Optimal trajectory of carbon pricing under a public-support constraint and opinion dynamics

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Abstract

This paper develops an analytical model to determine the optimal trajectory of carbon taxation under a carbon budget and a public-support constraint. Public support is modeled as an endogenous state variable, determined by tax levels and opinion dynamics. We find that the optimal tax path depends on the marginal sensitivities of public support and emissions to tax changes as well as on the characteristics of opinion dynamics. In particular, under conformist opinion dynamics, a low initial tax can generate strong public support, in turn triggering positive feedback that allows for subsequent tax increases. In contrast, when opinion dynamics are non-conformist, a flatter tax is preferable.

Keywords: climate change, mitigation policy, public support, opinion dynamics, policy acceptability, carbon taxation.

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1. Introduction

Building support for climate policies is key to ensuring their successful implementation. Opposition - whether expressed through electoral channels, as in the 2021 Swiss referendum that rejected a carbon price increase (Mildenberger et al., 2022), or via social movements, such as the Yellow Vests in France (Douenne and Fabre, 2022) - can impede the introduction and strengthening of policies, or may even lead to their discontinuation. Empirical research indicates that support for climate policies is shaped not only by their perceived impact on welfare, environment and equity (Drews and van den Bergh, 2016), but also by complex opinion dynamics, including social influence, political coalitions (Isley et al., 2015), and lobbying activities (Lackner et al., 2024).

Several recent modeling studies have explored the relationship between policy impacts and public support to understand how to create and maintain consistent public support for climate policies over time (Di Benedetto et al., 2025; Konc et al., 2022; Lackner et al., 2024; Lipari et al., 2024; Moore et al., 2022; Sordi and Dávila-Fernández, 2023). However, these studies rely primarily on numerical analysis, which limits the generality of their findings. This indicates the need for theoretical analyses of the co-dynamics of climate policy impacts and public support.

Analytical models of the optimal trajectory of carbon pricing over time typically neglect political or social constraints, such as public support. They build upon the Hotelling rule (Hotelling, 1931), which states that the optimal price of a non-renewable resource should rise over time at the discount rate. In the context of climate policy, this implies that the optimal carbon price should grow over time at the discount rate to ensure an optimal intertemporal welfare trade-off between mitigating emissions today and in the future (Nordhaus, 1991). Recent contributions show that environmental tipping points (Lemoine and Traeger, 2014; Cai et al., 2015), inertia in some sectors (Vogt-Schilb et al., 2018), fiscal distortions (Barrage, 2020), or fossil-fuel market responses to climate policies (Jensen et al., 2015) can differentiate optimal carbon price trajectories from the Hotelling rule. In particular, van der Ploeg and Withagen (2015) show that a steeply rising carbon tax may cause fossil fuel producers to accelerate extraction in anticipation of future reduced profits — an effect known as the Green Paradox — implying that the optimal tax should instead start higher and rise less rapidly. Surprisingly, political-economy constraints such as minimum public support are disregarded in theoretical modeling studies.

Here, we develop an analytical framework to study the optimal dynamics of carbon pricing under constraints of a carbon budget and minimal public support. Section 2 introduces the model. Section 3 derives the optimal carbon price trajectory. Section 4 explores the dynamics of the second-best optimal tax. Section 5 studies the role of opinion dynamics. Section 6 presents a numerical example to provide further insights. Section 7 concludes.

2. The model

Social planner

A social planner seeks to identify the path that maximises social welfare while limiting global warming by keeping emissions within a budget B. The setting is in continuous time, with a finite-horizon planning period $[0, T]$, reflecting real-world policy approaches such as France's Stratégie Nationale Bas-Carbone, which sets binding carbon budgets over defined time periods. The policymaker sets a dynamic carbon tax $\tau(t) \geq 0$ that affects the level of emissions $e(\tau(t))$ and households' utility $U(\tau(t))$. Functions e and U are both positive and non-increasing in the tax: $\forall \tau(t),\ \ e(\tau(t)) \geq 0$, $e'(\tau(t)) < 0$, $e''(\tau(t)) \geq 0$, $U(\tau(t)) \geq 0$, $U'(\tau(t)) \leq 0$.

Cumulative GHG emissions $M(t)$ at time t increase through net instantaneous emissions $e(\tau(t))$ and decrease through available options for carbon dioxide removal or "negative emissions" captured by exogenous parameter ϵ_{ref}:

$$\dot{M}(t) = e(\tau(t)) - \epsilon_{ref} \tag{1}$$

where dot notation indicates a time derivative.

To get or maintain the policy implemented, the policymaker has to ensure that public support by the population $S(t)$ is at each time above a certain threshold $\bar{S}$. We represent public support dynamics by a function $h(S(t), \tau(t))$, which reflects that changes in public support depend on the current level of public support (Levi et al., 2023), and on the stringency of climate policies (Goerg et al., 2025).

$$\dot{S}(t) = h(S(t), \tau(t)) \tag{2}$$

We assume that $h_\tau(S(t), \tau(t)) = \frac{\partial h(S(t),\tau(t))}{\partial \tau(t)} < 0$ and $h_{\tau\tau}(S(t), \tau(t)) = \frac{\partial^2 h(S(t),\tau(t))}{\partial \tau(t)^2} \geq 0$. Indeed, carbon taxes typically face declining public support as the tax rate increases, as higher tax rates impose higher costs on individuals, reducing their support for the policy (Carattini et al., 2018). We additionally assume that the marginal negative impact on support diminishes with increasing tax rates, in line with the idea of diminishing sensitivity to losses of the prospect theory (Tversky and Kahneman, 1992): individuals tend to react strongly to small taxes but become less responsive to further increases.

We similarly define $h_S(S(t), \tau(t)) = \frac{\partial h(S(t),\tau(t))}{\partial S(t)}$ and $h_{SS}(t) = \frac{\partial^2 h(S(t),\tau(t))}{\partial S(t)^2}$, the signs of which are unconstrained allowing for both positive and negative feedback in public support dynamics. While $U(\tau(t))$ captures only the direct welfare effect of the tax, $S(t)$ reflects the broader perception of the policy, including its perceived environmental benefits. For the sake of generality, the support dynamics function h is not explicitly specified in terms of the tax's environmental effectiveness or its welfare impacts. Finally, the initial levels of cumulative emissions $M(0) = M_0$ and public support $S(0) = S_0$ (such that $S_0 \geq \bar{S}$) are given.

The social planner selects a carbon-pricing trajectory in order to maximise the net present value of household utility over time:

$$\max_{\tau(t)} \int_0^T e^{-r(t)} U(\tau(t)) dt \tag{3}$$

subject to equations 1 and 2, $M(t) \leq B$, $S(t) \geq \bar{S}$, $M(0) = M_0$ and $S(0) = S_0$.

Households

We analyze a single representative household to derive utility $U(\tau(t))$ and emissions $e(\tau(t))$ at time t. The representative household maximizes its welfare at each time t, taking the tax $\tau(t)$ as given. It consumes a polluting ("dirty") good D at a price $p_D + \tau(t)$, a clean good C at a price p_C, and derives utility from these goods and leisure time $(1 - L)$ with L denoting labour time. Here, p_C, p_D, and wages ω are exogenous. Utility maximisation of a Cobb-Douglas function subject to a budget constraint is then:

$$\max_{C,D,L} U = D^\alpha C^\beta (1 - L)^{1-\alpha-\beta} \text{ such that } D(p_D + \tau(t)) + C p_C \leq \omega L \tag{4}$$

First order conditions lead to optimal demands $D = \frac{\alpha\omega}{p_D + \tau(t)}$ and $C = \frac{\beta\omega}{p_C}$. With κ noting the carbon intensity of D, we can then derive household emissions (equation 5) and optimal utility (equation 6):

$$e(\tau(t)) = \kappa D = \frac{\kappa\alpha w}{p_D + \tau(t)} \tag{5}$$

$$U(\tau(t)) = \beta^\beta \alpha^\alpha (1 - \beta - \alpha)^{1-\beta-\alpha} w^{\alpha+\beta} (\frac{1}{p_C})^\beta (\frac{1}{p_D + \tau(t)})^\alpha \tag{6}$$

The carbon tax $\tau(t)$ influences household consumption by making D relatively more expensive than C, inducing substitution toward the clean good. It does not alter the inherent carbon intensity of D, which remains κ.

3. Optimal climate policy under the two contraints

The social planner's problem (equation 3) is an optimal control theory problem with two pure state constraints, i.e. constraints that only involve state variables $M(t)$ and $S(t)$ and not the control variable $\tau(t)$: $M(t) \leq B$ and $S(t) \geq \bar{S}$. There are two ways of handling such constraints: namely, through a direct and an indirect approach (Lemoine and Rudik, 2017).

We first use the direct approach to solve for the optimal dynamic carbon tax. We write the Hamiltonian and Lagrangian with multipliers associated with the carbon budget and public-support constraints:

$$H(\tau(t), M(t), S(t)) = e^{-rt}U(\tau(t)) + \lambda_M(t)(\epsilon_{ref} - e(\tau(t))) + \lambda_S(t)h(S(t), \tau(t)) \quad (7)$$

$$L(\tau(t), M(t), S(t)) = H(\tau(t), M(t), S(t)) + \phi_M(t)(B - M(t)) + \phi_S(t)(S(t) - \bar{S}) \quad (8)$$

Here, $\lambda_M(t)$ and $\lambda_S(t)$ are the co-state variables, which can be interpreted as the shadow cost of emissions and of maintaining public support, respectively. Variables $\phi_M(t)$ and $\phi_S(t)$ are the Lagrange multipliers associated with the carbon budget constraint and public support threshold, respectively. The first-order conditions are:

$$\frac{\partial L}{\partial \tau(t)} = 0 \Rightarrow e^{-rt}U'(\tau(t)) = \lambda_M(t)e'(\tau(t)) - \lambda_S(t)h_\tau(S(t), \tau(t)) \quad (9)$$

$$\frac{\partial L}{\partial M(t)} = -\dot{\lambda}_M(t) \Rightarrow \dot{\lambda}_M(t) = \phi_M(t) \quad (10)$$

$$\frac{\partial L}{\partial S(t)} = -\dot{\lambda}_S(t) \Rightarrow \dot{\lambda}_S(t) = -\lambda_S(t)h_S(S(t), \tau(t)) - \phi_S(t) \quad (11)$$

Complementary slackness condition:

$$\forall t, \phi_M(t)(B - M(t)) = 0 \quad (12)$$

The carbon budget B is reached at date T. Before T, as $M(t) < B$, $\phi_M(t) = 0$. From equation 10, $\dot{\lambda}_M(t) = 0$ implying that the shadow cost of emissions $\lambda_M(t) = \lambda_M$

is constant over time.

The second complementary slackness condition is:

$$\forall t, \phi_S(t)(S(t) - \bar{S}) = 0 \tag{13}$$

When the public-support constraint is binding, $\phi_S(t) > 0$; otherwise, $\phi_S(t) = 0$.

From equations 11 and 13, it follows that the shadow cost of public support $\lambda_S(t)$ is discontinuous and "jumps":

- at entry time and exit time (Sethi, 2021) of "boundary intervals", i.e. intervals on which the optimal trajectory hits the boundary $S(t) = \bar{S}$.

- or, if the trajectory just touches the boundary at one "contact time" (i.e. $S(t) = \bar{S}$ and $\phi_S(t) \geq 0$ at that contact time, but $S(t) > \bar{S}$ and $\phi_S(t) = 0$ before and after), then $\lambda_S(t)$ "jumps" at that contact time (Sethi, 2021).

From equation 9, we have:

$$\frac{U'(\tau(t))}{e'(\tau(t))} = e^{rt}\left(\lambda_M - \lambda_S(t)\frac{h_\tau(S(t), \tau(t))}{e'(\tau(t))}\right) \tag{14}$$

Using equations 5 and 6 to derive $U'(\tau(t))$ and $e'(\tau(t))$, and defining constant $A = \frac{\beta^\beta \alpha^\alpha (1-\alpha-\beta)^{1-\alpha-\beta}}{p_C^\beta \kappa \omega^{1-\alpha-\beta}}$, this can be rewritten as:

$$A(p_D + \tau(t))^{1-\alpha} = e^{rt}\left(\lambda_M - \lambda_S(t)\frac{h_\tau(S(t), \tau(t))}{e'(\tau(t))}\right) \tag{15}$$

From equation 15, in the first-best case (i.e. in the absence of a public-support constraint, with $\lambda_S(t) = 0\ \forall t$), denoting the optimal carbon tax in this case by *, we have:

$$A(p_D + \tau^*(t))^{1-\alpha} = e^{rt}\lambda_M^* \tag{16}$$

implying that the optimal tax grows at a constant rate determined by the social discount rate, following the standard Hotelling rule (Hotelling, 1931; Nordhaus, 1991), and by households' preference for polluting goods.

By contrast, in the second-best case (equation 15), the Hotelling rule is modified: the tax increases with the social discount rate and the shadow cost of emissions, adjusted by the shadow cost of maintaining public support.

Next, we use the indirect approach to derive additional results regarding what happens when the public-support constraint is binding. The main idea underlying the indirect method is that when a pure state constraint becomes active, its first derivative must be nonnegative to make sure that the constraint is not exceeded (Sethi, 2021). In our case, if the public support constraint is met at time t^* (i.e if $S(t^*) = \bar{S}$), it means that we need to keep $\dot{S}(t^*) \geq 0$ to ensure that the public support constraint remains satisfied. This has two implications:

- There is at most one "boundary interval", which is located at the end of the period. Indeed, assuming that a boundary interval starts at time t^*, then $S(t^*) = \bar{S}$ and $\dot{S}(t^*) = 0$. Therefore, $h(\bar{S}, \tau(t)) = 0$, and since $h_\tau(S(t), \tau(t)) < 0$, the carbon tax remains constant between t^* and T.
- If the public support constraint is met at time t^* (i.e if $S(t^*) = \bar{S}$), then we need to keep $\dot{S}(t^*) \geq 0$ to ensure that the public support constraint is met. It means that only taxes $\tau(t^*)$ such that $h(\bar{S}, \tau(t^*)) \geq 0$ are possible. If all such taxes lead to the carbon budget being exceeded, then a solution is infeasible.

4. Dynamics of the second-best tax

We aim at analysing the dynamics of the carbon tax in the second-best case. For simplicity, we restrict this analysis to intervals where the public support constraint is not binding, i.e. where $S(t) > S^*$. This simplification is possible because, as discussed in section 3, the constraint is only binding at isolated contact times or during a unique boundary interval at the end of the period. On such unconstrained intervals, we have

$\phi_S(t) = 0$, so that equation 11 simplifies to $\dot{\lambda}_S(t) = -\lambda_S(t) h_S(S(t), \tau(t))$. To simplify the notations, we denote $h_\tau(S(t), \tau(t))$, $h_{\tau\tau}(S(t), \tau(t))$, $h_S(S(t), \tau(t))$, $h_{SS}(S(t), \tau(t))$, $e'(\tau(t))$ and $e''(\tau(t))$ by h_τ, $h_{\tau\tau}$, h_S, h_{SS}, e' and e''.

Differentiating equation 15, we have:

$$
\begin{aligned}
&\frac{A(1-\alpha)\dot{\tau}(t)}{(p_D + \tau_t)^\alpha} = re^{rt}\left(\lambda_M - \lambda_S(t)\frac{h_\tau}{e'}\right) + e^{rt}\left(\frac{\partial\left(-\lambda_S(t)\frac{h_\tau}{e'}\right)}{\partial t}\right) \\
\Leftrightarrow\ &\frac{A(1-\alpha)\dot{\tau}(t)}{e^{rt}(p_D + \tau(t))^\alpha} = r\left(\lambda_M - \lambda_S(t)\frac{h_\tau}{e'}\right) + \lambda_S(t)\frac{h_\tau}{e'}\left(-\dot{\tau}(t)\frac{h_{\tau\tau}}{h_\tau} + \dot{\tau}(t)\frac{e''}{e'} + h_S\right)
\end{aligned}
\tag{17}
$$

Collecting all the $\dot{\tau}(t)$ terms and solving gives:

$$
\dot{\tau}(t) \ = \ \frac{r\left(\lambda_M - \lambda_S(t)\frac{h_\tau}{e'}\right) \ + \ \lambda_S(t)\frac{h_\tau}{e'}\, h_S}{\frac{A(1-\alpha)}{e^{rt}(p_D + \tau(t))^\alpha} \ + \ \lambda_S(t)\frac{h_\tau}{e'}\left(\frac{h_{\tau\tau}}{h_\tau} - \frac{e''}{e'}\right)}
\tag{18}
$$

The right-hand side of equation 18 can be interpreted as follows:

- $r(\lambda_M - \lambda_S(t)\frac{h_\tau}{e'})$ corresponds to a *modified Hotelling rule*, where the tax increases with the social discount rate and the shadow cost of emissions, adjusted by the shadow cost of maintaining public support. It is generally positive (from equation 15, it is positive if $p_D + \tau(t)$ is).

- $h_S \lambda_S(t)\frac{h_\tau}{e'}$ captures *opinion dynamics*, i.e. how the evolution of public support depends on the current level of public support. As $\lambda_S(t)\frac{h_\tau}{e'}$ is positive, this term can be positive or negative depending on the sign of h_S. If $h_S \geq 0$, increasing public support triggers positive feedback, further increasing support. In this case, the optimal second-best tax starts low and then increases steeply: a low initial tax can generate high public support, in turn triggering positive feedback that enables later tax increases. If $h_S \leq 0$, high public support triggers negative feedback and decreases support. In this case, the optimal second-best tax is relatively flat or even decreasing: it should initially be high (and therefore, public support is initially low) to allow increases in support later on.

- The denominator term $\dfrac{A(1-\alpha)}{e^{rt}(p_D+\tau(t))^{\alpha}}$ is generally positive (if $p_D + \tau(t) > 0$) and decreases with r and $\tau(t)$. Therefore, the tax increases more steeply for high social discount rates r or tax levels $\tau(t)$, with precise effects depending on the household's utility function and budget constraints parameters α, β, p_C, and ω.

- The other term in the denominator, $\lambda_S(t)\frac{h_\tau}{e'}\left(\frac{h_{\tau\tau}}{h_\tau} - \frac{e''}{e'}\right)$ captures how changes in public support feedback into tax dynamics:

  - $\lambda_S(t)$, the shadow cost of public support, is positive. $\frac{h_\tau}{e'}$ is positive.

  - $\frac{h_{\tau\tau}}{h_\tau}$ captures *diminishing marginal opposition*, or diminishing marginal sensitivity of public support to tax increases: as the tax rises, each further increase causes less decline in public support. As $h_\tau < 0$ and $h_{\tau\tau} \geq 0$, it is negative, incentivizing steeper tax increases.

  - $-\frac{e''}{e'}$ captures the *diminishing marginal sensitivity of emissions* to tax increases: as the tax rises, emissions become less responsive. As $e' < 0$ and $e'' \geq 0$, it is negative, therefore pushing in favor of flatter taxes.

  - These terms can be interpreted jointly. If public support exhibits low diminishing marginal sensitivity to tax increases, while emissions exhibit stronger diminishing marginal sensitivity, then a flat, medium-level tax is optimal to maintain effectiveness. By contrast, if emissions exhibit low diminishing marginal sensitivity to tax increases, while public support exhibits stronger diminishing marginal sensitivity, then it is optimal to raise the tax in later periods, increasing emissions reductions while limiting the impact on support.

Among these terms, the role played by opinion dynamics h_S is the less straightforward. The next section therefore further explores opinion dynamics in detail.

5. The role of opinion dynamics

5.1. Specifying opinion dynamics

We study the dynamics of public opinion within the population, assuming that public support evolves as in equation 2, with the function h specified as:

$$\dot{S}(t) = h(S(t), \tau(t)) = g(S(t)) + f(\tau(t))[g(S(t)) - g(S(t))^2] - S(t) \tag{19}$$

with $f' \leq 0$ and $f'' \geq 0$ (and therefore $h'(\tau(t)) \leq 0$, $h''(\tau(t)) \geq 0$). This specification, inspired by Lipari et al. (2024), contains two elements:

- The function g captures peer-effect influence, or the contagion effect. Following Peralta et al. (2022), we assume that $g(x) = x^{\psi}$, with $\psi > 0$. Here, $\psi > 1$ represents "conformist" opinion dynamics (i.e. when an individual follows the opinion of the majority) and $\psi < 1$ denotes "non-conformist" opinion dynamics (i.e. when a small number of individuals has a large influence), as detailed in Table 1. Value $\psi = 1$ represents a case with no contagion effect.

- The second part $f(\tau(t))[g(S(t)) - g(S(t))^2]$ captures the impact of the policy on opinion dynamics. Here, $f(\tau(t)) \in [-1; 1]$ reflects the direct policy impact, and $[g(S(t)) - g(S(t))^2]$ the intensity of opinion polarization. The latter is largest when support is divided (i.e. $S(t)$ is around 0.5), and smallest when there is consensus (i.e. $S(t)$ close to 0 or 1). Consequently, the policy influences opinion dynamics more when opinions are contested and less when there is broad support or widespread opposition.[1]

The function in equation 19 ensures that $S(t)$ remains in $[0; 1]$ and can thus be interpreted as the share of citizens who support the policy. If $S = 0$ or $S = 1$, there

[1] In the particular case in which $f(\tau(t)) = 0\ \forall \tau(t)$, the public support trajectory is not influenced by the policy but fully determined by its level at $t = 0$. Here, $t = 0$ is a "contact time", and there is a "jump" in $\tau(t)$ and $\lambda_S(t)$ at $t = 0$.

Table 1: Conformist and non-conformist opinion dynamics

Type	Definition	Examples
Conformist ($\psi > 1$)	Individuals follow the opinion of the majority	– Perceived social norms are positively related to support for the renewable energy transition (Chan et al., 2022) – Social norms encourage pro-environmental behaviors (Cialdini and Jacobson, 2021)
Non-conformist ($\psi < 1$)	A small number of individuals holds a large influence	– Lobbyism influences climate policy (Vesa et al., 2020) – Opinion leaders encourage climate activism (Sabherwal et al., 2021) – Fossil fuel companies spread disinformation (Bonneuil et al., 2021)

is full consensus, either for or against the policy, and opinions are stable, meaning that $\dot{S} = 0$.

5.2. Analysis of the sign of $h_S(S(t), \tau(t))$

We analyse the sign of $h_S(S(t), \tau(t))$ in this case, i.e. how evolution of public support depend on the current level of public support. This will provide further insight into equation 17 determining policy dynamics. We study separately the first part of function h, i.e. expression $g(S(t)) - S(t)$, representing the contagion effect (we do this for the two cases of conformist and non-conformist opinion dynamics), and the second part, expression $f(\tau(t))[g(S(t)) - g(S(t))^2]$, capturing the policy impact.

Contagion effect - The case of conformism

In the case of conformism ($\psi > 1$):

$$\frac{\partial g(S(t)) - S(t)}{\partial S(t)} > 0 \Leftrightarrow \psi S(t)^{\psi-1} - 1 > 0 \Leftrightarrow S(t) > \psi^{\frac{1}{1-\psi}} \tag{20}$$

Therefore, if public support is above a certain threshold, the contagion effect has a positive impact on h_S, and therefore on the rate of increase of $\tau(t)$: it leads to the tax increasing over time. Indeed, starting with a low carbon tax allows for high levels of public support, which will allow to further increase public support due to conformist opinion dynamics, in turn permitting to raise the carbon tax.

However, if public support is below this threshold, the contagion effect causes a negative impact on h_S, and therefore on the rate of increase of $\tau(t)$: indeed, once public support is low, support will tend to decrease over time, not allowing to raise the tax.

Therefore, in line with the emerging literature on social tipping dynamics (Otto et al., 2020), $\psi^{\frac{1}{1-\psi}}$ can be interpreted as a tipping point in the dynamics of public support: public support must exceed $\psi^{\frac{1}{1-\psi}}$ for contagion to reinforce an increase of public support; below this level, contagion contributes to the decay of public support. We can notice that this threshold depends on ψ and is increasing with ψ: indeed, the more conformist are opinion dynamics, the more public support is needed to trigger positive feedback.

Contagion effect - The case of non-conformism

In the case of non-conformism ($\psi < 1$):

$$\frac{\partial g(S(t)) - S(t)}{\partial S(t)} > 0 \Leftrightarrow \psi S(t)^{\psi-1} - 1 > 0 \Leftrightarrow S(t) < \psi^{\frac{1}{1-\psi}} \tag{21}$$

Therefore, if public support is below a certain threshold, the non-conformism effect has a positive impact on h_S, and therefore on the rate of increase of $\tau(t)$. Indeed, below this threshold, non-conformist opinion dynamics will trigger further increases in public support, allowing for raising the tax. However, if public support is above this threshold, then the non-conformism effect negatively affect h_S, and therefore the rate of increase of $\tau(t)$.

Also here, $\psi^{\frac{1}{1-\psi}}$ can be interpreted as a tipping point in the dynamics of public support: public support must be below $\psi^{\frac{1}{1-\psi}}$ for contagion to reinforce support growth; above this level, contagion contributes to the decay of public support. The public support threshold $\psi^{\frac{1}{1-\psi}}$ depends on ψ and is increasing with ψ: the more non-conformist are opinion dynamics, the less public support is needed to trigger positive feedback.

If $\psi = 1$, then $g(S(t)) - S(t) = 0$, and $\frac{\partial g(S(t))-S(t)}{\partial S(t)} = 0$: there is no contagion effect that influences the tax dynamics.

Policy impact

Next, we continue analyzing the sign of $h_S(S(t), \tau(t))$ by looking at the second part of the function h, which captures that the policy has greater influence on opinion dynamics when opinions are more contested.

$$\frac{\partial f(\tau(t))(g(S(t)) - g(S(t))^2)}{\partial S(t)} > 0 \Leftrightarrow f(\tau(t))(\psi S(t)^{\psi-1} - 2\psi S(t)^{2\psi-1}) > 0 \quad (22)$$

Here, $f(\tau(t))$ captures the direct policy impacts on public support and can be positive or negative. We also have $\psi S(t)^{\psi-1} - 2\psi S(t)^{2\psi-1} > 0 \Leftrightarrow S(t) < 2^{-\frac{1}{\psi}}$.

Therefore, there are four possible cases:

- If $f(\tau(t)) \geq 0$ and $S(t) < 2^{-\frac{1}{\psi}}$: increasing public support strengthens opinion polarization, resulting in a higher weight $(g(S(t)) - g(S(t))^2)$ given to policy impacts $f(\tau(t)) \geq 0$. Therefore, $\frac{\partial f(\tau(t))(g(S(t))-g(S(t))^2)}{\partial S(t)} > 0$, meaning that this term has a positive impact on the rate of increase of the tax.

- If $f(\tau(t)) \leq 0$ and $S(t) < 2^{-\frac{1}{\psi}}$: increasing public support strengthens opinion polarization, resulting in a higher the weight $(g(S(t)) - g(S(t))^2)$ given to policy impacts $f(\tau(t)) \leq 0$. Therefore, $\frac{\partial f(\tau(t))(g(S(t))-g(S(t))^2)}{\partial S(t)} < 0$, meaning that this term has a negative impact on the rate of increase of the tax.

- If $f(\tau(t)) \geq 0$ and $S(t) > 2^{-\frac{1}{\psi}}$: increasing public support decreases opinion polarization, resulting in a lower weight $(g(S(t)) - g(S(t))^2)$ given to policy impacts $f(\tau(t)) \geq 0$. Therefore, $\frac{\partial f(\tau(t))(g(S(t))-g(S(t))^2)}{\partial S(t)} < 0$, meaning that this term has a negative impact on the rate of increase of the tax.

- If $f(\tau(t)) \leq 0$ and $S(t) > 2^{-\frac{1}{\psi}}$: increasing public support decreases opinion polarization, resulting in a lower weight $(g(S(t)) - g(S(t))^2)$ given to policy impacts $f(\tau(t)) \leq 0$. Therefore, $\frac{\partial f(\tau(t))(g(S(t))-g(S(t))^2)}{\partial S(t)} > 0$, meaning that this term has a positive impact on the rate of increase of the tax.

Synthesis

Substituting equation 19 in equation 18 gives:

$$\dot{\tau}(t) = \frac{r\left(\lambda_M - \lambda_S(t)\dfrac{h_\tau}{e'}\right) + \lambda_S(t)\dfrac{h_\tau}{e'}\left(\frac{\partial(g(S(t))-S(t))}{\partial S(t)} + \frac{\partial f(\tau(t))(g(S(t))-g(S(t))^2)}{\partial S(t)}\right)}{\dfrac{A(1-\alpha)}{e^{rt}(p_D+\tau(t))^\alpha} + \lambda_S(t)\dfrac{h_\tau}{e'}\left(\dfrac{h_{\tau\tau}}{h_\tau} - \dfrac{e''}{e'}\right)} \quad (23)$$

Table 2 summarizes the results of sections 4 and 5. It synthesizes the different elements of equation 23 and their impact on the slope of the tax.

Table 2: Factors determining the time pattern of carbon taxation, based on equation 23

Component	**Interpretation**	**Policy implications**
$r(\lambda_M - \lambda_S(t)\frac{h_\tau}{e'})$	Modified Hotelling rule	The tax should increase following the shadow cost of emissions, adjusted by the shadow cost of public support.
$\lambda_S(t)\frac{h_\tau}{e'}\frac{\partial(g(S(t))-S(t))}{\partial S}$	Contagion effect	Under conformist dynamics ($\psi > 1$), the tax should increase steeply if public support exceeds a threshold $\psi^{\frac{1}{1-\psi}}$. Under non-conformist opinion dynamics ($\psi < 1$), the tax should increase if public support is below the threshold $\psi^{\frac{1}{1-\psi}}$, as minority influencers impact support.
$\lambda_S(t)\frac{h_\tau}{e'}\frac{\partial f(\tau)(g(S(t))-g(S(t))^2)}{\partial S(t)}$	Amplification of policy impact by opinion polarization	Increasing support reinforces polarization, and therefore policy impact on support, up to a threshold.
$\dfrac{A(1-\alpha)}{e^{rt}(p_D+\tau(t))^\alpha}$	Denominator effect	Higher social discount rate r or tax $\tau(t)$ lead to steeper tax increase; precise effect depend on household's utility function and budget constraint parameters α, β, p_C, and ω.
$\lambda_S(t)\frac{h_\tau}{e'}(\frac{h_{\tau\tau}}{h_\tau})$	Diminishing marginal opposition	Encourages a steep increase of the tax, as support becomes less sensitive to higher taxes.
$-\lambda_S(t)\frac{h_\tau}{e'}(\frac{e''}{e'})$	Diminishing marginal sensitivity of emissions to tax increases	Encourages a flat tax, as emissions become less sensitive to higher taxes.

6. Numerical application

We propose numerical simulations of the optimal carbon tax under the public support dynamics specified in equation 19, using the Python package CasADi (Andersson et al., 2019) and the parameters listed in Appendix A. The minimal public support $\bar{S}$ is set at 0.5, reflecting the common threshold in parliamental decisions or citizen referenda where at least 50% of the votes must support a policy for it to be implemented or remain in effect. The other parameters are chosen so that:

- In the first-best case without the public support constraint, public support drops below the minimal threshold $\bar{S}$, ensuring that the optimal dynamic carbon taxes in the first and second-best cases differ and that, in the second-best case, the two constraints will be binding, at least at one point in time.
- A carbon taxation path exists that satisfies both the carbon budget and the minimal public support constraint.

Conformist opinion dynamics

Figure 1 illustrates the results of a simulation that compares paths of carbon taxation, public support, and cumulative emissions between the first and second-best cases, under conformist opinion dynamics. As the first-best carbon tax does not always maintain public support above the threshold $\bar{S} = 0.5$, the second-best carbon tax differs from the first-best one. It starts at a lower level in order to have higher initial public support, triggering positive opinion dynamics that ensure that public support remains sufficient over the entire period.

As initially the tax is lower in the second- than in the first-best case, cumulative emissions start increasing faster in the second-best case. However, once the carbon tax has become higher in the second- than in the first-best case, cumulative emissions increase at a slower pace in the second-best case, until the carbon budget B is reached at time T.

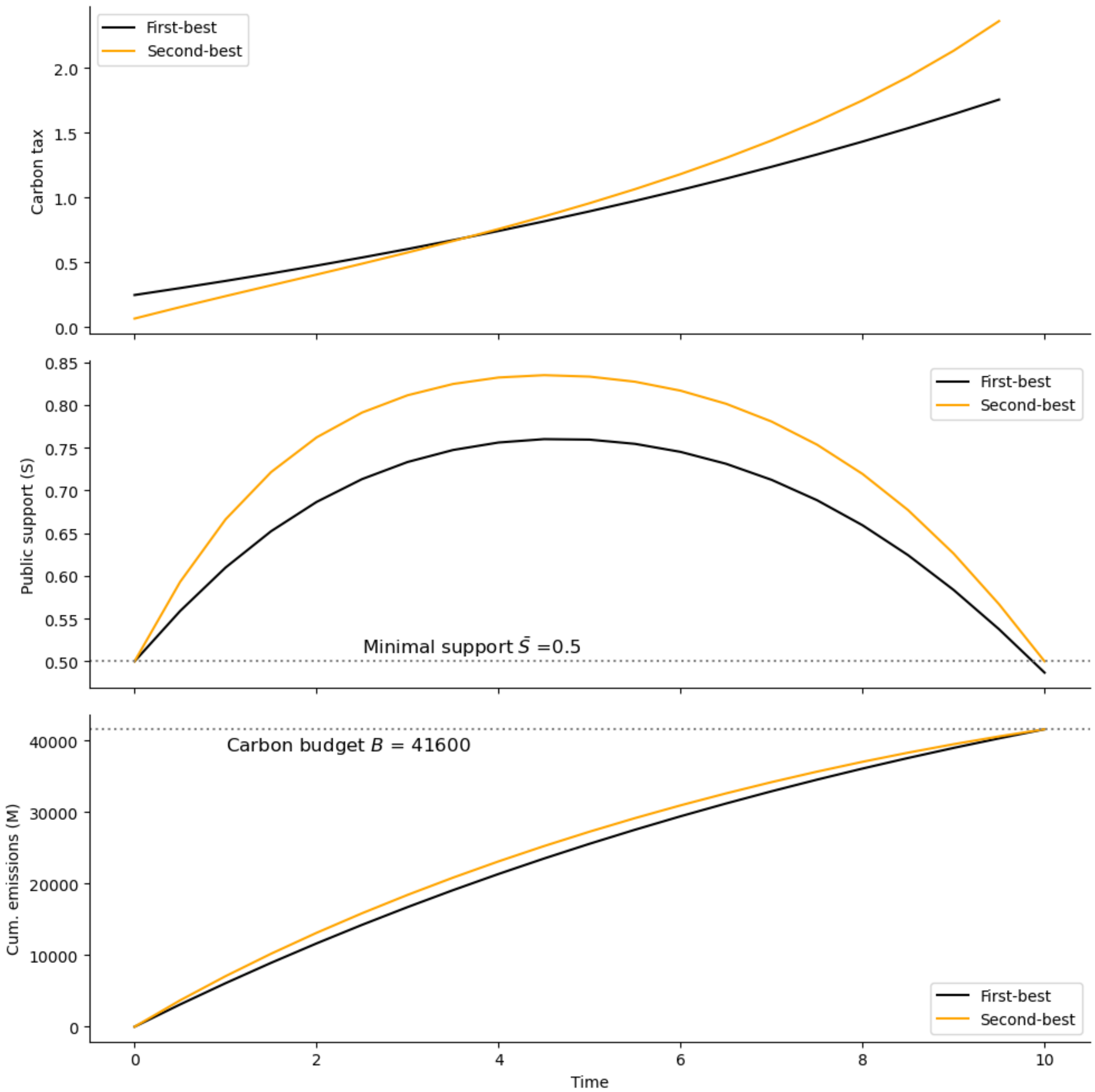


Figure 1: Numerical comparison of first- and second-best carbon taxes, public support and cumulative emissions under conformist opinion dynamics. Parameters are as follows: carbon budget $B = 41,600kgCO_2$, public support threshold $\bar{S} = 0.5$, opinion dynamics parameter $\psi = 1.1$.

Non-conformist opinion dynamics

Figure 2 illustrates the results of a simulation that compares paths of carbon taxation, public support, and cumulative emissions between the first and second-best cases, under non-conformist opinion dynamics. As the first-best carbon tax does not always maintain public support above the threshold $\bar{S} = 0.5$, the second-best carbon

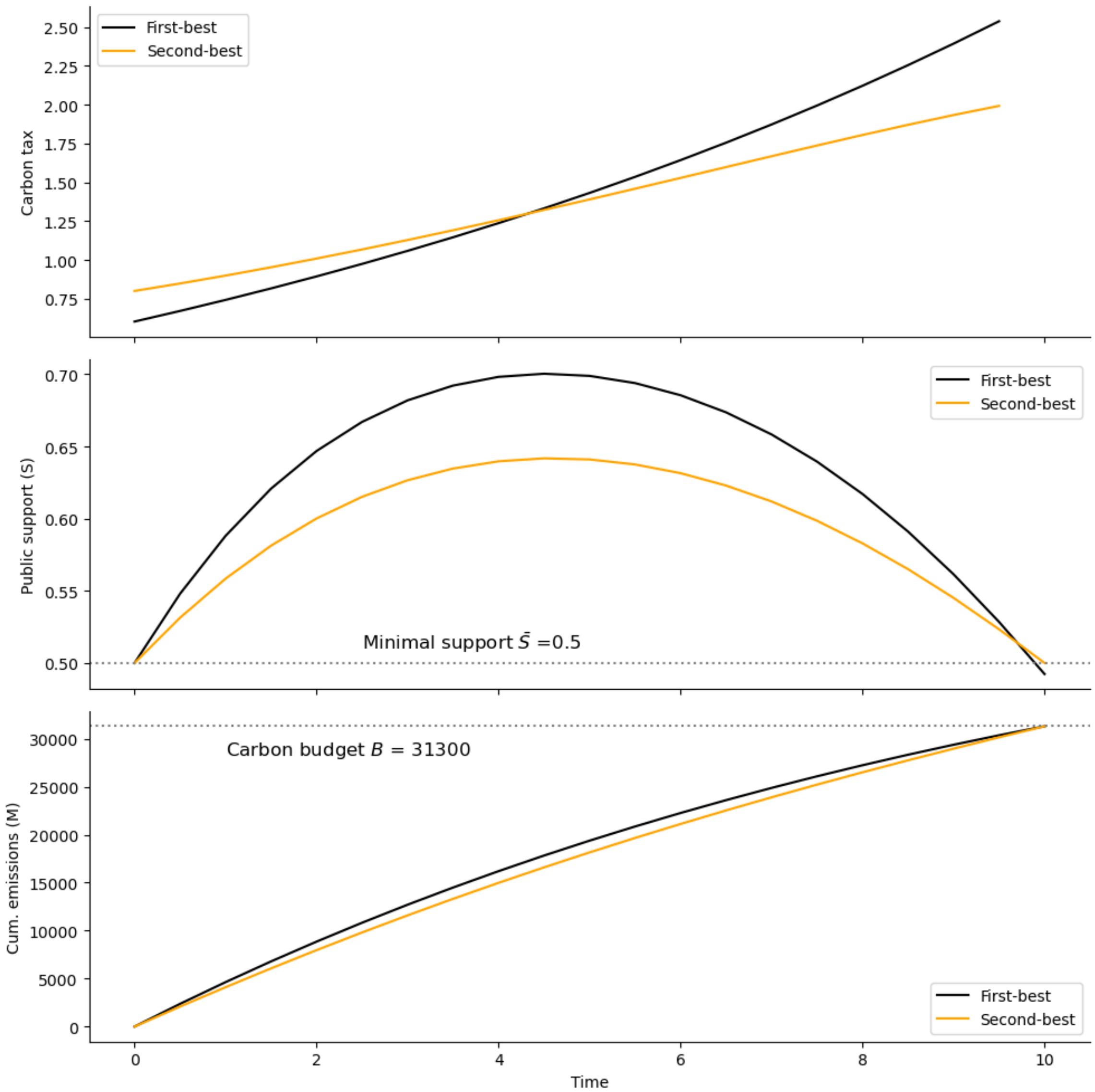


Figure 2: Numerical comparison of first- and second-best carbon taxes, public support and cumulative emissions under non-conformist opinion dynamics. Parameters are as follows: carbon budget $B = 31,300kgCO_2$, public support threshold $\bar{S} = 0.5$, opinion dynamics parameter $\psi = 0.9$.

tax differs from the first-best one. Here, contrary to the case of conformist opinion dynamics, the tax starts at a higher level but increases at a lower rate. This allows public support to remain relatively low over the period, never exceeding 65% (but also remaining above the 50% threshold).

Sensitivity analysis

Opinion dynamics parameter ψ: We compare the first- with the second-best carbon tax for $\psi \in [1.1, 1.105, 1.11]$, with $\psi = 1.11$ representing more conformist opinion dynamics than $\psi = 1.1$ or $\psi = 1.105$. Figure 3a compare the second-best carbon taxes in these three cases, while Figure B.4 in Appendix B also shows the evolution of public support and cumulative emissions in these three cases.

We find that the more conformist is the opinion dynamics, the longer the tax remains at a low level. This gives more time to build up public support, which in turn reinforces itself over time and enables future tax increases.[2] This illustrates the contagion effect, as described in table 2. The higher the ψ, the stronger is this effect[3].

Emissions function e: Next, we explore the sensitivity of the results to the emissions function. We set $e(\tau(t)) = \frac{\kappa \alpha w}{(p_D + \tau(t))^{\zeta}}$ and explore the sensitivity of the results to parameter ζ. Figure 3b compare the second-best carbon taxes in these three cases, while Figure B.5 in Appendix B also shows the evolution of public support and cumulative emissions in these three cases.

We find that the higher is the parameter ζ, the flatter is the optimal tax, due to the lower marginal sensitivity of emissions to increases in the tax (see table 2), which makes it less worth to steeply increase the tax at later stages[4].

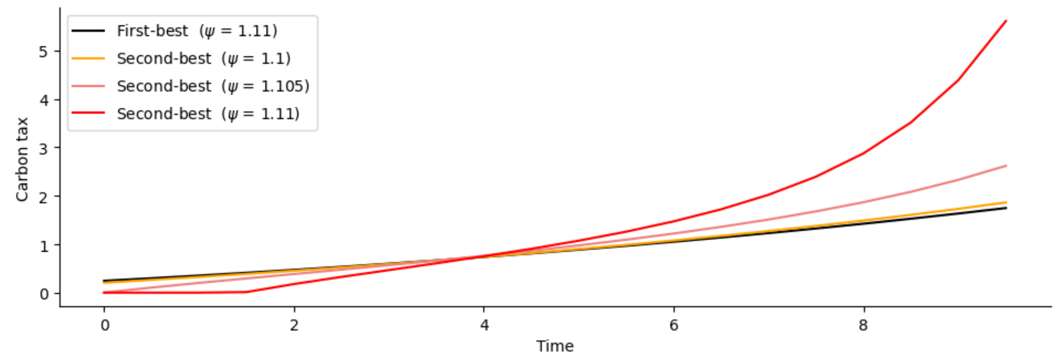
Policy impact function f: Next, we explore the sensitivity of the result to the policy impact function. We set $f(\tau(t)) = \frac{2}{(\tau(t)+1)^{\theta}} - 1$ and explore the sensitivity of the results to parameter θ. Figure 3c compare the second-best carbon taxes in these three

[2]We observe some non-smooth changes in the early part of the curve in the second-best cases. This arises because the tax is constrained to be non-negative.

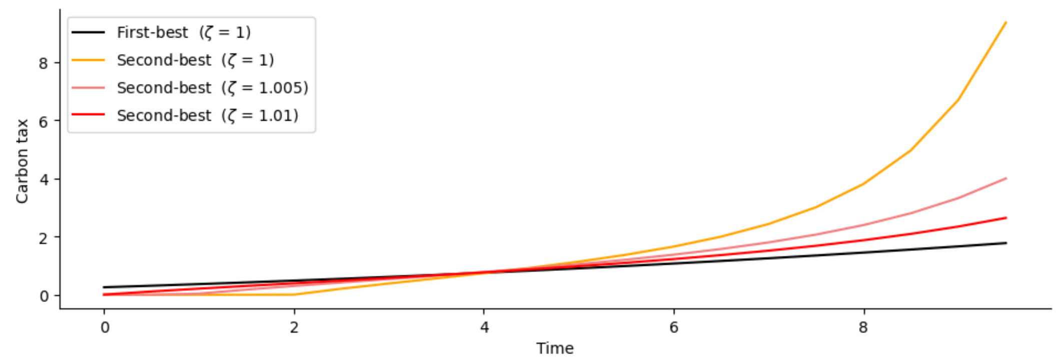
[3]Formally, the contagion effect is equal to $\psi S(t)^{\psi-1} - 1$. Its derivative with respect to ψ is $\frac{\partial \psi S(t)^{\psi-1} - 1}{\partial \psi} = S(t)^{\psi-1}(1 + \psi ln(S(t))$, which is positive for $\psi < \frac{-1}{ln(S(t))}$, which is verified here given that $S(t) > \bar{S}$ and $\psi < \frac{-1}{\ln(\bar{S})}$.

[4]Formally, the diminishing marginal sensitivity of emissions to a tax increase is equal to $\dot{\tau}(t)\frac{e''}{e'} = -\dot{\tau}(t)\frac{\zeta+1}{p_D+\tau(t)}$, which is decreasing in ζ.

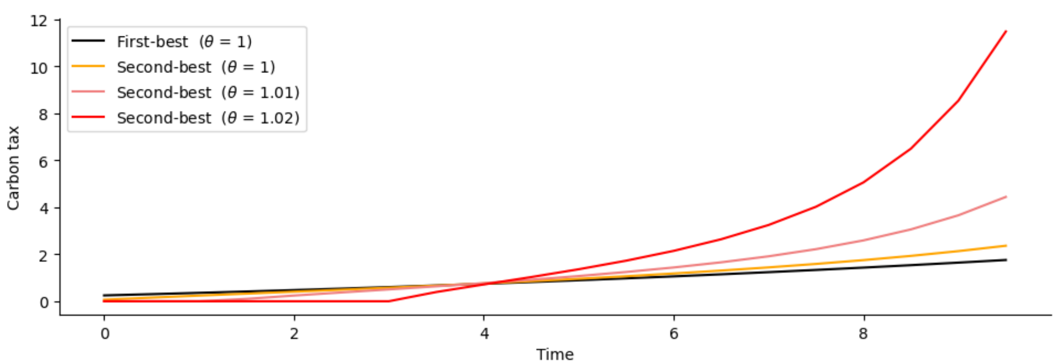
cases, while Figure B.6 in Appendix B also shows the evolution of public support and cumulative emissions in these three cases.



(a) Sensitivity analysis of ψ (opinion dynamics parameter). Parameters are as follows: carbon budget $B = 41,750 kgCO_2$ and support threshold $S = 0.5$.



(b) Sensitivity analysis of ζ (emissions–price elasticity parameter). Parameters are as follows: carbon budget $B = 41,300 kgCO_2$ and support threshold $S = 0.5$.



(c) Sensitivity analysis of θ (policy impact on opinions parameter). Parameters are as follows: carbon budget $B = 41,600 kgCO_2$ and support threshold $S = 0.5$.

Figure 3: Sensitivity analyses of optimal carbon tax trajectories.
Note: The remaining carbon budget varies depending on the simulations, in order to ensure that, in the first-best case, the public support drops below $\bar{S}$*, and that a second-best carbon tax path exists that satisfies both the carbon budget and the minimal public support constraint.*

We find that the higher is the parameter θ, the steeper is the increase of the optimal tax, due to the lower marginal sensitivity of policy impact on public support to increases in the tax (see table 2), which makes it logical to increase the tax more at later stages[5,6].

7. Conclusion

In this paper, we formally analyzed how introducing a public-support constraint affects the optimal trajectory of carbon pricing. We showed that the dynamics of the carbon tax in the second-best case depend on three main factors: (i) a modified Hotelling rule, adjusted for the shadow cost of public support, (ii) the marginal sensitivity of public support to tax increases relative to the marginal sensitivity of emissions to tax increases, and (iii) the nature of opinion dynamics, i.e. how changes in the current level of public support influence its future evolution.

Opinion dynamics affects public support through two mechanisms. First, we have the contagion effect: under conformist dynamics, the optimal tax should start low to generate public support that will trigger further increases in support, allowing for the tax to rise later. In contrast, under non-conformist opinion dynamics, a medium-level flat tax is preferred. The second mechanism is through the policy impact: the same tax can boost public support when opinions are polarized.

The results underscore the need to account for the dynamics of public support in the design of climate policy. Achieving stable support over time may require adjusting policy stringency in the short term to trigger opinion dynamics that will ensure long-term acceptability. Understanding the broader context of opinion dynamics, notably social norms or the influence of key opinion leaders, can help identify acceptability challenges and tailor policies accordingly.

[5] Formally, the diminishing marginal sensitivity of public support to tax increases is now equal to $-\dot{\tau}(t)\frac{h_{\tau\tau}}{h_{\tau}} = \dot{\tau}(t)\frac{\theta+1}{\tau(t)+1}$, which is increasing with θ.

[6] Note that, in this section, we have not computed the full derivative of the increase rate of the tax with respect to ψ, ζ, and θ because of tractability reasons.

Our study provides a theoretical framework to interpret and explain different results from the existing literature on co-dynamics of public support and climate policy. For instance, Konc et al. (2022) find that a gradual tax enhances acceptability, while Lackner et al. (2024) suggest that an early, ambitious carbon tax is preferable. Our framework suggests that this divergence partly stems from distinct assumptions about opinion dynamics: Konc et al. (2022) model a peer effect that is consistent with conformist opinion dynamics, whereas Lackner et al. (2024) emphasize lobbying by a few influential agents, aligning with non-conformist dynamics. Our approach generalizes these previous studies by addressing both types of opinion dynamics in a single framework and moreover obtaining analytical rather than only numerical results.

Further research could deepen the analysis of public support dynamics by explicitly accounting for population heterogeneity, notably across income groups and along the urban–rural divide. It could also incorporate the role of key stakeholders that influence policy feasibility, such as the media or lobby groups. In addition, alternative specifications of support dynamics could be explored, including asymmetric responses before and after policy implementation (Granulo et al., 2025). This would likely require a multi-stage modelling framework that distinguishes between policy preparation and implementation phases. Finally, it would be useful to empirically estimate the support dynamics function directly. This could then test whether, and to what extent, it varies across policy instruments.

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Appendix A. Parameter values for the numerical analysis

For generality, the parameter values used in the numerical analysis are expressed on a per capita and per year basis (see Table A.3):

- From the IPCC (2021), the remaining carbon budget is $300GtCO_2$ for a 83% probability of limiting global warming to 1.5°C and $400GtCO_2$ for a 67% probability of limiting global warming to 1.5°C: we set a carbon budget between these two values, chosen to ensure that, in the first-best case, the public support drops below $\bar{S}$, and that a second-best carbon tax path exists which satisfies both the carbon budget and the minimal public support constraint. From Fuss et al. (2018), the lower bound for negative emissions per year is about $4GtCO_2$. We translate both values at the per-capita level, assuming a world population of 8 billion.

- Without loss of generality, we assume that the price of both clean and polluting goods is 1€ and that the carbon intensity of polluting goods is 0.7, in line with Ivanova and Wood (2020) which finds that average EU carbon intensity is about 0.7 $kgCO_2eq$/€.

Table A.3: Parameter values for the numerical analysis of Section 6

Parameters and functions		**Value**	**Source or motivation**
T	Time horizon	10	Arbitrary without loss of generality
α	Share of polluting goods in utility	0.4	Konc et al. (2022)
β	Share of clean goods in utility	0.2	Konc et al. (2022)
κ	Carbon intensity of polluting goods	0.7 $kgCO_2$	Ivanova and Wood (2020)
w	Annual income per worker	30,000€	Eurostat[a]
p_D	Price of polluting goods	1€	Arbitrary without loss of generality
p_C	Price of clean goods	1€	Arbitrary without loss of generality
r	Social discount rate	0.05	Emmerling et al. (2019)
$\bar{S}$	Minimal public support threshold	0.5	Majority voting
B	Carbon budget per capita	41,600 $kgCO_2$[b]	IPCC (2021)
ϵ_{ref}	Yearly negative emission per capita	500 $kgCO_2$	Fuss et al. (2018)
$f(\tau(t))$	Direct policy impact on support	$\frac{2}{(\tau(t)+1)} - 1$	Decreasing and in $[-1, 1]$
S_0	Initial level of public support	0.5	Initial neutrality

[a] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Wages_and_labour_costs#Highlights

[b] The remaining carbon budget may vary depending on the simulation, in order to ensure that, in the first-best case, the public support drops below $\bar{S}$, and that a second-best carbon tax path exists that satisfies both the carbon budget and the minimal public support constraint.

Appendix B. Additional figures with sensitivity analysis

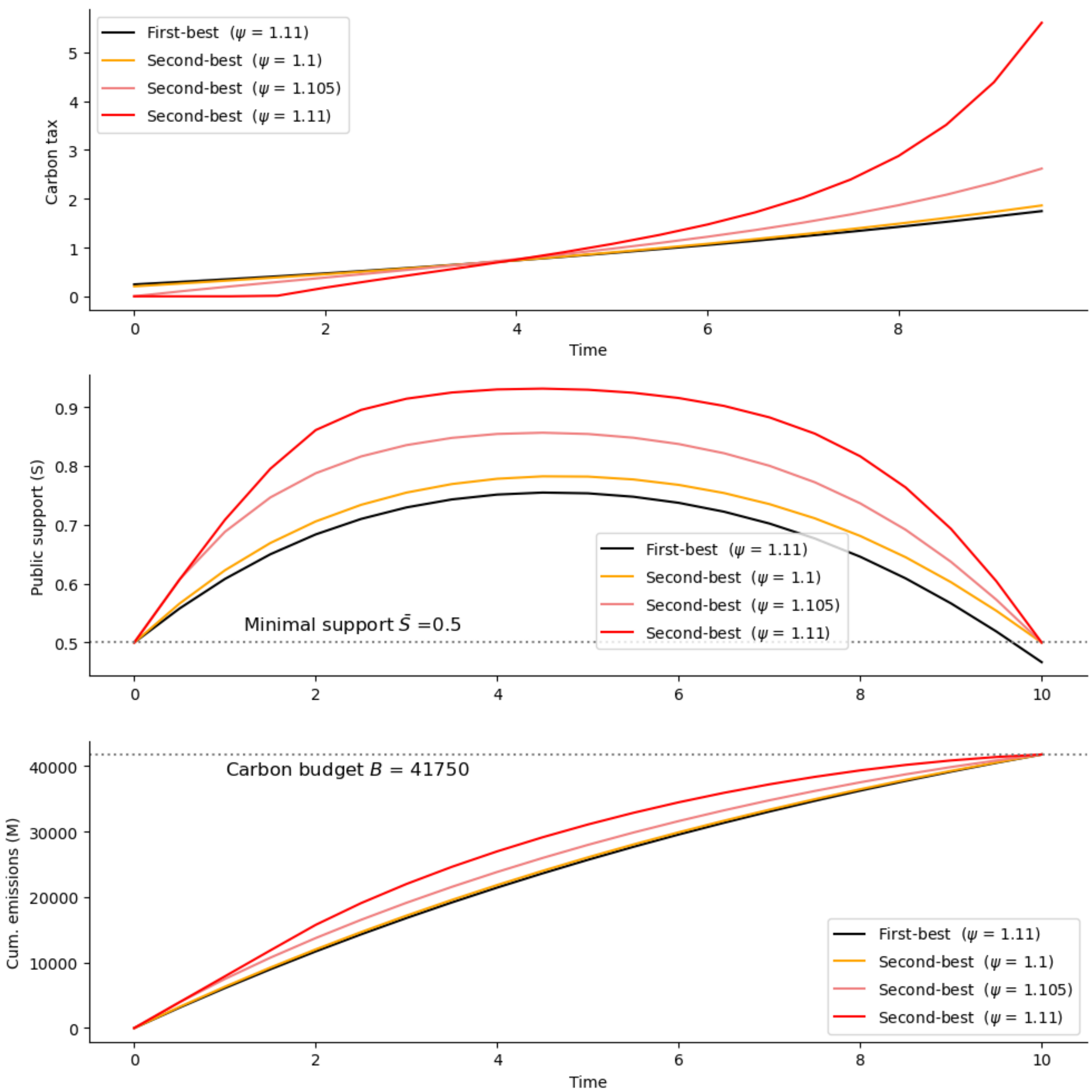

Figure B.4: Sensitivity analysis of parameter ψ. Parameters are as follows: carbon budget $B = 41,750kgCO_2$, public support threshold $S = 0.5$.

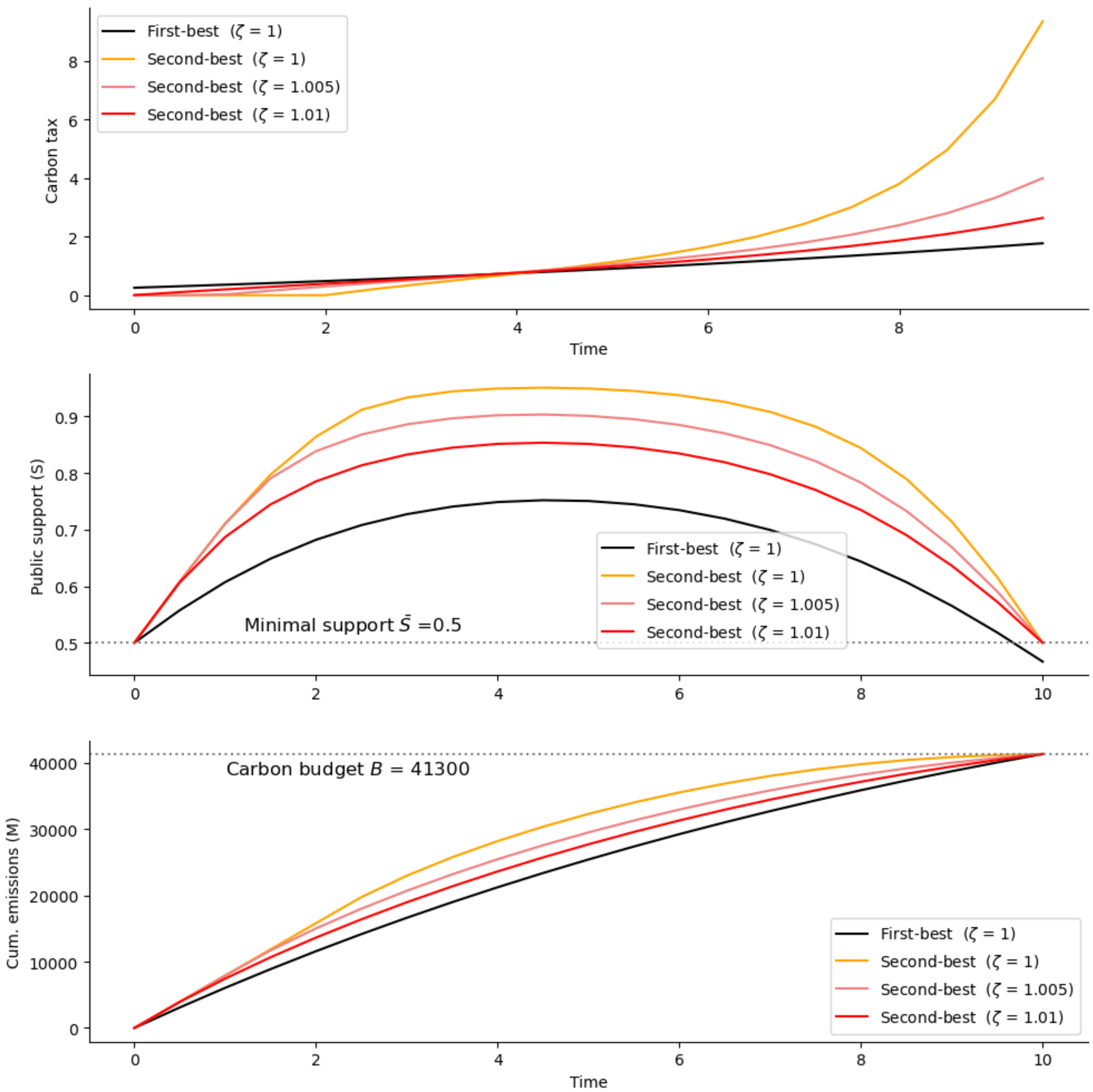

Figure B.5: Sensitivity analysis of parameter ζ. Parameters are as follows: carbon budget $B = 41,300kgCO_2$, public support threshold $S = 0.5$.

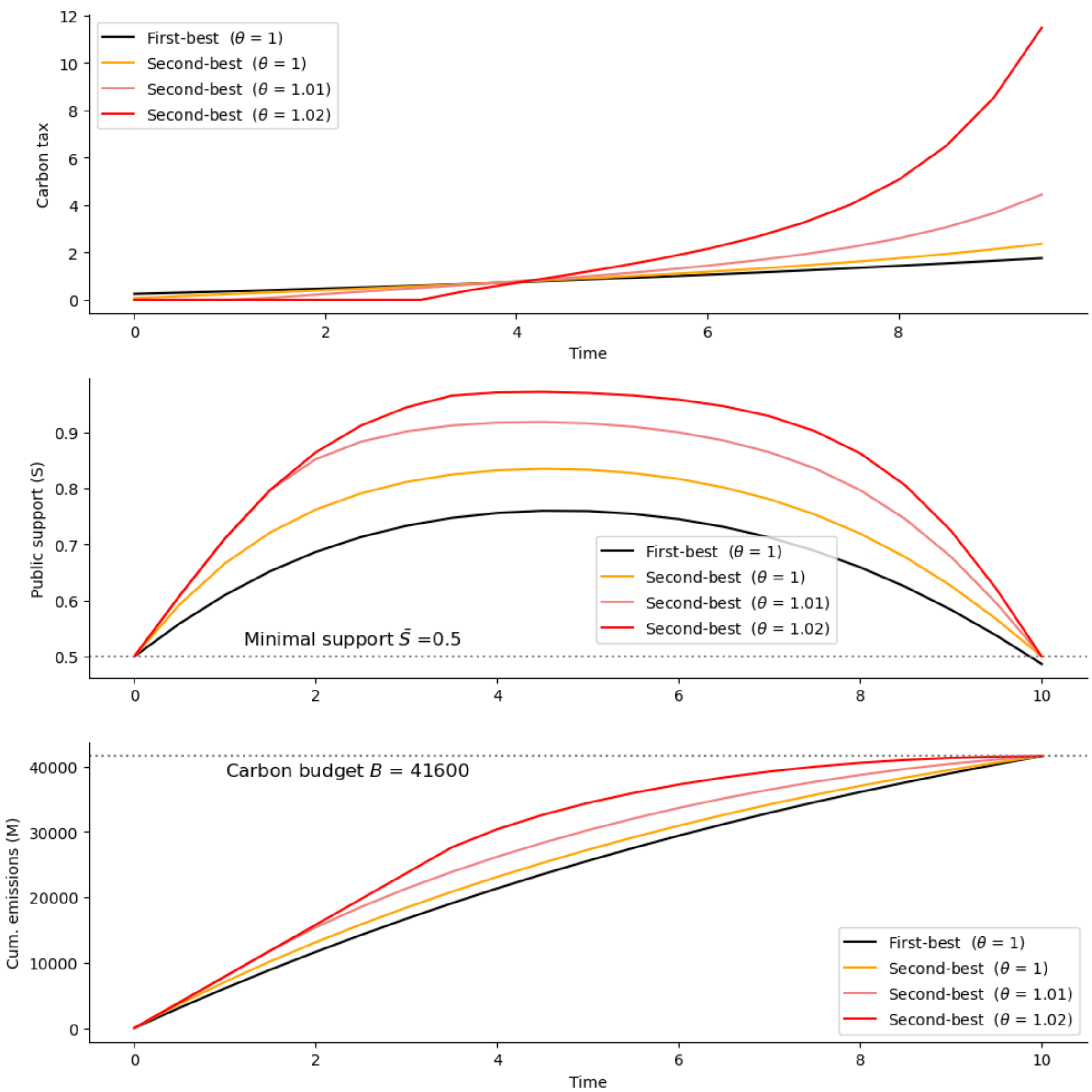

Figure B.6: Sensitivity analysis of parameter θ. Parameters are as follows: carbon budget $B = 41,600 kgCO_2$, public support threshold $S = 0.5$.