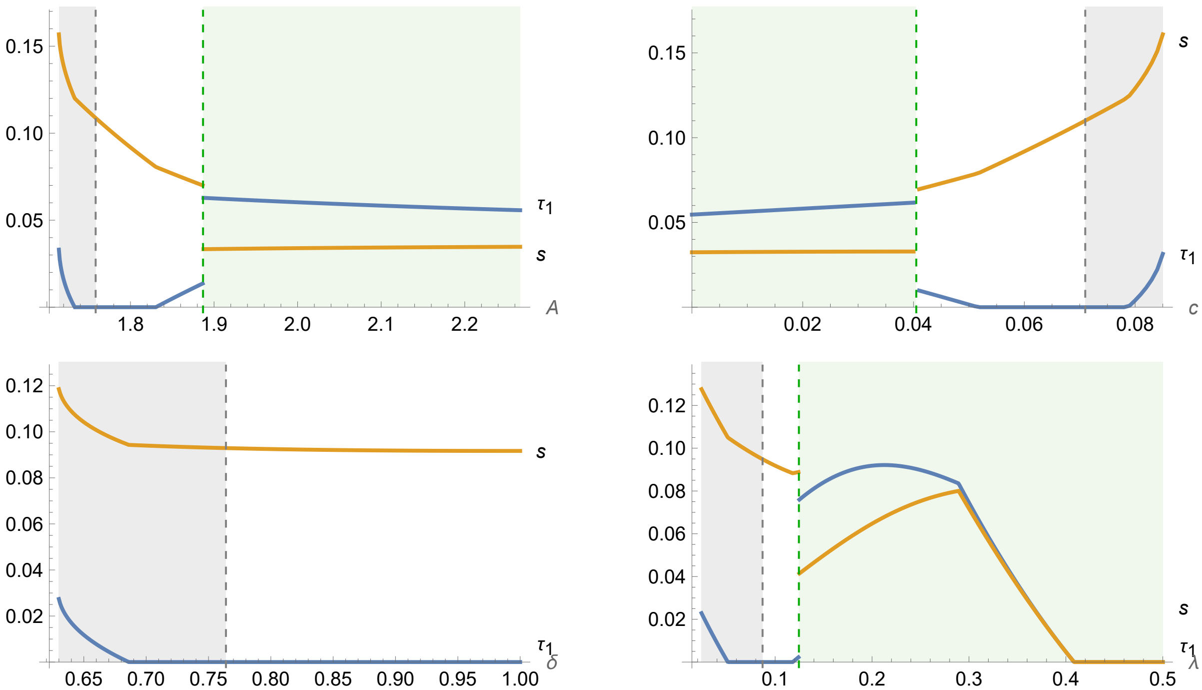

Figure 5: Equilibrium policy when $A = 1.8$, $c = 0.06$, $\delta = 0.9$, $\lambda = 0.1$ and $\rho = 1$, as each parameter changes. In the gray regions the optimal feasible policy is no better than BAU, and in equilibrium no policy is enacted. In the green regions the green equilibrium exists and is displayed.

Figure 5 shows how green expectations affect equilibrium policy. When they are possible (for large A, small c and large λ), demarcated by the green regions, the first-period carbon tax is increased, and the subsidy decreased, relative to the baseline equilibrium.

The existence of the green expectations equilibrium suggests that even *soft commitments* –non-binding declarations by governments that might otherwise be dismissed as mere "cheap talk"– can exert real effects on economic behavior and policy outcomes if they shift expectations of economic actors towards this equilibrium. Examples of such soft commitments include widespread net-zero targets and the Nationally Determined Contributions (NDCs) under the Paris Agreement. Stiglitz (2019) articulates this logic in the context of the latter: "[P]art of the rationale for the Paris strategy [was that] if enough firms believed that there was enough global commitment to climate change that there would be a high carbon price (implicit or explicit) going forward, they would have an incentive to make green investments; and to ensure that they were advantaged over firms that didn't make such investments and to ensure that they obtained the desired returns on those investments, they would then politically support, in coalition with other like-minded agents, a high carbon price." Ramadorai and Zeni (2024) show that, consistent with this idea, the announcement of the Paris Agreement led to a significant change in beliefs about future carbon taxation in a sample of North American public firms.

The analysis of the model, however, reveals that soft commitments do not work in all circumstances. Carbon-abating technology needs to be sufficiently advanced, the social cost of carbon perceived to be sufficiently large, and polarization around climate policy (captured by the probability of turnover) sufficiently low. Equation (3) makes the conditions precise. The fact that many governments undershot their emissions targets (de Silva and Tenreyro, 2021) suggests that policymakers may not always be able to trigger a change in expectations that paves the ground for ambitious policies.

5. Extensions

Green preferences. In Appendix A.1 I study the implications of assuming that legislators are concerned about the environment. In this case green districts no longer pose a constraint on the proposer, and the constraint imposed by pivotal districts is relaxed. Brown districts prefer zero carbon taxes and, unless the social cost of carbon is very large, in equilibrium the proposer starts implementing a carbon tax that is lower than Pigouvian plus a positive investment subsidy, and, once the green capital is sunk, raises the carbon tax to the optimal level. In sum, even though green preferences relax political constraints, the equilibrium features the same distortions and dynamics. As in the baseline model, improvements in technology, and reductions in capital costs or the discount rate, make it more likely that the policy sequence is started.

Targeted subsidies and transfers. In Appendix A.2 I consider the implications of allowing the policymaker to target transfers and subsidies, which so far I assumed to be uniform. I first argue that arbitrary targeting is implausible because of an information asymmetry: an optimal targeting strategy would require knowing exactly the identity of the minimal set of brown districts that are closest to the decarbonization frontier and form a winning coalition. Which constituencies are willing to make investments in the transition given the right incentives is a difficult empirical question, as we can infer from historical cases. Moreover, to the extent that we observe targeting (for example, the allocation of free allowances in the initial phases of the EU ETS), it does not respond to an optimal coalition-building strategy, but can be explained as a result of lobbying by particularly powerful industries (Winkler, 2022).

To take into account the information asymmetry I employ a mechanism design approach. I assume that legislators know the potential productivity of green capital investments in their district, but can choose to withhold that information. The policymaker proposes a menu of targeted taxes, subsidies and transfers. The legislature then votes on the entire menu, after which each district selects its preferred bundle. I find that the proposer can target subsidies and transfers to some extent, but the incentive compatibility constraints protect the brown districts excluded from the winning coalition, and prevent the policymaker from restrict the subsidy to only the pivotal districts. Consequently, the same fundamental distortion that arises with uniform subsidies and transfers emerges in this environment.

Production subsidies, standards and FITs. I considered so far investment subsidies as the inefficient policy instrument that the policymaker can use to build a winning coalition, but in practice other instruments are used for this purpose. In Appendix A.3 I show how a production subsidy in the green sector can be used with the purpose of inducing brown districts to transition. In Appendix A.4 I introduce an emissions standard, and show that it is equivalent to a revenue neutral combination of a production subsidy and a carbon tax. I also show that a feed-in tariff for goods produced using green capital is equivalent to a tradable emissions standard. The reason why these instruments are equivalent in the model, but not in reality, is that there is no volatility in output. A policymaker that can propose a production subsidy and a carbon tax would not choose to propose standards, because they can be replicated and, in general, improved upon. However, if a production subsidy was not available, the policymaker can (under some conditions) use the standard to start the policy sequence, because it implicitly subsidizes production in the green sector.

6. Conclusion

I have argued that politics imposes constraints on climate policy that are dynamic and local. These constraints are dynamic because policy instruments transform opponents today into future supporters by shaping incentives for investments in capital tied to decarbonization, thus linking policies intertemporally. The constraints are local because winning coalitions comprise interests that are tied to specific constituencies. Modeling climate policymaking in this way contrasts with existing approaches that take the power of carbon emitters as exogenous and unchanging, or only focus on political turnover as a source of political distortions. Thus, this paper falls under the unifying framework for the study of energy transitions proposed by Gazmararian and Tingley (2024), which is centered around credibility, both in terms of expectations of future policy, and in terms of expectations of future economic welfare in local communities.

The model I developed in this paper can explain both the increase in stringency of climate policy over time, and the shift from inefficient to efficient instruments. Several additional insights emerge from the analysis. First, if initial conditions are sufficiently adverse for the energy transition (e.g., the economy relies heavily on fossil-fuel production, emissions abatement technology is not sufficiently advanced, or economic agents discount the future too heavily), then no climate policy may be implemented in political equilibrium. This finding helps to understand why policy feedback has failed to take hold in several empirical cases. Second, even if there is a policy bundle that is time-consistent (i.e., credible) and acceptable to a winning coalition of interests, its social costs may be so large that a climate-concerned policymaker will decide not to implement it. This result suggests that a fruitful direction for future research is to estimate empirically the costs that political acceptability adds to climate policies. Recently, researchers have made important methodological advances in the estimation of the costs of climate policies (Hahn et al., 2024) as well as the design of policies that achieve acceptability by key political actors (Gazmararian and Tingley, 2023); it is time to combine them.

Third, the analysis reveals that managing economic actors' expectations of future policy is important, and can be achieved both by policy design and by soft commitments. The latter can influence beliefs because future policies are affected by investments that economic actors make in the present, which creates a coordination game that has multiple equilibria. Equilibrium policy, in turn, responds to these beliefs—expectations of stringent policy in the future strengthen the bargaining power of the policymaker to implement more stringent policies in the present. Thus, voluntary commitments such as the nationally determined contributions made in the context of the Paris Agreement can complement policy enactment domestically.

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Appendix

A. Extensions

A.1. *Green preferences*

In this section I assume that districts care about environmental damages as much as the green party, so payoffs are the same as before with an added term $-\lambda e_t$, i.e.,

$$\pi_{it} = \begin{cases} (1-\tau)y_{it} - \frac{1}{2}y_{it}^2 - \iota_{it}(c - s_t) + T_t - \lambda e_t & \text{if } i \text{ is brown,} \\ y_{it} - \frac{1}{2Ai}y_i^2 + T_t - \lambda e_t & \text{if } i \text{ is green,} \end{cases}$$

where $e_t = \int_0^1 \chi_{it} y_{it}\, di$ are aggregate emissions at time t. In a one-period interaction, if the brown districts are $[0, b)$ and the carbon tax is τ, the payoff of a brown district is $\frac{1}{2}(1-\tau)^2 + b\tau(1-\tau) - \lambda b(1-\tau)$. If $(1+\lambda)b > 1$, which requires $b > \frac{1}{2}$, then their ideal tax is $\tau = \frac{(1+\lambda)b-1}{2b-1} < \lambda$. Otherwise, their ideal tax is $\tau = 0$.

Assumption 2. $(1+\lambda)b_1 < 1$.

Under Assumption 2, brown districts always oppose a carbon tax. In this case, the equilibrium policy in the second period is the same as in the baseline model: $\tau_2 = \max\{\tau_1, \lambda\}$ if $b_2 \leqslant \frac{1}{2}$, and otherwise $\tau_2 = 0$.

As in the baseline model, the green districts prefer a high carbon tax. But, given that they care about carbon emissions, they are now willing to pay some taxes themselves in order to pay for investment subsidies if that is required to obtain a reduction in GHGs emissions. Moreover, given that, with these preferences, the payoff of the green policymaker is exactly aggregate welfare, $W_t = \int_0^1 \pi_{it}\, di$, because districts now internalize the environmental damage. Thus, if the green policymaker prefers a climate policy over BAU, then the green districts prefer it as well, because they value the benefits but do not internalize the costs. Therefore, green districts do not impose a constraint on policy in the first period.

Brown districts impose a political constraint. The proposer needs to induce $b_2 \leqslant \frac{1}{2}$ and obtain the approval of the median district, i.e.,

$$\underbrace{\frac{1}{2}(1-\tau_1)^2 + s - c + \frac{\delta A}{4} + T}_{\text{economic payoff}} - \underbrace{\lambda b_1(1-\tau_1) - \delta\lambda b_2(1-\tau_2)}_{\text{environmental damage}} \geqslant \underbrace{(1+\delta)\left(\frac{1}{2} - \lambda b_1\right)}_{\text{BAU payoff}}. \tag{PC$_B$}$$

Lemma 2. *Under the assumptions of this section, if PC$_B$ holds then $b_2 \leqslant \frac{1}{2}$.*

Thus, the green policymaker has two options: implement the best policy subject to the constraint

PC_B, or else keep BAU. Under what conditions is PC_B feasible? We have the following.

Observation 3. *If PC_B is feasible under (A, c, δ, λ) it is feasible under $(A', c', \delta', \lambda')$ if $A' \geqslant A$, $c' \leqslant c$, $\delta' \geqslant \delta$ and $\lambda' \geqslant \lambda$.*

In words, it is possible to implement climate policy in the first period if and only if A is large enough, c is small enough, δ is large enough, and λ is large enough. The first three conditions are also necessary in the baseline model, for essentially the same reason: they express that the economic cost of the transition is not too large. The final condition contrasts with the baseline model: if districts care about environmental damage as much as the green party, the higher the social cost of carbon is perceived to be, the easier it is for the green policymaker to convince economic actors to accept climate policy that leads to a carbon tax in the future.

Proposition 3. *Under Assumptions 1 and 2, the equilibrium policy is either first-best ($\tau_1 = \lambda$, $s = 0$), satisfies $\tau_1 < \lambda$ and $s > 0$, or is business-as-usual.*

Proof. See Appendix B.10. ■

Qualitatively, the only difference with the baseline model is that optimal policy (Pigouvian carbon tax with no subsidies) can be feasible in the first period. Otherwise, in equilibrium the green policymaker faces the same tradeoff: a larger carbon tax requires a greater subsidy, which is costly, so in equilibrium the carbon tax is less than optimal and the subsidy is used, or else BAU is maintained.

To conclude, when districts care about environmental damages as much as the green policymaker, the set of politically feasible climate policies expands, and, moreover, in very restrictive conditions first-best policy becomes feasible. In general, though, the qualitative features of the equilibrium are the same: the green party enacts a low-ambition carbon tax plus a subsidy in the first period, and a carbon tax set at optimal level subsequently. Committed representatives make climate policy more likely and less distorted, but significant distortions can remain.

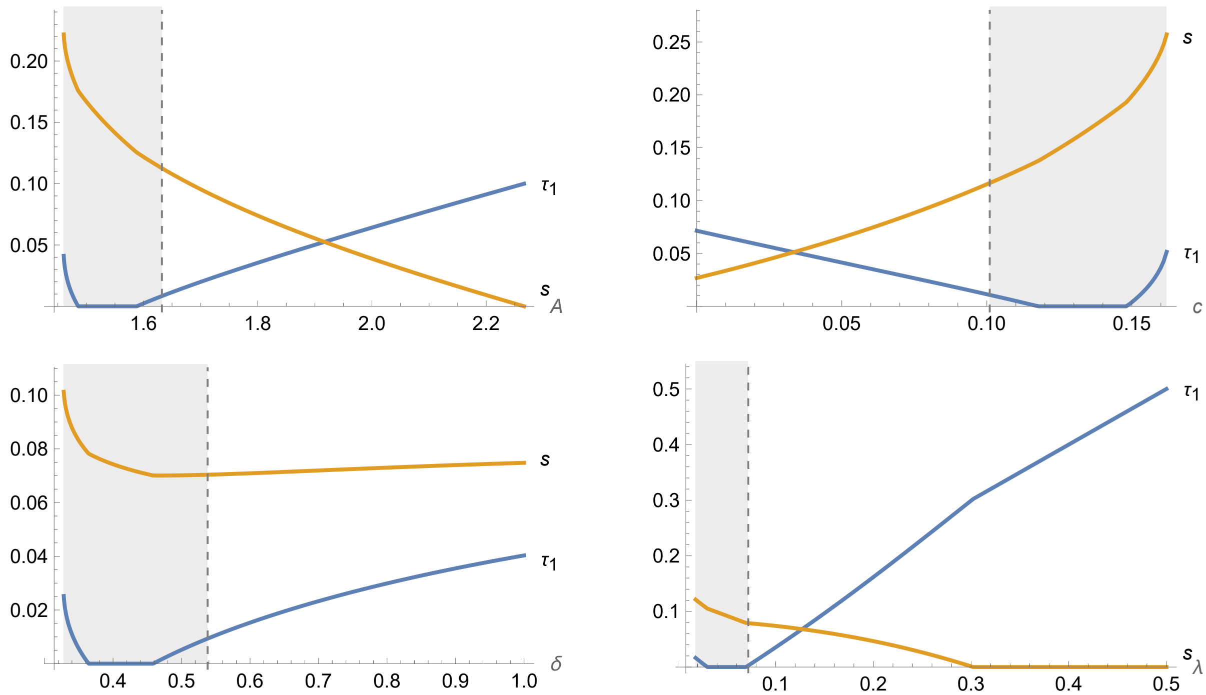


Figure 6: Equilibrium policy when $A = 1.8$, $c = 0.06$, $\delta = 0.9$ and $\lambda = 0.1$, as each parameter changes. The policies are always preferred over BAU.

Figure 6 shows the equilibrium policies as parameters change. The main differences with the baseline model (Figure 2) is that with green preferences for these parameters the best feasible policy is better than BAU, and $\tau_1 > 0$. Other than that, the comparative statics relative to A, c and δ are the same: the harder the political problem (small A, large c, small δ), the smaller the carbon tax and the greater the subsidy.

A.2. *Targeted transfers and subsidies*

If we assume that policymakers can us arbitrarily targeted lump-sum transfers and have perfect information, climate policy trivial: the government can tell each firm in the economy "if you take the socially optimal abatement actions today, tomorrow I'll send you a check that exactly covers your cost"; this needs no commitment, because lump-sum transfers are costless for the government, which implies that the policymaker is indifferent about them, and, hence, may as well follow through on its promise. The reason why this doesn't work in reality is mainly because the government lacks information, which implies that it doesn't know what the optimal abatement actions are, and cannot raise funds costlessly.

There are two facts that contradict this argument, though. First, governments do use targeted transfers to obtain political support for policies. This is clear in the case of free allowances in cap-and-trade systems, and is the basis of the idea of "just transition" strategies (Bolet et al., 2023), which bundle climate with redistributive policies to support affected communities, and "green bargains" (Meckling and Strecker, 2023), which tie regulations to public investments. But, for example, in the first two phases of the EU ETS, even though there is evidence that lobbying by particular firms impacted the allocation of free allowances, policymakers used rules (mainly based on historical emissions) and a large information asymmetry dominated the process (Ellerman et al., eds, 2007). From a theoretical point of view, the fact that the process was transparent constrained the ability of politicians to be cynical, which probably created inefficiencies (Coate and Morris, 1995), as policymakers had an incentive to try to appear fair. I couldn't find a precise number easily in the literature, but, for example, Goulder et al. (2010) estimate that "freely allocating fewer than 15% of the emissions allowances generally suffices to prevent profit losses in the most vulnerable U.S. industries". The fact that more than 90% of the allowances were allocated for free, plus the fact that there was substantial overallocation in several industries (i.e., they produced less emissions than the allowances they were given for free; see, e.g., Hanoteau, 2014) suggests that the allocation wasn't targeted in a surgically precise manner to assuage opposition.

If we add the possibility of corruption (which is the implicit assumption of common agency or rent-seeking models) then we should expect a targeted (but distorted) allocation. This targeting, however, responds to the incentives and ability for lobbying of each firm or industry, which can be (and should be expected to be) very different to the targeting that results from a strategy of building a "green coalition"—the optimal green coalition is formed by the set of constituencies that have the lowest costs of decarbonization or the greatest expected opportunities in a decarbonized economy; in contrast, the firms or industries most willing to lobby may include declining industries (see Grossman and Helpman, 1996 and Baldwin and Robert-Nicoud, 2007) and industries with assets that will lose value with decarbonization. This argument helps to justify that a coalition-building strategy cannot plausibly rely on finely targeted transfers, despite the fact that we see quite targeted transfers as part of climate policies in practice.

The second counterargument is that in practice subsidies and regulations tend to be technology- and industry-specific. See, for example, Gawel et al. (2017) on the FITs in Germany, and Hahn et al. (2024) for a list of specific subsidies in the US; moreover, Cullenward and Victor (2020) argue that industry-specific regulations are not just prevalent but desirable, since broad policies, despite having the potential for being more efficient, tend to be watered down by the pressure of the most affected industries (they don't provide systematic evidence or a sound theoretical argument for this assertion, though; theoretically, targeted interventions may lead to less internalization, and, thus, more lobbying in opposition). However, the fact that in Germany the demand for FITs exploded beyond expectations, and the subsidies in the IRA are uncapped and there is considerable uncertainty about their fiscal cost (Bistline et al., 2023), suggest that, again, subsidies in practice are far from being surgically targeted and policymakers face substantial uncertainty when designing them.

To address these arguments we can assume that there is information asymmetry between the policymaker and economic agents. Let's assume that the policymaker knows the distribution of A_i, but not the particular value of A_i for any i and, hence, can design the policies that I analyzed, but cannot implement individually targeted rebates or subsidies. The policy choice decision given the information constraint is a mechanism design problem. A mechanism is a communication protocol that elicits a message from the set of affected parties and implements a message-contingent policy. Given that the choice of message is payoff-irrelevant, setting up a mechanism is equivalent to a policy that offers a menu of options (τ, r, s), where τ is a carbon tax, r is an unconditional transfer, and s is an investment subsidy. The timing of the game is left unchanged: the agenda-setter proposes a menu to the legislature; each legislator votes in favor of the proposal if and only if they prefer it over the status quo, and then firms pick a regulation from the menu, and decide their production and investment levels.

A concern for firms is that the choice of an option from the policy menu can reveal their type, which can be exploited by the policymaker in the second period. However, it's easy to see that there is an equilibrium in which all brown firms that invest in green capital, and all brown firms that do not invest, choose the same option from the menu. Suppose that a brown firm takes an option (τ, r, s) and doesn't invest in green capital. Its payoff is $r + \frac{1}{2}(1-\tau)^2 + V(\tau, r, s)$, where V is its continuation value; it will choose the option that maximizes this quantity. This doesn't depend on their type i, so the choice doesn't reveal information. If we ignore equilibria in which the policymaker uses coordination failures among firms to induce behavior, $V(\tau, r, s)$ is constant for these firms, since the option τ, r, s doesn't have any consequence in the second period; therefore, brown firms that don't invest in green capital simply choose the option that maximizes $r + \frac{1}{2}(1-\tau)^2$.

Similarly, if a brown firms decides to invest, its payoff is $r + \frac{1}{2}(1-\tau)^2 + s - c + \frac{\delta A}{2} i + V(\tau, r, s)$, where V is a (different) continuation value ignoring $\frac{\delta A}{2} i$. Every such firm will choose the same option from the menu, so their choice doesn't reveal information, hence $V(\tau, r, s)$ doesn't depend on the choice. Thus, they choose the option that maximizes $r + \frac{1}{2}(1-\tau)^2 + s$. The key for this argument is that the subsidy and the type are separable in the utility function; this wouldn't work for an output subsidy, for example, since more productive firms value the subsidy more relative to a given transfer than less productive firms.

Incentive-compatible mechanisms in the first period are, thus, very simple. They consist of two options, a tax and rebate for brown firms that don't transition, (τ_1^b, r_1^b), and a tax, rebate and subsidy for firms that transition, $(\tau_1^{bg}, r_1^{bg}, s)$; a policy package also includes a rebate for green firms r_1^g. Incentive-compatibility imposes two conditions: $r_1^b + \frac{1}{2}(1-\tau_1^b)^2 \geqslant r_1^{bg} + \frac{1}{2}(1-\tau_1^{bg})^2$, i.e., brown firms that don't plan to transition do not take the tax and rebate intended for firms that do transition, and $r_1^{bg} + \frac{1}{2}(1-\tau_1^{bg})^2 + s \geqslant r_1^b + \frac{1}{2}(1-\tau_1^b)^2$, i.e., brown firms that plan to transition do not take the tax and rebate intended for firms that don't. In the second period the policymaker knows which green firms were brown in the first period, so their rebate can be different than the rebate for the rest of green firms, so policy is a carbon tax a rebate for brown firms (τ_2, r_2^b), which has to be the same for all of them, and rebates for ex brown firms, r_2^{bg}, and the rest of green firms, r_2^g.

The political constraints demand that brown firms in $[\frac{1}{2}, b_1]$ and green firms accept the menu $(\tau_1^b, r_1^b, \tau_1^{bg}, r_1^{bg}, s, r_1^g)$ in the first period, and both ex-brown and green firms accept the menu $(\tau_2, r_2^b, r_2^{bg}, r_2^g)$ in the second period. The brown firms that don't transition have no say in the legislature, but they are protected in the first period by the incentive-compatibility constraint. The set of firms that transition is given by $\tilde{s} - c + \frac{\delta A}{2} b_2 = \frac{\delta}{2}(1-\tau_2)^2$, and the political constraint for brown firms in the first period can be written as

$$r_1^b + \delta r_2^b + \frac{1}{2}(1-\tau_1^b)^2 + \tilde{s} - c + \frac{\delta A}{4} + T \geqslant \frac{1}{2} + \frac{\delta}{2},$$

where $\tilde{s} = s - \Delta_1 - \Delta_2 \geqslant 0$, $\Delta_1 = r_1^b + \frac{1}{2}(1-\tau_1^b)^2 - r_1^{bg} - \frac{1}{2}(1-\tau_1^{bg})^2 \geqslant 0$ and $\Delta_2 = \delta(r_2^b - r_2^{bg})$. The constraint is relaxed to some extent relative to the problem that assumes uniform rebates and subsidies, but the key inefficiency arises from the fact that the subsidy is used for political acceptability, but it spills over to wasteful investment decisions. The main driver of the results in the baseline model, viz, the fact that the political constraint creates a trade-off between the first-period carbon tax and the subsidy (a larger carbon tax requires a larger subsidy to compensate the pivotal district, since rebates cannot be perfectly targeted to offset the loss in profits), persists in this variation of the model.

A.3. *Production subsidies*

Consider a production subsidy for the green sector $\sigma \geqslant 0$. The way it works is that if a firm in district i produces y_i, they get a transfer σy_i. Given σ, the firm chooses y_i to maximize profits, $\pi_i = (1+\sigma)y_i - \frac{1}{2A_i}y_i^2$, so $y_i = (1+\sigma)A_i$. Thus, equilibrium profits are $\pi_i = (1+\sigma)^2\frac{1}{2}A_i$, and the fiscal cost is $\sigma(1+\sigma)A_i$, so the contribution to aggregate welfare is $(1+\sigma)^2\frac{1}{2}A_i - \sigma(1+\sigma)A_i = \frac{1}{2}(1-\sigma^2)A_i$.

To affect investment, the policymaker could use a production subsidy that starts acting in the second period. The political constraint for brown districts $[\frac{1}{2}, b_1)$ is

$$\frac{1}{2}(1-\tau_1)^2 + s - c + \underbrace{(1+\sigma)^2\frac{\delta A}{4}}_{\substack{\text{period-2 profit} \\ \text{with production subsidy}}} + T \geqslant (1+\delta)\frac{1}{2}, \tag{4}$$

and the political constraint for the green districts $[b_1, 1]$ is

$$\underbrace{(1+\sigma)^2 \frac{\delta A}{2} b_1}_{\substack{\text{period-2 profit} \\ \text{with production subsidy}}} + T \geqslant \frac{\delta A}{2} b_1, \tag{5}$$

where

$$T = \underbrace{b_1 \tau_1 (1-\tau_1) + \delta b_2 \tau_2 (1-\tau_2)}_{\text{carbon tax revenue}} - \underbrace{s(b_1 - b_2)}_{\substack{\text{fiscal cost of the} \\ \text{investment subsidy}}} - \underbrace{\delta \int_{b_2}^{1} \sigma(1+\sigma) A i \, di}_{\substack{\text{fiscal cost of the} \\ \text{production subsidy}}}.$$

The objective of the green policymaker is

$$\begin{aligned} W = {} & \frac{b_1}{2}(1-\tau_1^2) + \frac{A}{4}(1-b_1^2) - c(b_1 - b_2) - \lambda b_1 (1-\tau_1) \\ & + \delta \left[\frac{b_2}{2}(1-\tau_2^2) + \underbrace{(1-\sigma^2)}_{\substack{\text{distortion due to the} \\ \text{production subsidy}}} \frac{A}{4}(1-b_2^2) - \lambda b_2 (1-\tau_2) \right], \end{aligned}$$

where b_2 is now given by $s - c + (1+\sigma)^2 \frac{\delta A}{2} b_2 = \frac{\delta}{2}(1-\tau_2)^2$, and $\tau_2 = \max\{\tau_1, \lambda\}$.

What happens in numerical simulations is that in equilibrium σ is never used (I couldn't find a counterexample for this assertion, but proving it seems to be very hard). The investment subsidy s is always preferred to σ. If s wasn't available then σ would be used, but it's worse.

There are theoretical reasons for subsidizing output rather than inputs (capital), but in general it depends. If the objective is to increase output, then subsidizing inputs will distort productive efficiency, so subsidizing output is prima facie better. However, even taking into account this distortion, it may be cheaper to subsidize one input if it's a lot more elastic than another one. See Parish and McLaren (1982) for an exposition. Now, even though this is theoretically ambiguous, empirically Aldy et al. (2023) show that production subsidies for wind energy were more cost effective than investment subsidies, which goes against the prediction of the model. The reasons have to do with aspects of the production of renewables (the almost zero marginal cost) that my model doesn't capture, so what I can say is that a more realistic model may (perhaps should) make a different prediction regarding investment versus production subsidies. So this is not something to take as a firm prediction. However, I should point out that maximizing social welfare is not the same as maximizing the output of renewable energy production. Increasing production of wind energy is not the goal of climate policy. The goal is to decarbonize the economy with the least social cost.

A.4. *Standards and feed-in tariffs*

Consider a clean production standard $\mu \in [0, 1]$, such as a RPS (see Helfand, 1991; Holland et al., 2009; Holland, 2012; Schmalensee, 2012). It forces firms to emit no more than μ units of GHGs per unit of the good produced. Firms that produce more emissions than allowed can buy permits from firms that produce less emissions than allowed for a market price p. In the model, firms that use green capital do not emit GHGs, so if they produce y, they are allowed to emit μy, which they can sell, earning $p\mu y$. Firms with brown capital emit one unit of GHGs per unit produced, so they need to buy $(1-\mu)y$ allowances, paying a cost $p(1-\mu)y$. Profit maximization implies that $y_i = (1 + p\mu)Ai$ in green districts i, and $y_i = 1 - (1-\mu)p$ in brown districts. The price of allowances p is set by the market clearing condition:

$$\underbrace{\int_0^b (1-\mu) y_i \, di}_{\substack{\text{permits bought} \\ \text{by brown firms}}} = \underbrace{\int_b^1 \mu y_i \, di}_{\substack{\text{permits sold} \\ \text{by green firms}}},$$

which implies $\int_0^b y_i \, di = \mu \int_0^1 y_i \, di$, so, as intended, emissions are capped at a fraction μ of aggregate production. The equilibrium price of the permits is

$$p = \frac{(1-\mu)b - \mu \frac{A}{2}(1-b^2)}{(1-\mu)^2 b + \mu^2 \frac{A}{2}(1-b^2)}$$

if $b \geqslant \mu\Big(b + \frac{A}{2}(1-b^2)\Big)$, i.e., the standard is binding: emissions per unit produced are more than μ under BAU. Otherwise, the price is 0. The clean production standard is thus equivalent to a carbon tax $\tau = p(1-\mu)$ combined with a green production subsidy $p\mu$.

Let $\tau = p(1-\mu)$ and $\sigma = p\mu$ be the equivalent carbon tax and green production subsidy given a standard μ. The market clearing condition can be written in terms of τ and σ as

$$b\tau(1-\tau) = \frac{A}{2}(1-b^2)\sigma(1+\sigma).$$

Notice that the LHS is the fiscal revenue from the equivalent carbon tax τ, and the RHS is the fiscal cost of the equivalent production subsidy σ, so the market clearing condition is effectively a joint revenue neutrality condition for the tax and the subsidy. Thus, choosing a standard is equivalent to choosing a carbon tax τ and using the revenue to finance a green production subsidy σ. The greater the tax τ, the greater the subsidy σ, as long as $\tau \leqslant \frac{1}{2}$, i.e., the carbon tax is on the left side of the Laffer curve.

We can introduce a feed-in tariff (FIT) into the model as follows. A retailer is forced to buy the numéraire good at price $p_G \geqslant 1$ from green producers, and sets the price $p_B \geqslant 0$ it buys from brown producers to maximize profits obtained from selling the good at price 1. Profits are given by $\pi = (1 - p_B) \int_0^b y_i \, di - (p_G - 1) \int_b^1 y_i \, di = (1 - p_B) \int_0^b A_i p_B \, di - (p_G - 1) \int_b^1 p_G \, di = -\frac{A}{2}(1 - b^2) p_G (p_G - 1) + b p_B (1 - p_B)$. Perfect competition or free entry in the retail market brings profits to zero, so the price paid to brown producers is given implicitly by $b p_B (1 - p_B) = \frac{A}{2}(1 - b^2) p_G (p_G - 1)$. This is again equivalent to a revenue-neutral combination of a carbon tax $\tau = 1 - p_B$ and an output subsidy for green producers $\sigma = p_G - 1$. Thus, in this simple model a standard and a FIT are equivalent. (The instruments differ in reality if, for example, there is uncertainty about demand or productivity. A standard fixes the quantity of green production, creating price risk for clean producers; a FIT fixes the price of renewable energy, which reduces risk for producers and can stimulate investment, but increases risk for consumers. See Schmalensee, 2012.)

If a carbon tax and a production subsidy are available, a green policymaker would not use the standard or FIT, because its effects can be replicated, and in general improved, by using the other two instruments. However, if the carbon tax and the subsidy are not available, the standard can be used in equilibrium. Notice that brown districts will oppose any binding standard in a static environment. However, if the median district transitions, they expect to receive a subsidy in the second period, which acts as an investment incentive, and, thus, as a carrot for accepting a standard today. The policymaker cannot commit in the first period to a generous standard in the future, though, except by setting the standard high in the first period and relying on the fact that, once a majority of districts is green, they will not accept a reduction in the standard, because they profit from the allowances. However, increasing the standard in the first period creates a cost for the median district that exceeds the benefit it provides by increasing the implicit subsidy in the future.

The green policymaker chooses the second period standard (τ_2, σ_2) to maximize W given b_2. Anticipating this, the share of brown districts that decide to transition in the first period is given by

$$-c + (1 + \sigma_2)^2 \frac{\delta A}{2} b_2 = \frac{\delta}{2}(1 - \tau_2)^2.$$

The political constraint in the first period is

$$\frac{1}{2}(1 - \tau_1)^2 - c + (1 + \sigma_2)^2 \frac{\delta A}{4} - (1 + \delta)\frac{1}{2} \geqslant 0. \tag{PC$_G$}$$

Notice that in the first period the policymaker cannot affect σ_2 in order for PC_G to hold, except by making $\sigma_1 > \sigma_2$, but, as mentioned before, this is counterproductive as it increases τ_1.[8] Therefore,

[8]Suppose $\sigma_2 = \sigma_1$. Differentiating the fiscal neutrality condition yields $b_1(1 - 2\tau_1)\frac{d\tau_1}{d\sigma_1} = \frac{A}{2}(1 - b_1^2)(1 + 2\sigma_1)$. Differentiating the LHS of PC_G we obtain $-(1 - \tau_1)\frac{d\tau_1}{d\sigma_1} + \frac{\delta A}{2}(1 + \sigma_2) = \frac{A}{2}\left[-\frac{1 - b_1^2}{b_1}\frac{1 - \tau_1}{1 - 2\tau_1}(1 + 2\sigma_1) + \delta(1 + \sigma_2)\right] \leqslant 0$ if $1 - b_1^2 \geqslant b_1$, which is true if $b_1 \leqslant 0.618$. In that case, as claimed, increasing σ_1 beyond σ_2 is counterproductive.

the policymaker can only implement a standard in the first period if PC_G holds for $\tau_1 = 0$. In that case, they can increase τ_1 until PC_G binds or the efficiency cost of the subsidy σ_1 is greater than the benefit of the tax. In the first case, the first-period standard is too low relative to the optimum choice. (I don't think that the second case can happen. It would be nice to prove this.)

Thus, climate policy in the first period relies on the second-period standard being large enough so that it provides an incentive for the median district to upgrade its capital. This, in turn, requires that the social cost of carbon λ is large enough to justify a stringent standard. In fact, for large λ the standard may be feasible when a carbon tax plus an investment subsidy is not, because the subsidy has to be paid by green districts as well as brown districts, which makes it less appealing to the pivotal brown district, to the point where the political constraints become infeasible. This seems to contradict the assertion I made before that the standard can be improved upon by a combination of a tax and a subsidy. What's happening is that if the other instruments are available the policymaker will use them instead of the standard, but, given the time-inconsistency problem, the fact that the policymaker has that power may make it harder to satisfy the political constraints.

B. Proofs

B.1. *Proof of Observation 1*

We have

$$\begin{aligned} W &= \int_0^1 \pi_{i1}\, di - D_1(e_1) + \delta\left[\int_0^1 \pi_{i1}\, di - D_1(e_1 + e_2)\right] \\ &= \int_0^{b_1} \left((1-\lambda)y_{i1} - \frac{1}{2}y_{i1}^2\right) di + \int_{b_1}^1 \left(y_{i1} - \frac{1}{2A_i}y_{i1}^2\right) di - c(b_1 - b_2) \\ &\quad + \delta\left[\int_0^{b_2} \left((1-\lambda)y_{i2} - \frac{1}{2}y_{i2}^2\right) di + \int_{b_2}^1 \left(y_{i2} - \frac{1}{2A_i}y_{i2}^2\right) di\right]. \end{aligned}$$

Pointwise maximization of the integrals yields $y_{it} = 1 - \lambda$ for brown i and $y_{it} = A_i$ for green i, so

$$W = \frac{b_1}{2}(1-\lambda)^2 + \frac{A}{4}(1 - b_1^2) - c(b_1 - b_2) + \delta\left[\frac{b_2}{2}(1-\lambda)^2 + \frac{A}{4}(1 - b_2^2)\right].$$

We have $\frac{dW}{db_2} = c + \frac{\delta}{2}(1-\lambda)^2 - \frac{\delta A}{2}b_2$, so the optimal b_2 is given by $-c + \frac{\delta A}{2}b_2 = \frac{\delta}{2}(1-\lambda)^2$. Pigouvian carbon taxes $\tau_1 = \tau_2 = \lambda$ implement these choices in equilibrium, as desired.

B.2. *Proof of Observation 4*

Observation 4. *With political turnover the optimal carbon taxes are Pigouvian, and the investment subsidy is $s = \delta(1-\rho)\lambda$.*

Proof. Let $E_1 = E_0 + b_1(1-\tau_1)$ be the stock of emissions in period 1, $E_2^G = E_1 + b_2(1-\tau_2)$ be the stock of emissions in period 2 if the green party is in power, where $\tau_2 = D_2'(E_2^G)$ is the carbon tax rate set by the green party in period 2, and $E_2^B = E_1 + b_2$ be the stock of emissions in period 2 if the brown party is in power. The objective of the green party in period 1 is

$$\begin{aligned}W_G = {} & \frac{b_1}{2}(1-\tau_1^2) + \frac{A}{4}(1-b_1^2) - c(b_1 - b_2) - D_1(E_1) \\ & + \delta\left[\frac{b_2}{2}(1-\rho\tau_2^2) + \frac{A}{4}(1-b_2^2) - \rho D_2(E_2^G) - (1-\rho)D_2(E_2^B)\right].\end{aligned}$$

We have

$$\begin{aligned}\frac{\partial W_G}{\partial b_2} &= c + \frac{\delta}{2}(1-\rho\tau_2^2) - \frac{\delta A}{2}b_2 - \rho\delta D'(E_2^G)(1-\tau_2) + (1-\rho)\delta D_2'(E_2^B) \\ &= c + \frac{\delta}{2}(1-\rho\tau_2^2) - \left(c - s + \frac{\delta}{2}(1-\rho(2\tau - \tau_2^2))\right) - \rho\delta\tau_2(1-\tau_2) - (1-\rho)\delta D_2'(E_2^B) \\ &= s - (1-\rho)\delta D_2'(E_2^B).\end{aligned}$$

Therefore,

$$\begin{aligned}\frac{\partial W_G}{\partial s} &= \frac{\partial W_G}{\partial b_2}\frac{\partial b_2}{\partial s} = \frac{2}{\delta A}\left((1-\rho)\delta D'(E_2^B) - s\right), \\ \frac{\partial W_G}{\partial \tau_1} &= \left(D_1'(E_1) + \delta \mathrm{E}\left[D_2'(E_2^P)\right] - \tau_1\right)b_1 + \frac{\partial W_G}{\partial b_2}\frac{\partial b_2}{\partial \tau_1}.\end{aligned}$$

The first equation implies that the optimal s is $(1-\rho)\delta D_2'(E_2^B)$. This implies $\frac{\partial W_G}{\partial b_2} = 0$, so the optimal τ_1 is $D_1'(E_1) + \delta\mathrm{E}\left[D_2'(E_2^P)\right]$. Under the assumption of linear cumulative damages we obtain $\tau_1 = \lambda$ and $s = (1-\rho)\delta\lambda$, as desired. ∎

In order to relax the assumption that environmental damages are linear, I will assume that $D_t''(E) = \kappa \geqslant 0$ for all E and $t \in \{1,2\}$. We have $D_2'(E_2^B) = D_2''(\xi)(E_2^B - E_2^G) + D_2'(E_2^G) = \kappa(E_2^B - E_2^G) + D_2'(E_2^G) = \tau_2(1+\kappa b_2)$, where ξ is between E_2^G and E_2^B. Therefore, $s = (1-\rho)\delta\tau_2(1+\kappa b_2)$ and $\tau_1 = D_1'(E_1) + \delta\tau_2(1 + (1-\rho)\kappa b_2)$. Differentiating, we obtain

$$\begin{aligned}\frac{\partial \tau_2}{\partial \rho} &= D_2''(E_2^G)\frac{\partial E_2^G}{\partial \rho} = \kappa\left[-b_1\frac{\partial \tau_1}{\partial \rho} + \frac{\partial b_2}{\partial \rho}(1-\tau_2) - b_2\frac{\partial \tau_2}{\partial \rho}\right], \\ \frac{\partial s}{\partial \rho} &= -\delta\tau_2(1+\kappa b_2) + (1-\rho)\left[\frac{\partial \tau_2}{\partial \rho}(1+\kappa b_2) + \tau_2\kappa\frac{\partial b_2}{\partial \rho}\right], \\ \frac{\partial b_2}{\partial \rho} &= -\frac{2}{\delta A}\left[\frac{\partial s}{\partial \rho} + \delta\tau_2\left(1 - \frac{\tau_2}{2}\right) + \delta\rho(1-\tau_2)\frac{\partial \tau_2}{\partial \rho}\right], \\ \frac{\partial \tau_1}{\partial \rho} &= -\kappa b_1\frac{\partial \tau_1}{\partial \rho} + \delta\frac{\partial \tau_2}{\partial \rho}(1 + (1-\rho)\kappa b_2) - \delta\tau_2\kappa b_2 + \delta\tau_2(1-\rho)\kappa\frac{\partial b_2}{\partial \rho}.\end{aligned}$$

Taking $\rho = 1$, we obtain $\frac{\partial s}{\partial \rho} = -\delta\tau_2(1+\kappa b_2)$, so

$$\frac{\partial b_2}{\partial \rho} = \frac{2}{A}\left[\tau_2(1+\kappa b_2) - \tau_2\left(1-\frac{\tau_2}{2}\right) - (1-\tau_2)\frac{\partial \tau_2}{\partial \rho}\right] = \frac{2}{A}\left[\tau_2\left(\kappa b_2 + \frac{\tau_2}{2}\right) - (1-\tau_2)\frac{\partial \tau_2}{\partial \rho}\right].$$

Using this,

$$\begin{aligned}\frac{\partial \tau_2}{\partial \rho} &= \kappa\left\{-b_1\frac{\partial \tau_1}{\partial \rho} + \frac{2}{A}\left[\tau_2\left(\kappa b_2 + \frac{\tau_2}{2}\right) - (1-\tau_2)\frac{\partial \tau_2}{\partial \rho}\right](1-\tau_2) - b_2\frac{\partial \tau_2}{\partial \rho}\right\} \\ &= \frac{\kappa}{1+\kappa b_2 + \kappa\frac{2}{A}(1-\tau_2)^2}\left[-b_1\frac{\partial \tau_1}{\partial \rho} + \frac{2}{A}\tau_2(1-\tau_2)\left(\kappa b_2 + \frac{\tau_2}{2}\right)\right].\end{aligned}$$

Therefore, $\frac{\partial \tau_1}{\partial \rho} = -\kappa b_1 \frac{\partial \tau_1}{\partial \rho} + \delta\frac{\partial \tau_2}{\partial \rho} - \delta\tau_2\kappa b_2$, so

$$\left[1+\kappa b_1 + \frac{\delta\kappa b_1}{1+\kappa b_2+\kappa\frac{2}{A}(1-\tau_2)^2}\right]\frac{\partial \tau_1}{\partial \rho} = -\delta\tau_2\kappa\left[b_2 - \frac{2}{A}\left(\kappa b_2 + \frac{\tau_2}{2}\right)\frac{1}{1+\kappa b_2+\kappa\frac{2}{A}(1-\tau_2)^2}\right].$$

If b_2 is small enough, the RHS is positive, so $\frac{\partial \tau_1}{\partial \rho} > 0$, which implies that an increase in the probability of turnover, i.e., a drop in ρ, leads to a reduction in the first-period carbon tax. However, if τ_2 is small, the RHS is negative, so $\frac{\partial \tau_1}{\partial \rho} < 0$ and we obtain the opposite conclusion. Thus, the effect of turnover on the first-period carbon tax is ambiguous, as claimed in the text.

B.3. *Proof of Lemma 1*

We start with the second period. Suppose that first-period policy has been (τ_1, s, T_1, B), where B is public debt or savings, taken to balance the budget,

$$\underbrace{b_1\tau_1(1-\tau_1)}_{\text{carbon tax revenue}} - \underbrace{s(b_1-b_2)}_{\text{cost of subsidy}} - \underbrace{T_1}_{\substack{\text{taxes or}\\\text{transfers}}} + \underbrace{B}_{\substack{\text{debt or}\\\text{savings}}} = 0. \tag{6}$$

In the second period, the policymaker proposes a carbon tax τ_2, and a uniform lump-sum tax or transfer $T_2(\tau_2)$ (that includes rebates) is implemented automatically to balance the budget. Thus,

$$\underbrace{b_2\tau_2(1-\tau_2)}_{\text{carbon tax revenue}} - \underbrace{T_2(\tau_2)}_{\substack{\text{taxes or}\\\text{transfers}}} - \underbrace{\delta^{-1}B}_{\substack{\text{debt plus}\\\text{interest}}} = 0. \tag{7}$$

Districts accept the proposal if they prefer it to the status quo, τ_1. For green districts, this happens iff

$$\frac{1}{2}Ai + T_2(\tau_2) \geqslant \frac{1}{2}Ai + T_2(\tau_1),$$

i.e., iff $b_2\tau_2(1-\tau_2) - \delta^{-1}B \geqslant b_2\tau_1(1-\tau_1) - \delta^{-1}B$, i.e., iff $\tau_2 \geqslant \tau_1$ as long as $\tau_1 + \tau_2 \leqslant 1$. Brown districts accept the proposal iff

$$\frac{1}{2}(1-\tau_2)^2 + T_2(\tau_2) \geqslant \frac{1}{2}(1-\tau_2)^2 + T_2(\tau_1),$$

i.e., iff $\tau_2 \leqslant \tau_1$. The ideal carbon tax of a green policymaker is λ. Therefore, if $b_1 \leqslant \frac{1}{2}$, i.e., green districts form a majority in the legislature, the equilibrium carbon tax will be $\tau_2 = \max\{\tau_1, \lambda\}$. Otherwise, brown districts form a majority, and the equilibrium carbon tax will be $\tau_2 = \min\{\tau_1, \lambda\}$. The ideal carbon tax of a green policymaker is 0, so $\tau_2 = \tau_1$ if $b_2 \leqslant \frac{1}{2}$, and $\tau_2 = 0$ otherwise.

If the first period policy fails, $\tau_1 = s = T_1 = 0$, and $b_2 > \frac{1}{2}$, $\tau_2 = 0$. In this case, a brown district $i \in [0, b_1)$ upgrades its capital in the first period iff the cost of the investment plus the expected profits in the green sector is greater than the expected profits in the brown sector, i.e., iff $-c + \frac{\delta}{2}Ai \geqslant \frac{\delta}{2}(1-\tau_2)^2 = \frac{\delta}{2}$, which reduces to $i \geqslant b_1$. Thus, in this case no brown district transitions, and $b_2 = b_1$. Since $b_1 > \frac{1}{2}$ by assumption, $b_2 > \frac{1}{2}$, so this is an equilibrium of the proposal failure subgame. We call $\tilde{\tau}_2 = 0$ and $\tilde{b}_2 = b_1$ the carbon tax rate and the share of brown districts in this equilibrium.

A brown district i accepts a first-period policy (τ_1, s, T_1) if they prefer it to business as usual in both periods, i.e., iff

$$\underbrace{\frac{1}{2}(1-\tau_1)^2}_{\text{period-1 profit}} + \max\Big\{\underbrace{s - c + \frac{\delta}{2}Ai}_{\substack{\text{period-2 profit in}\\ \text{the green sector}\\ \text{plus net cost of transition}}},\ \underbrace{\frac{\delta}{2}\mathrm{E}\big[(1-\tau_2)^2\big]}_{\substack{\text{expected}\\ \text{period-2 profit in}\\ \text{the brown sector}}}\Big\} + \underbrace{T_1 + \delta T_2}_{\text{expected transfers}} \geqslant \underbrace{\frac{1}{2} + \frac{\delta}{2}}_{\substack{\text{business as}\\ \text{usual profits}}}. \tag{8}$$

Notice that the LHS is weakly increasing in i, so if i accepts, every district $j \geqslant i$ accepts as well. Therefore, to get a majority to approve the policy, the policymaker has two options. They can create a coalition with the brown districts in $[\frac{1}{2}, b_1)$ and the green districts, $[b_1, 1]$, or a purely brown coalition $[b_1 - \frac{1}{2}, b_1)$. In any case, the median district, $i = \frac{1}{2}$, has to approve the proposal for it to be implemented.

Suppose that in equilibrium the median district does not transition. In that case, (8) is

$$\frac{1}{2}(1-\tau_1)^2 + \frac{\delta}{2}\mathrm{E}\big[(1-\tau_2)^2\big] + T \geqslant \frac{1}{2} + \frac{\delta}{2},$$

where $T = T_1 + \delta T_2 = b_1\tau_1(1-\tau_1) + \delta b_2\mathrm{E}[\tau_2(1-\tau_2)] - s(b_1 - b_2)$, obtained by summing (6) and (7). Now, it is straightforward to verify that this condition cannot hold unless $\tau_1 = \tau_2 = s = 0$. Therefore, if the equilibrium policy is not business as usual, then (8) holds for the median district, which implies that this district transitions.

A green-brown coalition requires (8) to hold for $i = \frac{1}{2}$, i.e., that the median district approves, and that green districts prefer the policy proposal to business as usual, which happens iff $T_1 + \delta T_2 \geqslant 0$, i.e., if the expected transfers are nonnegative. In other words, green districts may tolerate a tax in the present as long as it is compensated by a transfer in the future. Thus, a green-brown coalition implements a non-BAU policy (τ_1, s) iff

$$\frac{1}{2}(1-\tau_1)^2 + s - c + \delta\frac{A}{4} + T \geqslant \frac{1}{2} + \frac{\delta}{2} \tag{PC$_B$}$$

and

$$T = b_1\tau_1(1-\tau_1) + \delta b_2 \mathrm{E}[\tau_2(1-\tau_2)] - s(b_1 - b_2) \geqslant 0, \tag{PC$_G$}$$

where $\tau_2 = \max\{\tau_1, \lambda\}$ if the green policymaker stays in power, which happens with probability ρ, and is $\tau_2 = \tau_1$ in case of turnover, which occurs with probability $1-\rho$. The conditions PC_B and PC_G are the *political constraints* for the brown and green districts, as desired.[9]

B.4. *Proof of Proposition 1*

Let

$$\begin{aligned} P &= \frac{1}{2}(1-\tau_1)^2 + s - c + \delta\frac{A}{4} + T - (1+\delta)\frac{1}{2}, \\ T &= b_1\tau_1(1-\tau_1) + \delta b_2\tau_2(1-\tau_2) - s(b_1 - b_2), \end{aligned}$$

so PC_B is $P \geqslant 0$, and PC_G is $T \geqslant 0$.

Claim 1. *If (τ_1, s) is optimal then $P = 0$ or $s = 0$.*

Proof. Suppose that $P > 0$ and $s > 0$. We have $\frac{\partial T}{\partial s} = -(b_1 - b_2) - \frac{2}{\delta A}[s + \delta\tau_2(1-\tau_2)] < 0$ and $\frac{\partial \Delta W}{\partial s} = \frac{2}{\delta A}[-\delta(\tau_2 - \lambda)(1-\tau_2) - s] < 0$, so we can reduce s a little bit improving the objective and keeping $P, T > 0$, $P > 0$ by continuity. ■

Claim 2. *If (τ_1, s) is optimal then $s > 0$.*

Proof. Suppose that $s = 0$. There are three cases: $\tau_1 = \lambda$, $\tau_1 > \lambda$, and $\tau_1 < \lambda$.

[9] A purely brown coalition requires approval by $i = b_1 - \frac{1}{2}$, and so it implements a non-BAU policy (τ_1, s) iff

$$\frac{1}{2}(1-\tau_1)^2 + s - c + \frac{\delta}{2}A\left(b_1 - \frac{1}{2}\right) + T \geqslant \frac{1}{2} + \frac{\delta}{2}. \tag{PC$_{BB}$}$$

Therefore, in equilibrium (τ_1, s) has to satisfy the political constraints PC_B and PC_G, or PC_{BB}. I will restrict attention to PC_B and PC_G, because in general PC_{BB} is much more restrictive, and analyzing the conditions under which it is not doesn't provide further insights.

Case 1: $\tau_1 = \lambda$. We have $\tau_2 = \lambda$ and

$$0 \leqslant P = -\left(\lambda - \frac{1}{2}\lambda^2 + \frac{\delta A}{2}\left(b_1 - \frac{1}{2}\right)\right) + \left((1+\delta)b_1 - \frac{\delta}{A}(2-\lambda)\lambda\right)\lambda(1-\lambda),$$

i.e.

$$\lambda - \frac{1}{2}\lambda^2 + \frac{\delta A}{2}\left(b_1 - \frac{1}{2}\right) + \frac{\delta}{A}(2-\lambda)(1-\lambda)\lambda^2 \leqslant (1+\delta)b_1\lambda(1-\lambda).$$

When $\delta = 0$ this is

$$\lambda - \frac{1}{2}\lambda^2 \leqslant b_1\lambda(1-\lambda),$$

i.e., $1 - \frac{1}{2}\lambda \leqslant b_1(1-\lambda)$, but $1 - \frac{1}{2}\lambda - b_1(1-\lambda) = 1 - b_1 + (b_1 - \frac{1}{2})\lambda > 0$, absurd. When $\delta = 1$ this is

$$\lambda - \frac{1}{2}\lambda^2 + \frac{A}{2}\left(b_1 - \frac{1}{2}\right) + \frac{1}{A}(2-\lambda)(1-\lambda)\lambda^2 \leqslant 2b_1\lambda(1-\lambda).$$

When $b_1 = \frac{1}{2}$ this is

$$\lambda - \frac{1}{2}\lambda^2 + \frac{1}{A}(2-\lambda)(1-\lambda)\lambda^2 \leqslant \lambda(1-\lambda),$$

which can't happen because $\lambda - \frac{1}{2}\lambda^2 > \lambda(1-\lambda)$. When $b_1 = 1$ this is

$$\lambda - \frac{1}{2}\lambda^2 + \frac{A}{4} + \frac{1}{A}(2-\lambda)(1-\lambda)\lambda^2 \leqslant 2\lambda(1-\lambda).$$

By AM-GM we have

$$\frac{A}{4} + \frac{1}{A}(2-\lambda)(1-\lambda)\lambda^2 \geqslant \sqrt{(2-\lambda)(1-\lambda)\lambda^2} > \sqrt{(1-\lambda)^2\lambda^2} = \lambda(1-\lambda),$$

so, summing, we get a contradiction. Since the expressions are linear in b_1 and the inequality doesn't hold at the extremes, it cannot hold for any b_1. By the same argument, it cannot hold for any δ, and, hence, it cannot hold. This proves that $P < 0$, so $\tau_1 = \lambda$ is not feasible.

Case 2: $\tau_1 > \lambda$. This is the same as Case 1 replacing λ with τ_1. We obtain that $P < 0$, so $\tau_1 > \lambda$ is not feasible.

Case 3: $\tau_1 < \lambda$. We have $\tau_2 = \lambda$ and $T = b_1\tau_1(1-\tau_1) + \delta b_2\lambda(1-\lambda) > 0$ since $b_2 = b_1 - \frac{1}{A}(2-\lambda)\lambda \geqslant \frac{1}{A}(Ab_1 - \frac{3}{4}) \geqslant \frac{1}{4A} > 0$. We have $\frac{\partial}{\partial\tau_1}\Delta W = b_1(\lambda - \tau_1) > 0$. If $P > 0$ we can increase τ_1 a little bit, so $P, T > 0$ still hold by continuity, and we increase $\frac{\partial \Delta W}{\partial \tau_1}$, absurd. Suppose that $P = 0$. We have $\frac{\partial P}{\partial s} = 1 - \frac{1}{A}(2-\lambda)\lambda - \frac{2}{A}\lambda(1-\lambda) = \frac{1}{A}(A - (4-3\lambda)\lambda)$. If $\frac{\partial P}{\partial s} \neq 0$, by the implicit function theorem we can define $s(\tau_1)$ such that $P|_{s=s(\tau_1)} = 0$ in an interval around τ_1, and

s is differentiable. Now,

$$\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}\frac{\partial s}{\partial \tau_1} = b_1(\lambda - \tau_1) - \frac{2}{\delta A}\underbrace{(s + \delta(\tau_2 - \lambda)(1 - \tau_2))}_{=0}\frac{\partial s}{\partial \tau_1} = b_1(\lambda - \tau_1) > 0,$$

so we can increase τ_1 keeping $P = 0, T > 0$ by continuity, and increasing ΔW, absurd.

To finish, suppose that $\frac{\partial P}{\partial s} = 0$, i.e., $A = (4 - 3\lambda)\lambda$. We have

$$P = -\left(\tau_1 - \frac{1}{2}\tau_1^2\right) - \frac{\delta A}{2}\left(b_1 - \frac{1}{2}\right) + b_1\tau_1(1 - \tau_1) + \delta b_1\lambda(1 - \lambda) - \frac{\delta}{A}(2 - \lambda)(1 - \lambda)\lambda^2,$$

which is linear in b_1. When $b_1 = \frac{1}{2}$ we have $P = -\frac{1}{2}\tau_1 - \frac{\delta(1-\lambda)\lambda^2}{2(4-3\lambda)} < 0$. When $b_1 = 1$ we have $P = -\frac{1}{2}\tau_1^2 - \frac{\delta(8-8\lambda+\lambda^2)\lambda}{4(4-3\lambda)} < 0$. Therefore, $P < 0$, so (τ_1, s) cannot be feasible, absurd. ■

Claim 3. *If (τ_1, s) is optimal then $\tau_1 < \lambda$.*

Proof. We know that $P = 0$ and $s > 0$ by the previous claims. There are two cases: $\tau_1 = \lambda$, and $\tau_1 > \lambda$.

Case 1: $\tau_1 = \lambda$. Suppose that $T > 0$. We have $\frac{\partial P}{\partial s} = \frac{4}{\delta A}(\bar{s} - s) \geqslant 0$, because otherwise we can reduce s and increase P, T and ΔW, so s is not optimal, absurd. If $\frac{\partial P}{\partial s} > 0$, by the implicit function theorem, there is a differentiable function $s(\tau_1)$ defined in an interval $(\lambda - \epsilon, \lambda]$ for some $\epsilon > 0$ such that $P|_{s=s(\tau_1)} = 0$, and we have $\frac{ds}{d\tau_1} = -\frac{\frac{\partial P}{\partial \tau_1}}{\frac{\partial P}{\partial s}}$. Now, $\frac{\partial P}{\partial \tau_1} = -(1 - b_1 + (2b_1 - 1)\tau_1) < 0$, so $\frac{ds}{d\tau_1} > 0$. We have

$$\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}\frac{\partial s}{\partial \tau_1} = \underbrace{b_1(\lambda - \tau_1)}_{=0} - \frac{2}{\delta A}[s + \delta(\tau_2 - \lambda)(1 - \tau_2)]\frac{ds}{d\tau_1} < 0,$$

so we can reduce τ_1 a little bit, keeping $P = 0$ and $T > 0$, and we increase the objective, which contradicts that (τ_1, s) is optimal. If $\frac{\partial P}{\partial s} = 0$, the same argument essentially carries over, except that $\frac{ds}{d\tau_1} = +\infty$. Formally: take $h > 0$ and consider $(\tau_1 - h, s - h)$. We have $\frac{dP}{dh} = -\frac{\partial P}{\partial \tau_1} - \frac{\partial P}{\partial s} = -\frac{\partial P}{\partial \tau_1} > 0$ and $\frac{d\Delta W}{dh} = -\frac{\partial \Delta W}{\partial \tau_1} - \frac{\partial \Delta W}{\partial s} = \frac{2}{\delta A}[s + \delta(\tau_2 - \lambda)(1 - \tau_2)] > 0$, hence if h is small enough we can increase P and ΔW, and keep $T > 0$ by continuity, so (τ_1, s) is not optimal.

Suppose that $T = 0$. If $\frac{\partial \tilde{P}}{\partial \tau_1} < 0$ then we can decrease τ_1 a little and take $s = \tilde{s}$, since $\tilde{P}$ increases, which implies that (τ_1, s) is feasible, and the effect on ΔW is positive, since

$$\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}\frac{d\tilde{s}}{d\tau_1} = -\frac{2}{\delta A}[s + \delta(\tau_2 - \lambda)(1 - \tau_2)](1 - \tau_1) < 0,$$

so the new policy is strictly better, absurd. The remaining case is $\tilde{P} = 0$ and $\frac{\partial \tilde{P}}{\partial \tau_1} \geqslant 0$. According to Mathematica, this implies that $\Delta W < 0$, so, again, (τ_1, s) cannot be optimal, since BAU is an option.

Case 2: $\tau_1 > \lambda$. We have $\tau_2 = \tau_1$. We have

$$\frac{\partial \Delta W}{\partial \tau_1} = -(b_1 + \delta b_2)(\tau_1 - \lambda) - \frac{2}{A}(1-\tau_1)[s + \delta(\tau_1 - \lambda)(1-\tau_1)] < 0.$$

Suppose that $T > 0$. If $\frac{\partial P}{\partial \tau_1} < 0$ then by decreasing τ_1 a little we improve the objective and obtain $P, T > 0$, which is better, absurd. According to Mathematica, $P = 0$ and $\frac{\partial P}{\partial \tau_1} \geqslant 0$ are not compatible, so we don't have to consider that case.

Finally, suppose that $T = 0$. If $\frac{\partial \tilde{P}}{\partial \tau_1} < 0$ then we can decrease τ_1 a little and take $s = \tilde{s}$, since $\tilde{P}$ increases, which implies that (τ_1, s) is feasible, and the effect on ΔW is positive, since

$$\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}\frac{d\tilde{s}}{d\tau_1} = \frac{\partial \Delta W}{\partial \tau_1} - \frac{2}{\delta A}[s + \delta(\tau_1 - \lambda)(1-\tau_1)](1-\tau_1) < 0,$$

so the resulting policy is better, absurd. The remaining case is $\tilde{P} = 0$ and $\frac{\partial \tilde{P}}{\partial \tau_1} \geqslant 0$. According to Mathematica, this implies that $\Delta W < 0$, so, again, (τ_1, s) cannot be optimal. ∎

Comming soon: proof for the $\rho < 1$ case.

B.5. *Proof of Proposition 4*

In this section I prove Proposition 4, below, which shows how the feasibility of the political constraints depend on the exogenous parameters of the model. I only consider the case $\rho = 1$, i.e., no political turnover for now.

We say that (A, c, δ, λ) is *feasible* if $\frac{1}{2} < b_1 < 1$ and there is (τ_1, s) such that $P \geqslant 0$ and $T \geqslant 0$, where (b_1, b_2, τ_2) are given by $-c + \frac{\delta A}{2} b_1 = \frac{\delta}{2}$, $s - c + \frac{\delta A}{2} b_2 = \frac{\delta}{2}(1-\tau_2)^2$, $\tau_2 = \max\{\tau_1, \lambda\}$, and P, T are defined in Appendix B.4.

Proposition 4. *The following hold:*

(1) If (A, c, δ, λ) is feasible, $A' \geqslant A$ and $c' \leqslant c$, then $(A', c', \delta, \lambda)$ is feasible.
(2) If $A \geqslant 1.82$ and $\lambda \geqslant 0.006$ then if (A, c, δ, λ) is feasible and $\delta' \geqslant \delta$, (A, c, δ', λ) is feasible.
(3) If $b_1 \leqslant 0.65$ then there is $\bar{\lambda} > 0$ such that (A, c, δ, λ) is feasible for any $\lambda \leqslant \bar{\lambda}$.
(4) There is an increasing function $\underline{A}(b_1)$ such that if $A < \underline{A}(b_1)$ then there is $\bar{\lambda} < \frac{1}{2}$ such that if (A, c, δ, λ) is feasible then $\lambda < \bar{\lambda}$.

Observation. We can restrict attention to $\tau_1 \leqslant \frac{1}{2}$.

Proof. If $\tau_1 > \frac{1}{2}$ then $\tau_1 > \lambda$, hence $\tau_2 = \tau_1$. We have $\frac{\partial T}{\partial \tau_1} = (b_1 + \delta b_2)(1 - 2\tau_1) - \frac{1}{A}(s + \delta\tau_1(1 - \tau_2))(1-\tau_1) < 0$, $\frac{\partial P}{\partial \tau_1} = -(1-\tau_1) + \frac{\partial T}{\partial \tau_1} < 0$ and $\frac{\partial W}{\partial \tau_1} = (b_1 + \delta b_2 + \frac{\delta}{A}(1-\tau_1)^2)(\lambda - \tau_1) - \frac{s}{A}(1-\tau_1) < 0$. Therefore, if (A, c, δ, λ) is feasible at (τ_1, s) with $\tau_1 > \frac{1}{2}$ then it's also feasible at $(\frac{1}{2}, s)$, if $\Delta W \geqslant 0$ at (τ_1, s) with $\tau_1 > \frac{1}{2}$ then also at $(\frac{1}{2}, s)$, and $\tau_1 > \frac{1}{2}$ cannot be an equilibrium. ∎

Let $\tilde{s}$ be given by $P|_{s=\tilde{s}} = T|_{s=\tilde{s}}$, i.e., $\tilde{s} = \tau_1 - \frac{1}{2}\tau_1^2 + \frac{\delta A}{2}(b_1 - \frac{1}{2}) > 0$.

Claim 4. *If $P, T \geqslant 0$ at (τ_1, s) then $P|_{s=\tilde{s}} \geqslant 0$.*

Proof. We have $\tilde{s} > 0$, $\frac{\partial^2 T}{\partial^2 s} = \frac{\partial^2 P}{\partial^2 s} = -\frac{4}{\delta A} < 0$ and $\frac{\partial T}{\partial s}\Big|_{s=0} = -\frac{1}{A}(4 - 3\tau_2)\tau_2 \leqslant 0$, so $\frac{\partial T}{\partial s}\Big|_{s=\tilde{s}} < 0$. If $\frac{\partial P}{\partial s}\Big|_{s=\tilde{s}} \geqslant 0$ we are done, because if $P|_{s=\tilde{s}} < 0$ then $P < 0$ for $s \leqslant \tilde{s}$, and $T < 0$ for $s > \tilde{s}$, so $P \geqslant 0$ and $T \geqslant 0$ cannot happen simultaneously, absurd. So it's enough to show that $\frac{\partial P}{\partial s}\Big|_{s=\tilde{s}} \geqslant 0$.

Suppose that $\frac{\partial P}{\partial s}\Big|_{s=\tilde{s}} < 0$. We have $\frac{\partial P}{\partial s}\Big|_{s=\tilde{s}} = 2(1 - b_1) - \frac{1}{\delta A}[2(2 - \tau_1)\tau_1 + \delta(4 - 3\tau_2)\tau_2]$, so

$$A < \tilde{A} = \frac{2(2 - \tau_1)\tau_1 + \delta(4 - 3\tau_2)\tau_2}{2\delta(1 - b_1)}.$$

Let $\overline{P} = \max_{s' \in \mathbb{R}} P|_{s=s'}$. I will show that if $1 < A < \tilde{A}$ then $\overline{P} < 0$, which contradicts that $P \geqslant 0$ for some s.

We have

$$\overline{P} = \frac{-4A^2 b_1 \delta + 3A^2\delta - 8Ab_1\delta\tau_2^2 + 8Ab_1\delta\tau_2 - 8Ab_1\tau_1^2 + 8Ab_1\tau_1 + 6A\delta\tau_2^2 - 8A\delta\tau_2 + 4A\tau_1^2 - 8A\tau_1 + \delta\tau_2^4}{8A}.$$

Since we are only interested in the sign, I'll ignore the denominator, which is positive. Let

$$\begin{aligned}\tilde{P} = \overline{P}|_{A=\tilde{A}} = \frac{1}{4\delta(1 - b_1)^2}\big(&-44b_1^2\delta^2\tau_2^4 + 40b_1\delta^2\tau_2^4 + 112b_1^2\delta^2\tau_2^3 - 112b_1\delta^2\tau_2^3 - 64b_1^2\delta^2\tau_2^2 + 64b_1\delta^2\tau_2^2 - 80b_1^2\delta\tau_2^2\tau_1^2 \\ &+ 80b_1\delta\tau_2^2\tau_1^2 + 96b_1^2\delta\tau_2\tau_1^2 - 96b_1\delta\tau_2\tau_1^2 + 112b_1^2\delta\tau_2^2\tau_1 - 112b_1\delta\tau_2^2\tau_1 - 128b_1^2\delta\tau_2\tau_1 \\ &+ 128b_1\delta\tau_2\tau_1 - 32b_1^2\tau_1^4 + 32b_1\tau_1^4 + 96b_1^2\tau_1^3 - 96b_1\tau_1^3 - 64b_1^2\tau_1^2 + 64b_1\tau_1^2 - 5\delta^2\tau_2^4 + 24\delta^2\tau_2^3 \\ &- 16\delta^2\tau_2^2 - 12\delta\tau_2^2\tau_1^2 + 16\delta\tau_2\tau_1^2 + 24\delta\tau_2^2\tau_1 - 32\delta\tau_2\tau_1 - 4\tau_1^4 + 16\tau_1^3 - 16\tau_1^2\big).\end{aligned}$$

Again, we can ignore the denominator, which is positive. I will show that $\tilde{P} \leqslant 0$. We have $\frac{\partial^2}{\partial^2 b_1}\frac{\partial^2 \tilde{P}}{\partial^2 \delta} = -16\tau_2^2(11\tau_2^2 - 28\tau_2 + 16) < 0$, so $\frac{\partial^2 \tilde{P}}{\partial^2 \delta}$ is concave in b_1, hence maximized at $\tilde{b}_1$ such that $\frac{\partial}{\partial b_1}\frac{\partial^2 \tilde{P}}{\partial^2 \delta}\Big|_{b_1=\tilde{b}_1} = 0$, i.e., $\tilde{b}_1 = \frac{5\tau_2^2 - 14\tau_2 + 8}{11\tau_2^2 - 28\tau_2 + 16}$. We have

$$\frac{\partial^2 \tilde{P}}{\partial^2 \delta}\bigg|_{b_1=\tilde{b}_1} = \frac{-2(4 - 3\tau_2)^2\tau_2^3(4 - 5\tau_2)}{11\tau_2^2 - 28\tau_2 + 16} < 0,$$

so $\frac{\partial^2 \tilde{P}}{\partial^2 \delta} < 0$. Now,

$$\frac{\partial^2}{\partial^2 b_1}\frac{\partial \tilde{P}}{\partial \delta}\bigg|_{\delta=0} = -32\tau_1\tau_2(8 - 7\tau_2 - \tau_1(6 - 5\tau_2)) \leqslant 0,$$

so $\frac{\partial \tilde{P}}{\partial \delta}\Big|_{\delta=0}$ is concave in b_1, hence maximized at the value of b_1 such that $\frac{\partial^2 \tilde{P}}{\partial b_1 \partial \delta}\Big|_{\delta=0} = 0$, which is $b_1 = \frac{1}{2}$. At that value of b_1 we have $\frac{\partial \tilde{P}}{\partial \delta}\Big|_{\delta=0} = -4\tau_1\tau_2(2\tau_1(1 - \tau_2) + \tau_2) \leqslant 0$. This, plus $\frac{\partial^2 \tilde{P}}{\partial^2 \delta} < 0$, implies that $\tilde{P}$ is maximized at $\delta = 0$. In that case we have $\tilde{P} = -4A\tau_1(1-(2b_1-1)(1-\tau_1)) \leqslant 0$. Hence $\tilde{P} \leqslant 0$, as desired.

$\tilde{A} > 1$ requires b_1 to be above a threshold $\underline{b}_1$ given by $\tilde{A}|_{b_1=\underline{b}_1} = 1$. $\overline{P}|_{A=1}$ is linear in b_1, and $\overline{P}|_{A=1,b_1=\underline{b}_1} = \overline{P}|_{A=\tilde{A}} = \tilde{P} \leqslant 0$, as we just proved. Also, $\overline{P}|_{A=1,b_1=1} = -4\tau_1^2 - \delta - \delta\tau_2^2(2-\tau_2^2) < 0$, so $\overline{P}|_{A=1} \leqslant 0$.

Now, $\frac{\partial^2 \overline{P}}{\partial^2 A} = 8\delta(\frac{3}{4} - b_1)$. If $b_1 < \frac{3}{4}$ then $\overline{P}$ is strictly convex in A, and to show that $\overline{P} < 0$ for $1 < A < \tilde{A}$ it's enough to show that $\overline{P}|_{A=\tilde{A}} \leqslant 0$ and $\overline{P}|_{A=1} \leqslant 0$, which I proved in the previous paragraph. If $b_1 \geqslant \frac{3}{4}$ then $\overline{P}$ is concave in A. Now, $\frac{\partial^2 \overline{P}}{\partial b_1 \partial A}\Big|_{A=0} = 8[\tau_1(1-\tau_1) + \delta\tau_2(1-\tau_2)] \geqslant 0$, so $\frac{\partial \overline{P}}{\partial A}\Big|_{A=0} \leqslant \frac{\partial \overline{P}}{\partial A}\Big|_{A=0,b_1=1} = -4\tau_1^2 - 2\delta\tau_2^2 < 0$. Therefore, $\frac{\partial \overline{P}}{\partial A}$ is decreasing for $A > 0$, hence $\overline{P} < \overline{P}|_{A=1} \leqslant 0$, so $\overline{P} < 0$, as desired. ∎

Claim 5. *If (A, c, δ, λ) is feasible then there is (τ_1, s) such that $P = T = 0$.*

Proof. We use the previous result. Let $f(\tau_1) = P(\tau_1, \tilde{s}(\tau_1))$. If (A, c, δ, λ) is feasible then there is $\tau_1 \in [0, \frac{1}{2}]$ such that $f(\tau_1) \geqslant 0$. Now,

$$f(1) = -\frac{(2+\delta A(2b_1-1))(2+2\delta+\delta A(2b_1-1))}{8\delta A} < 0,$$

so there must be $\tau_1' \in [\tau_1, 1)$ such that $f(\tau_1') = 0$ by continuity of f. ∎

Claim 6. *If (A, c, δ, λ) is feasible and $A' \geqslant A$, $c' \leqslant c$ are such that $(A', c', \delta, \lambda)$ satisfies $b_1 \in (\frac{1}{2}, 1)$ then $(A', c', \delta, \lambda)$ is feasible.*

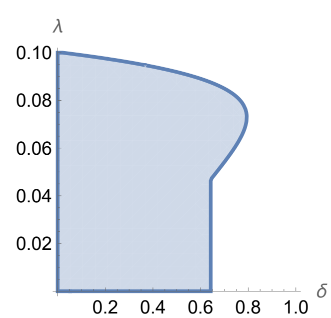
Proof. Let (τ_1, s) such that $P = T = 0$. We have $\frac{\partial T}{\partial A} = -\frac{T}{A} = 0$ if $T = 0$ and $\frac{\partial P}{\partial A} = \frac{\delta}{2} + \frac{\partial T}{\partial A} = \frac{\delta}{2} > 0$, so if we increase A to A' we keep $T = 0$ and P increases, so (τ_1, s) is still feasible.

Take (τ_1, s) such that $P = T = 0$ for (A, c, δ, λ). Let $\tilde{P} = P|_{s=\tilde{s}}$. We have

$$\frac{\partial \tilde{P}}{\partial c} = \frac{\delta(A-2) - 4c - 2\tau_1 - \delta(2-\tau_2)\tau_2}{\delta A}.$$

If $A \geqslant 2$ we have $c > \frac{\delta}{4}(A-2)$ since $b_1 > \frac{1}{2}$. Hence $\frac{\partial \tilde{P}}{\partial c} \leqslant -\frac{2\tau_1 + \delta(2-\tau_2)\tau_2}{\delta A} < 0$. If $A < 2$ then $c \geqslant 0$ so $\frac{\partial \tilde{P}}{\partial c} < -\frac{2\tau_1+\delta(2-\tau_2)\tau_2}{\delta A} \leqslant 0$ as well. Therefore, $\frac{\partial \tilde{P}}{\partial c} < 0$, so by decreasing c, starting from (τ_1, s) such that $P = T = 0$, we obtain $(\tau_1, \tilde{s}(\tau_1))$ such that $P = T \geqslant 0$, hence $(A', c', \delta, \lambda)$ is still feasible. ∎

In many cases we also have that, fixing the other variables, (A, c, δ, λ) is feasible iff δ is large and λ is small. However, this is not always the case. When $A = 1.51$ and $c = 0$ we have that the maximum δ that is feasible is less than 1, and when $\delta = 0.7$ the set of feasible λ is nonempty but does not include 0. (See the figure on the right. The blue area is the region where the parameters are feasible.)



CLAIM 7. *If $\lambda \geqslant 0.006$ and $A \geqslant 1.82$ then if (A, c, δ, λ) is feasible then (A, c, δ', λ) is feasible for any $\delta' \geqslant \delta$.*

Proof. Let $\tilde{P} = P|_{s=\tilde{s}}$. We have

$$\frac{\partial \tilde{P}}{\partial \delta} = \frac{\frac{1}{4}\delta^2\left[-(A-2-(4-3\tau_2)\tau_2)^2 + 8\tau_2(1-\tau_2) + \tau_2^4\right] + 4c^2 + 4c\tau_1 + \tau_1^2(2-\tau_1)^2}{2\delta^2 A}.$$

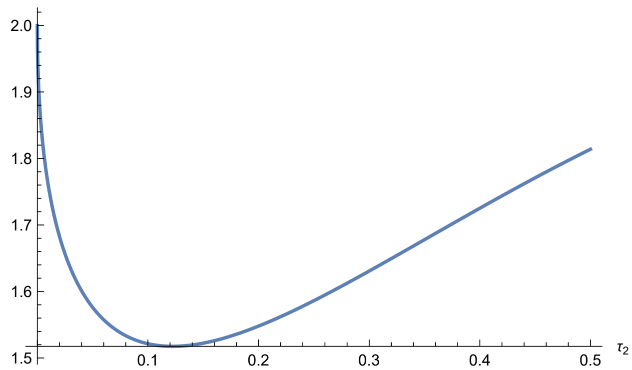
If $A \geqslant 2$ we have $c > \frac{1}{4}\delta(A-2)$ since $b_1 > \frac{1}{2}$, so

$$\frac{\partial \tilde{P}}{\partial \delta} > \frac{2\delta^2\tau_2(1-\tau_2)^3 + \tau_1^2(2-\tau_1)^2 + \delta(A-2)\left[\tau_1 + \frac{\delta}{2}\tau_2(4-3\tau_2)\right]}{2\delta^2 A} \geqslant 0.$$

If $A < 2$ and $-(A-2-(4-3\tau_2)\tau_2)^2 + 8\tau_2(1-\tau_2) + \tau_2^4 \geqslant 0$, i.e.,

$$A \geqslant \underline{A} = 2 + (4-3\tau_2)\tau_2 - \sqrt{8\tau_2(1-\tau_2) + \tau_2^4},$$

then the numerator of $\frac{\partial \tilde{P}}{\partial \delta}$ is weakly increasing in δ, so $\frac{\partial \tilde{P}}{\partial \delta} \geqslant 0$. Plot of $\underline{A}$:



A sufficient condition for $A \geqslant \underline{A}$ is $\lambda \geqslant 0.006$ and $A \geqslant 1.82$. In this case if $\tilde{P} \geqslant 0$ for some δ, it also holds for any $\delta' \geqslant \delta$, as desired. ∎

CLAIM 8. *$\tilde{P}$ is single peaked in τ_1 for $\tau_1 \in [0, \lambda]$.*

Proof. If $\tilde{P}$ is strictly concave we are done. Otherwise, since $\frac{\partial^3 \tilde{P}}{\partial^3 \tau_1} = \frac{12}{\delta A}(1-\tau_1) > 0$ it must be strictly convex for $\tau_1 \geqslant \underline{\tau}_1$ for some $\underline{\tau}_1$. But setting $\tau_2 = \lambda$, we have

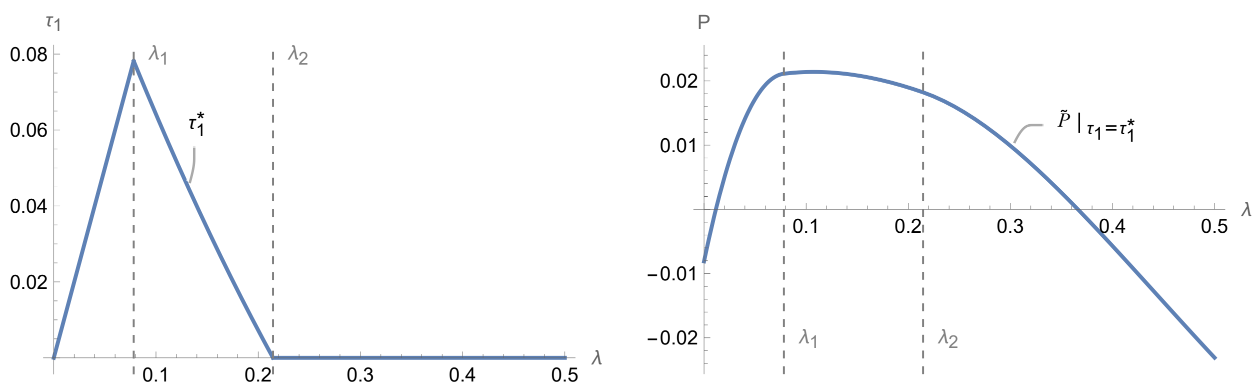
$$\left.\frac{\partial \tilde{P}}{\partial \tau_1}\right|_{\tau_1 = \frac{1}{2}} = -\frac{3 + 2\delta A(2b_1 - 1) + 2\delta\lambda(4-3\lambda)}{4\delta A} < 0.$$

Therefore, $\left.\frac{\partial \tilde{P}}{\partial \tau_1}\right|_{\tau_1 = \underline{\tau}_1} \leqslant \left.\frac{\partial \tilde{P}}{\partial \tau_1}\right|_{\tau_1 = \frac{1}{2}} < 0$, so $\tilde{P}$ is decreasing for $\tau_1 \geqslant \underline{\tau}_1$, and single-peaked for $\tau_1 < \underline{\tau}_1$ by strict concavity, so it's single-peaked, as desired. ∎

Given λ, let $\tau_1^* \in [0, \lambda]$ be the value of τ_1 that maximizes $\tilde{P}$, which is unique by the previous Claim. By Berge's maximum theorem, τ_1^* is continuous. We must have $\frac{\partial \tilde{P}}{\partial \tau_1}\big|_{\tau_1=\tau_1^*} = 0$ and $\frac{\partial^2 \tilde{P}}{\partial^2 \tau_1}\big|_{\tau_1=\tau_1^*} < 0$ if $\tau_1^* \in (0, \lambda)$, because $\frac{\partial^3 \tilde{P}}{\partial^3 \tau_1} > 0$. Conversely, if $\frac{\partial \tilde{P}}{\partial \tau_1}$ for some $\tau_1 \in (0, \lambda)$, by the proof of the previous Claim we must have $\tau_1 = \tau_1^*$. Now, if $\tau_1^* \in (0, \lambda)$, by the implicit function theorem there is a neighnorhood of λ and a function $\tilde{\tau}_1(\lambda)$ with image in $(0, \lambda)$ defined in that neighborhood such that $\frac{\partial \tilde{P}}{\partial \tau_1}\big|_{\tau_1=\tilde{\tau}_1} = 0$, and

$$\tilde{\tau}_1'(\lambda) = -\frac{\frac{\partial^2 \tilde{P}}{\partial \lambda \partial \tau_1}\big|_{\tau_1=\tilde{\tau}_1}}{\frac{\partial^2 \tilde{P}}{\partial^2 \tau_1}\big|_{\tau_1=\tilde{\tau}_1}} = \frac{1}{\frac{\partial^2 \tilde{P}}{\partial^2 \tau_1}\big|_{\tau_1=\tilde{\tau}_1}} \frac{2(1-\tilde{\tau}_1)(2-3\lambda)}{A} < 0.$$

By the previous argument, $\tilde{\tau}_1 = \tau_1^*$. Hence, we obtained that if $\tau_1^* \in (0, \lambda)$ then $\frac{\partial \tau_1^*}{\partial \lambda} < 0$. Therefore, if (λ_1, λ_2) is a maximal interval where $\tau_1^* \in (0, \lambda)$, we must have $\tau_1^*(\lambda_1) = \lambda_1$ and $\tau_1^*(\lambda_2) = 0$ by continuity of τ_1^*. Therefore, there are $\lambda_1 \leqslant \lambda_2$ such that $\tau_1^* = \lambda$ for $\lambda \in [0, \lambda_1]$, $\tau_1^* \in (0, \lambda_1)$ for $\lambda \in (\lambda_1, \lambda_2)$, and $\tau_1^* = 0$ for $\lambda \in [\lambda_2, \frac{1}{2}]$. See the figure for an example:



Let $\tilde{P} = P|_{s=\tilde{s}}$. If $\lambda = 0$ we have $\frac{\partial \tilde{P}}{\partial \tau_1}\big|_{\tau_1=0} = 8(1+\delta)\delta A(1-b_1) > 0$. Hence, if $(A, c, \delta, \lambda = 0)$ is feasible, then it's feasible for some $\tau_1 > 0$. Notice that if $\lambda \leqslant \tau_1$ then $\tilde{P}$ doesn't depend on λ, since in that case $\tau_2 = \tau_1$. Therefore, if $(A, c, \delta, \lambda = 0)$ is feasible, it's also feasible for $\lambda \in [0, \overline{\lambda}]$ for some $\overline{\lambda} > 0$.

Claim 9. *If $b_1 \leqslant 0.65$ then $\lambda = 0$ is feasible.*

Proof. If $\lambda = 0$ then $\tau_2 = \max\{\tau_1, \lambda\} = \tau_1$. Given $\tau \in [0, \frac{1}{2}]$ let $f(\tau) = \tilde{P}|_{\tau_1=\tau}$. We have $f(\tau) = f(0) + f'(0)\tau + \frac{1}{2}f''(\xi)\tau^2 \geqslant f(0) + f'(0)\tau + \frac{1}{2}f''(0)\tau^2$ for some $\xi \in [0, \tau]$, since $f'''(\tau) = \frac{\partial^3 \tilde{P}}{\partial^3 \tau_1}\big|_{\tau_1=\tau} = \frac{6(1+\delta)(2+3\delta-(2+4\delta)\tau)}{\delta A} > 0$, so f'' is increasing. So let $g(\tau) = f(0) + f'(0)\tau + \frac{1}{2}f''(0)\tau^2$. Since $\tilde{P} \geqslant g(\tau_1)$, it's enough to show that there is $\tau \in [0, \frac{1}{2}]$ such that $g(\tau) \geqslant 0$. Now,

$g'(0) = f'(0) = \frac{\partial \tilde{P}}{\partial \tau_1}\big|_{\tau_1=0} = (1+\delta)(1-b_1) > 0$, and

$$g'\left(\frac{1}{2}\right) = -\frac{8 + 2\delta(8 + A(2b_1 - 1)) + \delta^2(8 + (2b_1 - 1)A)}{4\delta A} < 0,$$

so g is maximized at $\tau^* \in (0, \frac{1}{2})$ defined by $g'(\tau^*) = 0$. We have

$$\tau^* = \frac{2\delta(1+\delta)A(1-b_1)}{8 + 2\delta(8+A) + \delta^2(8 + A(3-2b_1))}.$$

We want to show that $g(\tau^*) \geqslant 0$. We have

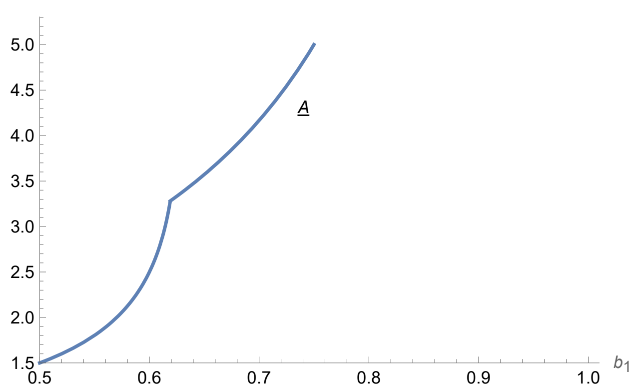
$$g(\tau^*) = \frac{\begin{aligned}\delta A(16b_1 - 24b_1^2 - 2A\delta + 32b_1\delta + 8Ab_1\delta - 48b_1^2\delta - 8Ab_1^2\delta \\ - 3A\delta^2 + 16b_1\delta^2 + 14Ab_1\delta^2 - 24b_1^2\delta^2 - 20Ab_1^2\delta^2 + 8Ab_1^3\delta^2)\end{aligned}}{8(8 + 2\delta(8+A) + \delta^2(8 + A(3-2b_1)))}.$$

Let h be the parenthesis in the numerator. We have $\frac{\partial h}{\partial A} = -\delta(2b_1 - 1)^2(2 + \delta(3 - 2b_1)) < 0$ and $0 \leqslant c = \frac{\delta}{2}(Ab_1 - 1)$, so $A \geqslant \frac{1}{b_1}$ and $h \geqslant \underline{h} := h|_{A=1/b_1}$. We have $\frac{\partial^2 \underline{h}}{\partial^2 b_1} = -\frac{2\delta(2+3\delta)}{b_1^3} - 16(3 + 6\delta + 2\delta^2) < 0$, so $\frac{\partial \underline{h}}{\partial b_1} \leqslant \frac{\partial \underline{h}}{\partial b_1}\big|_{b_1=\frac{1}{2}} = -8(1+\delta)^2 < 0$, so $\underline{h} \geqslant \underline{h}|_{b_1=0.65} = \frac{8\delta^2}{325} + \frac{79\delta}{325} + \frac{13}{50} > 0$, since we assume that $b_1 \leqslant 0.65$. This completes the proof. ■

Claim 10. *If $\lambda = \frac{1}{2}$ then (A, c, δ, λ) is feasible only if*

$$A \geqslant \underline{A} := \begin{cases} \frac{5 - 6b_1 - \sqrt{1 + 36b_1 - 60b_1^2}}{4(4b_1^2 - 4b_1 + 1)} & \text{if } b_1 \leqslant \frac{1}{64}(19 + 5\sqrt{17}) \approx 0.62, \\ \frac{5}{4(1-b_1)} & \text{otherwise,} \end{cases}$$

which is increasing in b_1:



Proof. Suppose that $\lambda = \frac{1}{2}$. We have $\frac{\partial \tilde{P}}{\partial \tau_1}\big|_{\tau_1=0} = 1 - b_1 - \frac{5}{4A}$, so $\frac{\partial \tilde{P}}{\partial \tau_1}\big|_{\tau_1=0} \leqslant 0$ iff $A \leqslant \frac{5}{4(1-b_1)}$. In this case, $\tilde{P}$ is maximized at $\tau_1 = 0$ by Claim 3. We have

$$\tilde{P}|_{\tau_1=0} = -\frac{\delta(2A^2(2b_1-1)^2 - A(5-6b_1)+3)}{16A}.$$

The smallest root is

$$A_1 = \frac{5-6b_1-\sqrt{1+36b_1-60b_1^2}}{4(4b_1^2-4b_1+1)},$$

which exists iff $1+36b_1-60b_1^2 \geqslant 0$, i.e., iff $b_1 \leqslant \frac{1}{30}(9+4\sqrt{6}) \approx 0.63$. Hence, if $A \leqslant \frac{5}{4(1-b_1)}$ then the constraints are feasible only if $A \geqslant A_1$. So, either $A > \frac{5}{4(1-b_1)}$ or $A_1 \leqslant A \leqslant \frac{5}{4(1-b_1)}$. We have $A_1 \leqslant \frac{5}{4(1-b_1)}$ iff $b_1 \leqslant \frac{1}{64}(19+5\sqrt{17}) \approx 0.62$, so A is feasible only if $A \geqslant A_1$ and $b_1 \leqslant \frac{1}{64}(19+5\sqrt{17})$ or, else, $A > \frac{5}{4(1-b_1)}$, as desired. ■

B.6. *Proof of Observation 2*

We have

$$\Delta W = b_1\tau_1\left(\lambda - \frac{1}{2}\tau_1\right) + \delta b_2 \mathrm{E}\left[\tau_2\left(\lambda - \frac{1}{2}\tau_2\right)\right] + \delta\lambda(b_1-b_2) - \frac{\delta A}{4}(b_1-b_2)^2.$$

When $\lambda = 0$, $\Delta W = -\frac{1}{2}b_1\tau_1^2 - \frac{\delta}{2}\mathrm{E}\tau_2^2 - \frac{\delta A}{4}(b_1-b_2)^2$, so $\Delta W \geqslant 0$ iff $\tau_1 = \tau_2 = s = 0$. However, in that case $P = -\frac{\delta A}{4}(2b_1-1) < 0$.

B.7. *Proof of Proposition 2*

In order to keep the notation consistent with the proof of the previous results, I will call P and T the quantities that need to be nonnegative for the political constraints PC_B and PC_G to hold, respectively. Thus, we have

$$T = b_1\tau_1(1-\tau_1) + \delta b_2\tau_2(1-\tau_2) - s(b_1-b_2) - \delta\tilde{b}_2\lambda(1-\lambda),$$
$$P = s - \frac{1}{2}(2-\tau_1)\tau_1 + T.$$

The proof of Claim 1 works verbatim, so we have that $P = 0$ or $s = 0$ in equilibrium.

Claim 11. *If (τ_1, s) is optimal then $s > 0$.*

Proof. Suppose that $s = 0$ is optimal. Two cases: $\tau_1 \geqslant \lambda$ and $\tau_1 < \lambda$.
Case 1: $\tau_1 \geqslant \lambda$. We have $\tau_2 = \tau_1$, $b_2 = b_1 - \frac{1}{A}(2-\tau_1)\tau_1$, $\tilde{b}_2 = b_1 - \frac{1}{A}(2-\lambda)\lambda$, and

$$0 \leqslant P = -\left(\tau_1 - \frac{1}{2}\tau_1^2\right) + b_1\tau_1(1-\tau_1) + \delta b_2\tau_1(1-\tau_1) - \delta\tilde{b}_2\lambda(1-\lambda)$$

$$= -\left(\tau_1 - \frac{1}{2}\tau_1^2\right) + b_1[(1+\delta)\tau_1(1-\tau_1) - \delta\lambda(1-\lambda)]$$
$$- \frac{\delta}{A}\left[\tau_1^2(2-\tau_1)(1-\tau_1) - \lambda^2(2-\lambda)(1-\lambda)\right]$$

This last expression is linear in δ, so it's maximized at either $\delta = 0$ or $\delta = 1$. If $\delta = 0$ its value is $-(1 - b_1 + (b_1 - \frac{1}{2})\tau_1) < 0$. If $\delta = 1$, using $b_1 \leqslant \frac{1}{2} + \frac{\lambda(2-\lambda)}{A}$ it is

$$\leqslant -\left(\tau_1 - \frac{1}{2}\tau_1^2\right) + \left(\frac{1}{2} + \frac{\lambda(2-\lambda)}{A}\right)[2\tau_1(1-\tau_1) - \lambda(1-\lambda)]$$
$$- \frac{1}{A}\left[\tau_1^2(2-\tau_1)(1-\tau_1) - \lambda^2(2-\lambda)(1-\lambda)\right]$$
$$= -\left(\tau_1 - \frac{1}{2}\tau_1^2\right) + \frac{1}{2}[2\tau_1(1-\tau_1) - \lambda(1-\lambda)] + \frac{2}{A}\tau_1(1-\tau_1)\lambda(2-\lambda)$$
$$- \frac{1}{A}\tau_1^2(2-\tau_1)(1-\tau_1).$$

This is a quadratic on λ with leading coefficient $\frac{1}{2} - \frac{2}{A}\tau_1(1-\tau_1) \geqslant 0$ since $\tau_1(1-\tau_1) \leqslant \frac{1}{4}$ and $A > 1$. Therefore, it is convex in λ, and it is maximized at either $\lambda = 0$ or $\lambda = \tau_1$. If $\lambda = 0$ it is $-\frac{\tau_1^2}{2} - \frac{1}{A}\tau_1^2(2-\tau_1)(1-\tau_1) < 0$. If $\lambda = \tau_1$ it is $-\frac{\tau_1}{2} + \frac{1}{A}\tau_1^2(1-\tau_1)(2-\tau_1)$

$$\leqslant -\frac{\tau_1}{2}(1 - \tau_1(1-\tau_1)(2-\tau_1)) \leqslant -\frac{\tau_1}{2}\left(1 - \left(\frac{\tau_1 + 1 - \tau_1 + 2 - \tau_1}{3}\right)^3\right) = -\frac{\tau_1}{2}\left(1 - \left(1 - \frac{\tau_1}{3}\right)^3\right) < 0.$$

This proves that $P < 0$, a contradiction.

Case 2: $\tau_1 < \lambda$. We have $\tau_2 = \lambda$, $b_2 = \tilde{b}_2 = b_1 - \frac{1}{A}(2-\lambda)\lambda$, $T = b_1\tau_1(1-\tau_1)$ and $P = -\frac{1}{2}(2-\tau_1)\tau_1 + b_1\tau_1(1-\tau_1) = -(1 - b_1 + (b_1 - \frac{1}{2})\tau_1)\tau_1 \leqslant 0$, with equality only if $\tau_1 = 0$, so τ_1 must be 0. If we increase τ_1 with $s = \frac{1}{2}(2-\tau_1)\tau_1$ the effect on ΔW is $\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}(1-\tau_1) = b_1\lambda - \frac{2s}{\delta A} = b_1\lambda > 0$, and P and T increase, so $\tau_1 = s = 0$ is not optimal. ■

Claim 12. *If (τ_1, s) is optimal then $\tau_1 < \lambda$.*

Proof. We know that $P = 0$ and $s > 0$ by the previous claims. Moreover, $\frac{\partial P}{\partial s} \geqslant 0$, because otherwise we can decrease s and increase P, T and ΔW, absurd. Two cases: $\tau_1 = \lambda$, and $\tau_1 > \lambda$.

Case 1: $\tau_1 = \lambda$. If $T > 0$ the same argument as in the proof of Claim 3 carries over, and we obtain a contradiction. Suppose that $T = 0$. Again, we have that $\tilde{s} = \tau_1 - \frac{1}{2}\tau_1^2$ is the only solution to $P|_{s=\tilde{s}} = T|_{s=\tilde{s}}$. Let $\tilde{P} = P|_{s=\tilde{s}}$. If $\frac{\partial \tilde{P}}{\partial \tau_1} < 0$ (taking the left derivative) the same argument as in the proof of Claim 3 carries over. The remaining case is $\tilde{P} = 0$ and $\frac{\partial \tilde{P}}{\partial \tau_1} \geqslant 0$. In this case Mathematica says that $\Delta W < 0$, which contradicts that (τ_1, s) is optimal.

Case 2: $\tau_1 > \lambda$. Suppose that $T > 0$. It's enough to prove that $\frac{\partial P}{\partial \tau_1} < 0$, since in that case we should decrease τ_1 a little, absurd. We have $\frac{\partial^2 P}{\partial^2 s}\tau_1 = \frac{2}{A}(-2 + 3\tau_1) < 0$, so it's enough to prove

$\frac{\partial P}{\partial \tau_1} < 0$ for $s = 0$. In that case, $\frac{\partial^4 P}{\partial^4 \tau_1} = -\frac{24\delta}{A} < 0$, and $\frac{\partial^3 P}{\partial^3 \tau_1}\Big|_{\tau_1=\frac{1}{2}} = \frac{6\delta}{A} > 0$, so $\frac{\partial^3 P}{\partial^3 \tau_1} > 0$. Now, $\frac{\partial^2 P}{\partial^2 \tau_1}\Big|_{\tau_1=\frac{1}{2}} = 1 + \frac{2\delta}{A} - 2b_1(1+\delta) \leqslant 1 + 2b_1\delta - 2b_1(1+\delta) = 1 - 2b_1 < 0$, because $c \geqslant 0$ implies $Ab_1 \geqslant 1$. Hence, $\frac{\partial^2 P}{\partial^2 \tau_1} < 0$. Therefore, it's enough to show that $\frac{\partial P}{\partial \tau_1} < 0$ for $\tau_1 \to \lambda^+$. We have

$$\begin{aligned}
\frac{\partial P}{\partial \tau_1}\Big|_{\tau_1=\lambda} &= (1+\delta)b_1(1-2\lambda) - (1-\lambda) - \frac{\delta}{A}\lambda(4 - 9\lambda + 4\lambda^2) \\
&\leqslant (1+\delta)\left(\frac{1}{2} + \frac{\lambda(2-\lambda)}{A}\right)(1-2\lambda) - (1-\lambda) - \frac{\delta}{A}\lambda(4 - 9\lambda + 4\lambda^2) \\
&= -\frac{1}{2}(1 - \delta + 2\delta\lambda) + \frac{\lambda(2 - 5\lambda + 2\lambda^2 - 2\delta(1-\lambda)^2)}{A} \\
&\leqslant -\frac{1}{2}(1 - \delta + 2\delta\lambda) + \lambda(2 - 5\lambda + 2\lambda^2 - 2\delta(1-\lambda)^2) \\
&= -\frac{1}{2}(1 - 4\lambda + 10\lambda^2 - 4\lambda^3 - \delta(1 - 6\lambda + 8\lambda^2 - 4\lambda^3)).
\end{aligned}$$

This is maximized for $\delta = 0$ or $\delta = 1$. In the first case, the expression is $-\frac{1}{2}((1-2\lambda)^2 + \lambda^2(6-4\lambda)) < 0$. In the second case, the expression is $-\lambda(1+\lambda) < 0$. Hence, $\frac{\partial P}{\partial \tau_1} < 0$ for $\tau_1 \to \lambda^+$, so $\frac{\partial P}{\partial \tau_1} < 0$ for all $\tau_1 > \lambda$, as desired.

Finally, suppose that $T = 0$. Let $\tilde{s} = \tau_1 - \frac{1}{2}\tau_1^2$ and $\tilde{P} = P|_{s=\tilde{s}} = T|_{s=\tilde{s}}$. We have $s = \tilde{s}(\tau_1)$. If $\frac{\partial \tilde{P}}{\partial \tau_1} < 0$ we are done. Mathematica says that $\tilde{P} = 0$ and $\frac{\partial \tilde{P}}{\partial \tau_1} \geqslant 0$ cannot happen. ■

B.8. *Proof of Lemma 2*

We have

$$\begin{aligned}
P &= \frac{1}{2}(1-\tau_1)^2 + s - c + \frac{\delta A}{4} + T - \lambda b_1(1-\tau_1) - \delta\lambda b_2(1-\tau_2) - (1+\delta)\left(\frac{1}{2} - \lambda b_1\right), \\
T &= b_1\tau_1(1-\tau_1) + \delta b_2\tau_2(1-\tau_2) - s(b_1 - b_2).
\end{aligned}$$

We want to show that $P \geqslant 0$ implies that $b_2 \leqslant \frac{1}{2}$, i.e., $s - c + \frac{\delta A}{4} \geqslant \frac{\delta}{2}(1-\tau_2)^2$. It's enough to show that $s - c + \frac{\delta A}{4} - P \geqslant \frac{\delta}{2}(1-\tau_2)^2$, since I can sum $P \geqslant 0$ and obtain the result. Thus, it's enough to show that

$$J = \frac{1}{2}(1-\tau_1)^2 + \frac{\delta}{2}(1-\tau_2)^2 + T - \lambda b_1(1-\tau_1) - \delta\lambda b_2(1-\tau_2) - (1+\delta)\left(\frac{1}{2} - \lambda b_1\right) \leqslant 0.$$

If $\tau_1 \leqslant \lambda$ we have $\tau_2 = \lambda$, so

$$J = \frac{1}{2}(1-\tau_1)^2 + \frac{\delta}{2}(1-\lambda)^2 - b_1(\lambda - \tau_1)(1-\tau_1) - s(b_1 - b_2) - (1+\delta)\left(\frac{1}{2} - \lambda b_1\right).$$

We have $\frac{\partial J}{\partial \tau_1} = -(1-\tau_1) + b_1(1+\lambda-2\tau_1) = -(1-(1+\lambda)b_1 + (2b_1-1)\tau_1) \leqslant 0$, so

$$J \leqslant J|_{\tau_1=0} = -\delta\lambda\left(1-b_1-\frac{\lambda}{2}\right) - s(b_1-b_2) \leqslant -\delta\lambda\left(1-\frac{1}{1+\lambda}-\frac{\lambda}{2}\right) = -\delta\frac{\lambda^2(1-\lambda)}{2(1+\lambda)} < 0,$$

using Assumption 2.

If $\tau_1 > \lambda$ we have $\tau_2 = \tau_1$, so

$$J = -(1+\delta)\frac{1}{2}(2-\tau_1)\tau_1 + (b_1+\delta b_2)(\tau_1-\lambda)(1-\tau_1) + (1+\delta)\lambda b_1 - s(b_1-b_2).$$

Noting that $b_1 - b_2 = \frac{2}{\delta A}\left[\frac{\delta}{2}(2\tau_1-\tau_1^2)+s\right]$ it is clear that $\frac{\partial J}{\partial b_1} \geqslant 0$, so $J \leqslant \tilde{J} = J|_{b_1=\frac{1}{1+\lambda}}$. Now,

$$\begin{aligned}\frac{\partial \tilde{J}}{\partial \lambda} &= \frac{\partial J}{\partial \lambda} - \frac{1}{(1+\lambda)^2}\frac{\partial J}{\partial b_1} = (b_1+\delta b_2)\tau_1 + \delta(b_1-b_2) - b_1^2[(\tau_1-\lambda)(1-\tau_1)+(1+\delta)\lambda] \\ &\geqslant (1+\delta)(b_1-b_1^2\lambda) - b_1^2(\tau_1-\lambda)(1-\tau_1) \geqslant b_1^2\left[b_1^{-1}-\lambda-(\tau_1-\lambda)(1-\tau_1)\right] \\ &= b_1^2[1-(\tau_1-\lambda)(1-\tau_1)] \geqslant 0,\end{aligned}$$

so $\tilde{J} \leqslant \tilde{J}|_{\lambda=\tau_1}$, but

$$\begin{aligned}\tilde{J}|_{\lambda=\tau_1} &= -(1+\delta)\tau_1\left(1-b_1-\frac{\tau_1}{2}\right) - s(b_1-b_2) \leqslant -(1+\delta)\tau_1\left(1-\frac{1}{1+\lambda}-\frac{\tau_1}{2}\right) \\ &= -(1+\delta)\tau_1\left(1-\frac{1}{1+\tau_1}-\frac{\tau_1}{2}\right) = -\delta\frac{\tau_1^2(1-\tau_1)}{2(1+\tau_1)} < 0,\end{aligned}$$

hence $J < 0$, as desired.

B.9. *Proof of Observation 3*

PC_B is feasible given (A, c, δ, λ), iff there is (τ_1, s) such that $P \geqslant 0$. Now, P is a concave quadratic in s, maximized at $s = \hat{s} = \frac{\delta}{4}(A-(4\tau_2-3\tau_2^2)+2\lambda(1-\tau_2)) > 0$. So $P \geqslant 0$ only if $\tilde{P} = P|_{s=\hat{s}} \geqslant 0$. Now, if $\tau_1 \leqslant \lambda$, $\frac{d\tilde{P}}{d\tau_1} = -(1-(1+\lambda)b_1+(2b_1-1)\tau_1) \leqslant 0$, so $\tilde{P} \geqslant 0$ implies $\tilde{P}|_{\tau_1=0} \geqslant 0$. If $\tau_1 > \lambda$, $\tau_2 = \tau_1$, so

$$\begin{aligned}\frac{d\tilde{P}}{d\tau_1} &= \frac{\partial P}{\partial \tau_1} + \frac{\partial P}{\partial \tau_2} + \frac{\partial P}{\partial b_2}\frac{db_2}{d\tau_2} + \frac{\partial P}{\partial s}\frac{\partial \hat{s}}{\partial \tau_2} \\ &= -(1-(1+\lambda)b_1+(2b_1-1)\tau_1) + \delta b_2(1+\lambda-2\tau_1) - \frac{2}{A}(1-\tau_1)[\hat{s}+\delta(\tau_1-\lambda)(1-\tau_1)].\end{aligned}$$

Now, some algebra yields $\frac{\partial^2}{\partial^2\lambda}\frac{d\tilde{P}}{d\tau_1} = -\frac{2\delta}{A}(1-\tau_1) < 0$ and

$$\frac{\partial}{\partial\lambda}\frac{d\tilde{P}}{d\tau_1}\bigg|_{\lambda=\tau_1} = (1+\delta)b_1 - \frac{\delta}{2} - \frac{\delta}{A}\left(1-\frac{1}{2}\tau_1\right)\tau_1 \geqslant (1+\delta)b_1 - \frac{\delta}{2} - \delta b_1\left(1-\frac{1}{2}\tau_1\right)\tau_1$$
$$= \left(1+\frac{\delta}{2}\left(1+(1-\tau_1)^2\right)\right)b_1 - \frac{\delta}{2} \geqslant \frac{1}{2}\left(1+\frac{\delta}{2}\left(1+(1-\tau_1)^2\right)-\delta\right) > 0.$$

Therefore, $\frac{\partial}{\partial\lambda}\frac{d\tilde{P}}{d\tau_1} > 0$, so $\frac{d\tilde{P}}{d\tau_1} \leqslant \frac{d\tilde{P}}{d\tau_1}\big|_{\lambda=\tau_1} = -(1+\delta)(1-b_1)(1-\tau_1) \leqslant 0$. Therefore, $\tilde{P} \geqslant 0$ implies $\tilde{P}|_{\tau_1=\lambda} \geqslant 0$, which implies $\tilde{P}|_{\tau_1=0} \geqslant 0$ by the previous finding. In sum, (A, c, δ, λ) is feasible iff $\bar{P} = P|_{\tau_1=0, s=\hat{s}} \geqslant 0$, where $\hat{s} = \frac{\delta}{4}(A - 2\lambda + \lambda^2)$.

We have

$$\bar{P} = \frac{-8(A-2\lambda)c + \delta(3A^2 - 2(2+2\lambda-\lambda^2)A + \lambda(8+4\lambda-4\lambda^2+\lambda^3))}{8A}.$$

We have $b_1 \leqslant \frac{1}{1+\lambda}$, so $0 \leqslant c \leqslant \frac{\delta(A-1-\lambda)}{2(1+\lambda)}$, which implies $A \geqslant 1+\lambda$. Now,

$$\frac{\partial\bar{P}}{\partial A} = \frac{3}{8}\delta - \frac{\lambda(16c + \delta(8+4\lambda-4\lambda^2+\lambda^3))}{8A^2} \geqslant \frac{3}{8}\delta - \frac{\lambda(8\frac{\delta(A-1-\lambda)}{1+\lambda} + \delta(8+4\lambda-4\lambda^2+\lambda^3))}{8A^2}$$
$$= \frac{\delta}{8}\left(3 - \frac{\lambda^2(1-\lambda)^2}{A^2} - \frac{8\lambda}{A(1+\lambda)}\right) \geqslant \frac{\delta}{8}\left(3 - \frac{\lambda^2(1-\lambda)^2}{(1+\lambda)^2} - \frac{8\lambda}{(1+\lambda)^2}\right) > 0,$$

since $3(1+\lambda)^2 - \lambda^2(1-\lambda)^2 - 8\lambda \geqslant 3(1+\lambda) - \frac{1}{16} - 8\lambda = 3 - \frac{1}{16} - 5\lambda \geqslant 3 - \frac{1}{16} - \frac{5}{2} = \frac{7}{16} > 0$. This shows that if $\bar{P} \geqslant 0$ for A, then $\bar{P} \geqslant 0$ for any $A' \geqslant A$. Also, $\frac{\partial\bar{P}}{\partial c} = -\frac{1}{A}(A-2\lambda) < 0$, hence if $\bar{P} \geqslant 0$ for c, then $\bar{P} \geqslant 0$ for any $c' \leqslant c$. Now, $\bar{P}$ is linear in δ. If $\frac{\partial\bar{P}}{\partial\delta} < 0$ then $\bar{P}$ is maximized at $\delta = 0$, but $\bar{P}|_{\delta=0} = -\frac{1}{A}(A-2\lambda)c \leqslant 0$, hence $\bar{P} < 0$ for any $\delta > 0$. Therefore, if δ is feasible, $\frac{\partial\bar{P}}{\partial\delta} \geqslant 0$; in that case we obtain the desired result, viz, that if $\bar{P} \geqslant 0$ for δ then it's also the case for $\delta' \geqslant \delta$.

Finally, $b_1 > \frac{1}{2}$ implies $c > \frac{\delta}{4}(A-2)$, so

$$\frac{\partial\bar{P}}{\partial\lambda} = \frac{4c + \delta(2 - (1-\lambda)A + 2\lambda - 3\lambda^2 + \lambda^3)}{2A} > \frac{\delta\lambda(A + 2 - 3\lambda + \lambda^2)}{2A} \geqslant \frac{\delta\lambda(A+\frac{1}{2})}{2A} \geqslant 0,$$

and $\bar{P} \geqslant 0$ for λ implies $\bar{P} \geqslant 0$ for any $\lambda' \in [\lambda, \frac{1}{2})$, as desired.

B.10. *Proof of Proposition 3*

We have to prove that $\tau_1 < \lambda$ implies $s > 0$, $\tau_1 = \lambda$ implies $s = 0$, and $\tau_1 > \lambda$ cannot happen.

Claim 13. *If (τ_1, s) is optimal and $\tau_1 < \lambda$ then $s > 0$.*

Proof. Suppose that $s = 0$. If $P > 0$ we can increase τ_1 a bit improving the objective, absurd, so $P = 0$. We have $\frac{\partial P}{\partial s} = \frac{1}{A}(A - (2-\lambda)\lambda) > 0$, so by the implicit function theorem there is $\tilde{s}(\tau_1)$

defined around τ_1 such that $P|_{s=\tilde{s}} = 0$, and it is differentiable. We have

$$\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}\frac{\partial \tilde{s}}{\partial \tau_1} = b_1(\lambda - \tau_1) - \frac{2}{\delta A}\underbrace{(s + \delta(\tau_2 - \lambda)(1 - \tau_2))}_{=0}\frac{\partial \tilde{s}}{\partial \tau_1} = b_1(\lambda - \tau_1) > 0,$$

since $\tau_2 = \lambda$ and $s = 0$, so we should increase τ_1, absurd. ■

Claim 14. *If (τ_1, s) is optimal and $\tau_1 = \lambda$ then $s = 0$.*

Proof. Suppose that $s > 0$. If $P > 0$ we can decrease s and improve the objective, so $P = 0$. We have that the left derivative $\frac{\partial P}{\partial \tau_1}$ is $-(1 - b_1)(1 - \lambda) < 0$. If $\frac{\partial P}{\partial s} < 0$ we should decrease s, so $\frac{\partial P}{\partial s} \geqslant 0$. If $\frac{\partial P}{\partial s} > 0$ then by the implicit function theorem there is a differentiable function $\tilde{s}(\tau_1)$ defined for τ_1 in an interval $(\lambda - \epsilon, \lambda]$ for some $\epsilon > 0$ such that $P|_{s=\tilde{s}} = 0$. We have

$$\frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s}\frac{\partial \tilde{s}}{\partial \tau_1} = b_1(\lambda - \tau_1) - \frac{2}{\delta A}(s + \delta(\tau_2 - \lambda)(1 - \tau_2))\frac{\partial \tilde{s}}{\partial \tau_1} = \frac{2s}{\delta A}\frac{\frac{\partial P}{\partial \tau_1}}{\frac{\partial P}{\partial s}} < 0,$$

so we should decrease τ_1, absurd. If $\frac{\partial P}{\partial s} = 0$ take $h \geqslant 0$ and consider $(\tau_1 - h, s - h)$. We have $\frac{dP}{dh}\big|_{h=0} = -\frac{\partial P}{\partial \tau_1} - \frac{\partial P}{\partial s} > 0$, and $\frac{d\Delta W}{dh}\big|_{h=0} = \frac{\partial \Delta W}{\partial \tau_1} + \frac{\partial \Delta W}{\partial s} = \frac{2s}{\delta A} > 0$, so by taking $h > 0$ small we improve the objective satisfying the constraint, absurd. ■

Claim 15. *If (τ_1, s) is optimal then $\tau_1 \leqslant \lambda$.*

Proof. Suppose that $\tau_1 > \lambda$, so $\tau_2 = \tau_1$. If $s > 0$ and $\frac{\partial P}{\partial s} < 0$ then we can decrease s, keeping $P \geqslant 0$ and improving the objective, absurd. Hence, either $s = 0$ or $\frac{\partial P}{\partial s} \geqslant 0$. Now, $\frac{\partial P}{\partial s} = \frac{4}{\delta A}(s - \bar{s})$ with $\bar{s} = \frac{\delta}{4}(A - 4\tau_1 + 3\tau_1^2 + 2(1 - \tau_1)\lambda) < \frac{\delta}{4}(A - (2 - \tau_1)\tau_1)$, so $\frac{\partial P}{\partial s} \geqslant 0$ implies $s \leqslant \frac{\delta}{4}(A - (2 - \tau_1)\tau_1)$.

Let $D = \frac{\partial \Delta W}{\partial \tau_1}\frac{\partial P}{\partial s} - \frac{\partial \Delta W}{\partial s}\frac{\partial P}{\partial \tau_1}$. I will show that $D < 0$. We have that D is linear in λ and b_1, so it's enough to show that $D < 0$ for $(\lambda, b_1) \in \{0, \tau_1\} \times \{\max\{\frac{1}{A}, \frac{1}{2}\}, \frac{1}{1+\lambda}\}$. We can verify this using Mathematica. ■