Role of Institutions in the Macroeconomics of Climate Change

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Abstract

This paper extends the model by Barrage (2020) and develops a theory that includes institutions in the felicity function, which is corroborated by a simulation exercise to address how institutional quality, together with macroeconomic policies, has direct effects on consumption, labor supply, and climate resilience, and its indirect impact on carbon taxation. Weak institutions exacerbate climate damages, necessitating a higher Pigouvian tax, which eventually has a dampening effect on economic growth. Strong institutions reduce the carbon tax needed to internalize welfare damages while boosting growth. Declining institutional quality necessitates higher taxes, which risks stagnation, highlighting the interplay between governance, climate policy, and economic outcomes. Modelling institutions in this paper shows that strong institutional quality brings carbon taxes closer to their Pigouvian benchmark, even when distortionary taxes are present. Under robust institutions, initial carbon taxes are 8–12% lower than in weak institutional settings, and the divergence between policies diminishes over time. In contrast, weak institutions create a persistent policy (Pigouvian vs optimal) gap of \$40–\$60/mtC. This divergence highlights how poor governance hinders the effectiveness of climate policy. The consumption gap between the strong-institution first-best scenario and the weak-institution second-best scenario widens from about \$3,000 in 2025 to nearly \$17,000 by 2250.

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1 Introduction

No longer a looming problem on the horizon, climate change now functions as an active economic force that is redefining growth patterns in countries worldwide (Parmesan et al., 2022). Some economies manage climate shocks with limited disruption, while others face persistent losses. What explains this divergence? The long-term economic trajectory of a country, particularly its ability to manage large-scale challenges such as climate change, is inextricably linked to the architecture of its political and economic institutions (Bulkeley, 2015). Institutions—through their influence on governance, incentives, and public capacity—determine whether climate risks translate into resilience or vulnerability. This paper examines the role institutions play in shaping the economic consequences of climate change, highlighting why institutional quality is a critical – and yet understudied – determinant of climate-economy dynamics.

This fundamental divide in governance gives rise to two institutional archetypes: *extractive institutions* and *inclusive institutions* (Acemoglu, 2005). The former is engineered to channel power and prosperity upwards, creating a perverse incentive structure for climate action. In such a system, elites often derive wealth from environmentally damaging activities and will logically resist policies that threaten their income streams, leaving the long-term environmental costs to be borne by the public. Conversely, an *inclusive* framework is a precondition for a robust climate response. It empowers the citizens to demand environmental quality, and by upholding the rule of law, establishes the stable, predictable policy environment essential to unlock the vast private capital needed for a green transition[1]. This reframes the climate challenge: it is not merely a technological problem, but also a fundamental challenge of governance and institutions. From this perspective, climate policies like carbon taxes are not neutral tools; there are institutions whose very adoption and design are forged in the arena of political power (Nightingale, 2017). This is the point of exploration of this paper, where the idea and objective are situated in the role of institutions in the macroeconomics of climate change. Specifically, it examines the impact of institutional quality on consumption, climate resilience, and optimal carbon taxation.

To have a glimpse of the country level governance, we plot the Worldwide Governance Indicators (WGI) against Gross Domestic Product per capita (GDPPC, constant 2015 US dollars) in 21 countries[2], covering advanced, developing, and underdeveloped economies for the years – 1996, 2004, 2014, and 2023. The WGI consists of – *Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law*, and *Control of Corruption*. Figure 1 depicts that WGI, which captures the quality of institutions, is positively associated with GDPPC [3]. Countries with more robust institutions—such as Denmark, Finland, Australia,

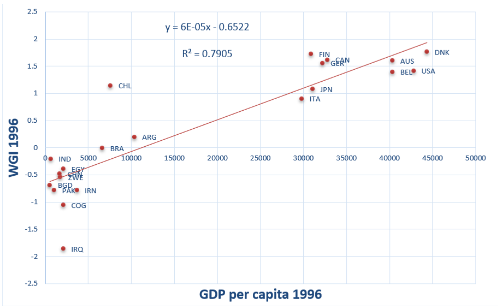
[1] Evidence from South Asian economies (2000–2018) indicates that stronger institutional quality and financial development contribute positively to green economic growth. By fostering legislation that curbs CO_2 emissions, institutions play a central role in aligning economic expansion with sustainability (Ahmed et al., 2022).

[2] The 21 countries are – Argentina, Australia, Bangladesh, Belgium, Brazil, Canada, Chile, China, the Republic of Congo, Denmark, the Arab Republic of Egypt, Finland, Germany, India, Islamic Republic of Iran, Iraq, Italy, Japan, Pakistan, the United States, Zimbabwe.

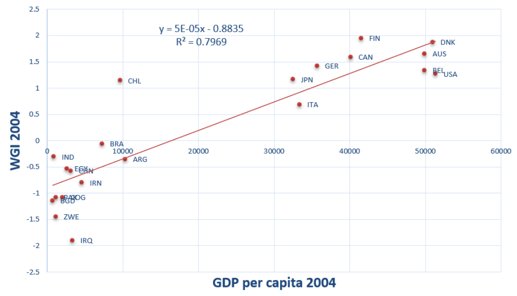
[3] The estimated linear relationship between WGI (y) and GDPPC (x) reveal a strong positive relationship, such as in 1996 the fitted line is $WGI = 6 \times 10^{-5} \cdot GDPPC - 0.6522$ with $R^2 = 0.7905$, in 2004 it is $WGI = 5 \times 10^{-5} \cdot GDPPC - 0.8835$ with $R^2 = 0.7969$, in 2014 it is $WGI = 5 \times 10^{-5} \cdot GDPPC - 0.8749$ with $R^2 = 0.8125$, and in 2023 it is $WGI = 4 \times 10^{-5} \cdot GDPPC - 0.8438$ with $R^2 = 0.7868$.

Figure 1: Worldwide Governance Indicators and GDP Per Capita

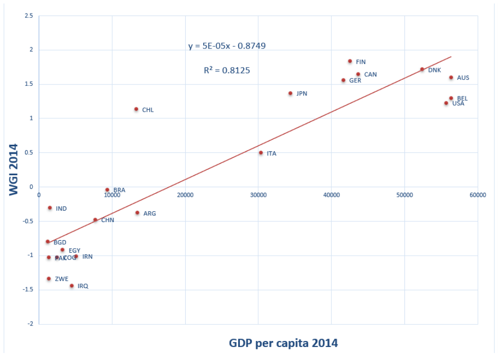
(a) WGI vs GDP per capita in 1996



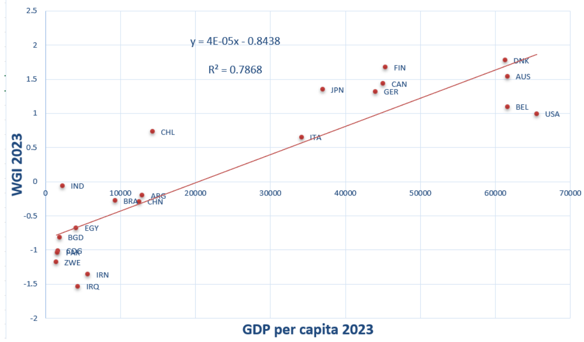
(b) WGI vs GDP per capita in 2004



(c) WGI vs GDP per capita in 2014



(d) WGI vs GDP per capita in 2023



Source: The World Bank and Authors' Calculation

and Canada—exhibit markedly higher levels of per capita income. In contrast, economies including Zimbabwe, Bangladesh, and India tend to display comparatively poorer institutional quality and consequently lower income levels.

A broad literature now demonstrates that economic and political institutions are central to explaining cross-country differences in long-run growth, reflecting a growing consensus on their foundational role in development (Barro, 1996; Huang and Xu, 1999; Hall and Jones, 1999). Building on this, Easterly and Levine (2003) argue that geographic endowments influence income primarily through their impact on institutions, showing that once institutional quality is accounted for, geography and policy variables lose explanatory power. Rodrik et al. (2004) further reinforce the primacy of institutions, finding that institutional quality has a stronger effect on income levels than either trade integration or geographic factors. Complementing the cross-country evidence, Banerjee and Iyer (2005) provide within-country proof from India that colonial land-tenure systems have lasting effects on economic performance, with historically extractive institutions leading to lower productivity and weaker public goods provision. Extending the discussion to political institutions, Nistico (2022) finds that democracy's positive impact on income emerges mainly after 1950 and becomes stronger after 1990, suggesting that the benefits of democracy depend on historical and developmental contexts. Drèze and Sen (1990) provides a normative foundation by arguing that democracy is a universal value, both intrinsically and instrumentally important for human development, as it promotes accountability and prevents large-scale economic and social failures such as famines.

The second set of literature highlights institutional inequality across countries and its effect on the ingredients of economic development, including climate change. That is, the institutional inequality between countries and climate change are among the two most critical issues societies face today (Islam and Winkel, 2017; Singer, 2018). This inequality appears in limited access to basic and quality education, healthcare, financial credit, fair legal systems, and discriminatory job market practices. In addition to the enduring challenge of institutional inequality, which continues to skew economic outcomes, modern societies now face the compounding pressure of rising temperatures driven by climate change (Tol, 2018). The Stern Review characterized climate change as 'the most profound instance of market failure ever experienced globally' (Stern, 2007). Climate change influences multiple dimensions of the economy, including annual income, labour productivity, migration, and demographic patterns (Deryugina and Hsiang, 2014; Somanathan et al., 2021; Graff Zivin and Neidell, 2014; Cattaneo et al., 2019; Walsh et al., 2019). Developing countries, especially those in warmer regions, experience substantially larger output losses than cooler advanced economies, thereby widening global inequality (Diffenbaugh and Burke, 2019; Desbordes and Eberhardt, 2024; Méjean et al., 2024). Bilal and Känzig (2024) structurally estimated that a $1°C$ rise in global temperature leads to a persistent decline in global GDP, with the impact peaking at about 12 percent roughly six years after the initial shock. Taconet et al. (2020) show that higher temperatures depress economic growth, with the impact being strongest in low-income economies. Dell et al. (2012, 2014) find that a $1°C$ rise in temperature lowers annual economic growth in these countries by about 1.3 percentage points. Their evidence further suggests that temperature shocks impact both output levels and growth rates, negatively affecting agriculture, industry, and overall political–economic stability. Kalkuhl and Wenz (2020) estimate that a projected rise of about $3.5°C$ in global mean temperature by 2100 could lower global economic output by 7–14%, with disproportionately large losses in tropical and low-income regions. Colacito et al. (2019) show that a $1°F$ increase in average annual temperature is associated with a reduction of the U.S. state-level per capita income growth by approximately 0.15–0.25 percentage points. They further document that these adverse effects are concentrated in the summer months and are particularly pronounced in non-agricultural sectors. Nath et al. (2024) find that warming generates persistent medium-run GDP losses of approximately 2.2–3.5% per ℃, corresponding to a global GDP reduction of about 8–13% under a 3.7℃ warming scenario. Zhang et al. (2024) estimate that a $1°C$ rise above historical temperature norms increases economic policy uncertainty by an average of 1.35 percent across 20 major economies during the period 1997–2017. Hassan et al. (2020) show that poor institutional quality intensifies CO_2 emissions in Pakistan, emphasizing that strong governance is vital for controlling pollution and achieving sustainable growth. Deschênes et al. (2009) find that exposure to extreme heat during pregnancy significantly lowers birth weight, especially in later trimesters. Climate fluctuations are associated with a range of human health impacts, including heat-related cardiovascular and respiratory mortality, shifts in infectious disease transmission, and malnutrition arising from climate-induced crop failures (Patz et al., 2005).

The interplay between institutions and climate change has been put forth in the third set of literature, such as –North (1984), Arrow and Hahn (1999), Coggan et al. (2010), and Shapiro (2025). Institutions play a critical role in addressing deviations in transaction costs from equilibrium by shaping rules and norms that reduce uncertainty and facilitate efficient economic exchanges (North, 1984). Any expense incurred in making an economic exchange above the price of goods and services is the transaction cost (Arrow and Hahn, 1999). These costs predominantly include measurement costs (quality verification and performance evaluation) and enforcement costs, such as protecting property rights and monitoring compliance. Since transaction costs create inefficiencies, societies develop institutions to minimize these costs and facilitate exchanges. This transaction cost framework extends compellingly to the domain of environmental governance and climate change mitigation (Coggan et al., 2010). The effectiveness of fiscal instruments designed to combat climate change, such as carbon taxes, cap-and-trade systems, or green subsidies, is fundamentally contingent on the institutional quality of the implementing jurisdiction. For instance, the success of the carbon tax relies not merely on setting an economically optimal price for emissions, but on the state's capacity to accurately measure carbon output across thousands of firms (lowering measurement costs) and its ability to enforce collection and penalize non-compliance (lowering enforcement costs). Often, the 'green transaction costs' act as a critical intermediary variable determining the success or failure of climate policy.[4] Shapiro (2025) contends that stronger financial, judicial, and labor institutions promote cleaner industries by lowering domestic pollution through the offshoring of pollution-intensive production.

The fourth set of literature, such as (Acemoglu, 2005; Nickell and Layard, 1999), provides brief insights into the interplay between institutions and the labour market. Historically, the average number of hours worked per person each year has dropped by nearly 40% since 1870 in developed OECD countries (Maddison, 2001).[5] While technological progress has played a vital role in this decline, it is not the only factor. In fact, according to Acemoglu (2005), institutional characteristics such as laws, policies, and social systems are the key drivers of productivity[6] and prosperity in a country, and have contributed predominantly to the reduction in working hours.

On the backdrop of the above literature, this paper seeks to explore the macroeconomic impacts of climate change by incorporating the role of institutions. Acemoglu (2005) emphasizes the vital role of institutions in shaping the market economy by providing agents the opportunity to improve their living standards. In fact, both political and economic institutional structures serve as key determinants of economic success, influencing how societies allocate their resources and achieve productive efficiency (Acemoglu and Robinson, 2013). There is a broad consensus on

[4]Green transaction costs are the specific, often hidden, costs associated with designing, implementing, monitoring, and enforcing environmental policies and sustainable economic exchanges.

[5]For instance, the annual hours worked per person employed in the United Kingdom decreased from $2,984$ in 1870 to $1,489$ in 1998, representing a reduction of $1,495$ hours (approximately 50 percent).

[6]For example, in 1973 labor productivity—measured as GDP per hour worked—was nearly the same in Venezuela (19.27 in 1990 US dollars) and Canada (19.74). However, twenty-five years later, Canada's productivity had risen to 26.04, almost twice that of Venezuela, which had declined to 13.72. The sharp divergence reflects Venezuela's lack of economic and political stability following the oil crisis of the 1970s, combined with its failure to diversify the economy and sustain effective market mechanisms (Maddison, 2001). This experience underscores that strong governance and institutional quality are essential prerequisites for technological advancement and, ultimately, sustained productivity growth.

using fiscal instruments to address institutional inequality and climate change-induced temperature rises. This paper enriches the broad area of literature through theoretical exposition and simulation exercises by addressing how institutions can mitigate climate impacts, affect consumption patterns, enhance climate resilience, and their effects on optimal carbon taxation.

To address the effect of the quality of institutions and macroeconomic implications of climate change on consumption, labor supply, climate resilience, and its effects on optimal carbon taxation, this paper relies on the model building blocks of Barrage (2020) through theoretical exposition, followed by the simulation. This study has the following novel contributions:

- **Innovation Outweighs Intervention:** A fundamental reduction in the cost of abatement technology is the most powerful lever, capable of lowering the necessary carbon tax by over 30%. In contrast, financial interventions like subsidies for existing, more expensive technologies have a marginal effect on the optimal tax path.
- **The Governance Gap in Climate Policy:** A significant divergence emerges between the first-best (FB) and the second-best (SB) carbon tax, and this gap is governed by institutional quality. Strong governance ($\Omega = 0.7$) enables policy to approach the FB, whereas weak governance ($\Omega = 0.1$) necessitates a lower tax to avoid harmful economic side effects.
- **Economic Prosperity Hinges on Institutions:** The long-term standard of living is demonstrated to be highly dependent on the quality of governance. An economy with strong institutions with FB scenario can support policies that yield a per capita consumption roughly 26% higher by 2250 when compared to an economy with weak institutions and SB scenario.
- **Complex Temperature Path Dynamics:** While all analyzed paths lead to a peak global temperature anomaly between 1.6°C and 1.7°C around the year 2060, a notable finding is that the severe economic suppression under weak institutions can paradoxically lead to a slightly lower stabilized temperature in the distant future.
- **Policy is Context-Dependent:** The effectiveness of a carbon tax cannot be evaluated in isolation. Its ability to balance climate and economic objectives is strongly shaped by the quality of institutions, making sound governance essential for achieving efficient outcomes.

The remainder of this paper is organized as follows. Section 2 presents the model, outlining the household and firm sectors along with their first-order conditions. Section 3 discusses the government sector. Section 4 introduces the carbon and climate sector and develops its mathematical formulations. Section 5 defines the competitive equilibrium. Sections 6, 7, and 8 cover the formulation of optimal taxation, calibration, and key propositions, respectively. Section 9 provides the simulation framework and graphical results, while Section 10 concludes the paper.

2 Model

This paper extends the climate economy model of Barrage (2020) and Golosov et al. (2014). The institutional parameter is incorporated into the objective function of the representative household.

2.1 Household

The household's utility function is additively separable, where it depends on consumption and leisure; disutility arises from labour supply. Climate change (T_t) enters additively to capture its broader impacts. The analysis uses the standard measure of mean global surface temperature change relative to pre-industrial levels. Households and firms treat T_t as given, implying that climate change operates as an externality. Consider an infinite-horizon discrete-time economy populated by a continuum of representative households with preferences:

$$U = \sum_{t=0}^{\infty} \beta^t \left[u(C_t, \Omega) - h(L_t, \Omega) - g(T_t, \Omega)\right] \tag{1}$$

Let $C_t \geq 0$ denote consumption and $L_t \geq 0$ represent labor supply. $T_t \geq 0$ represents the mean global surface temperature change over pre-industrial levels. The citizens' discount factor is denoted by $\beta \in (0, 1)$. Ω denotes the institutional parameter, which captures the underlying governance as well as the quality of a country's economic and political institutions. The functions $u : \mathbb{R}_+ \to \mathbb{R}_+$, $h : \mathbb{R}_+ \to \mathbb{R}_+$, and $g : \mathbb{R}_+ \to \mathbb{R}_+$ are twice continuously differentiable and strictly increasing. Furthermore, $u(\cdot)$ is strictly concave, $h(\cdot)$ is strictly convex, and $g(\cdot)$ is strictly convex.

At the heart of climate–economics debates is the choice of a discount rate—the parameter that determines how society values the well-being of future generations by converting future outcomes into present terms. That is, the choice of the appropriate discount rate becomes one of the most consequential and challenging decisions in economics (Weitzman, 2001, 2013). One argues that discounting should rest on ethical considerations, which believe that the people born decades or centuries in the future deserve the same moral weight as those living today (Stern, 2006). This implies that the discount rate should be low so that future climate damages are not treated as insignificant. On the other hand, discounting should follow the logic of actual economic behavior, where individuals and firms make decisions based on prevailing interest rates and the opportunity cost of capital. This market-based approach implies a higher discount rate and gives relatively less weight to far-future outcomes (Nordhaus, 2007). The choice between these two positions has major policy implications: a lower rate justifies stronger and more immediate climate action, while a higher rate supports a more gradual response.

Integrated Assessment Models (IAMs) utilise advanced computational tools to bridge simplified representations of natural systems — such as climate dynamics and land use — with human systems, including economic, energy, and technological sectors (Nordhaus, 2013). The author generates quantitative evaluations of global environmental change and the potential consequences of various policy interventions. However, existing models fail to endogenise institutional quality, such as the rule of law and administrative capacity, which may lead to over-optimistic projections regarding the feasibility and cost-effectiveness of global mitigation strategies. The paper incorporates institutional quality (Ω) into a climate–economy model, embedding its influence consistently within the household felicity function. The optimal carbon tax is determined within a Ramsey framework (Ramsey, 1928), followed by calibration and simulation of the extended model, with the outcomes compared against those of Barrage (2020). The findings demonstrate that institutional quality lowers the optimal carbon tax through both direct and indirect channels, providing policy-relevant insights that underscore the importance of pairing carbon pricing with institutional strengthening.

2.1.1 Utility Function

Authors extend the Barrage (2020) framework as follows[7]:

$$U = \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t(1+\Omega_t)^{\alpha_{\text{inst}}})^{1-\sigma} - 1}{1-\sigma} - \frac{L_t^{1+\frac{1}{\epsilon_f}}}{1+\frac{1}{\epsilon_f}} (1+\Omega_t)^{-\gamma_{\text{inst}}} - \theta T_t^2 (1+\Omega_t)^{-\kappa_{\text{inst}}} \right], \quad \text{for } \sigma \neq 1, \tag{2}$$

The key variables in the equation include consumption at time t, denoted by C_t[8]; labor supply, L_t; and the change in global mean temperature, T_t. A central feature is the institutional quality parameter, $\Omega_t \in (0,1)$, mapped WGI using the logistic function $\Omega_t = \frac{1}{1+e^{-\text{WGI}}}$. Household preferences capture the discount factor, $\beta \in (0,1)$; the coefficient of relative risk aversion, $\sigma > 0$; and the Frisch elasticity of labor supply, $\epsilon_f > 0$. The welfare impact of climate change is governed by the climate damage coefficient, $\theta > 0$. The model also introduces three non-negative sensitivity parameters, $\alpha_{\text{inst}} \geq 0$, $\gamma_{\text{inst}} \geq 0$, and $\kappa_{\text{inst}} \geq 0$, which capture the effects of institutional quality on the utility derived from consumption, the disutility of labor, and the disutility from temperature changes, respectively. The non-negative parameters α_{inst}, γ_{inst}, and κ_{inst} quantify the sensitivity of household welfare to the quality of public institutions. A positive value for α_{inst} suggests better institutions, such as strong property rights that enhance the utility derived from consumption. Similarly, a positive γ_{inst} implies that good governance mitigates the disutility of labor, reflecting benefits, such as improved working conditions or stronger labor protections. Similarly, a positive κ_{inst} indicates that effective institutions reduce the welfare damages from climate change, representing a society's increased capacity for adaptation and resilience. For each parameter, a value of zero would imply that institutional quality has no effect on that specific dimension of well-being, while a larger positive value signifies a stronger influence.

[7]When institutional quality does not play any role in preferences, then $\Omega = 0$; however, the quality of institutions has been considered between 0 and 1. That is, $\Omega = 0$ eliminates additional channels through which institutions affect consumption utility, labor disutility, and climate damage, and the resulting utility function coincides with the benchmark climate-economy specification analyzed in Barrage (2020).

[8]This functional form is standard in macroeconomic and climate-economy models to capture utility from consumption. The term $C^{1-\sigma}$ reflects risk preferences and intertemporal substitution, while subtracting 1 and dividing by $(1-\sigma)$ normalizes the utility for $\sigma \neq 1$. In the special case $\sigma = 1$, the function converges to $\log(C)$. The parameter σ governs curvature: higher σ implies greater risk aversion and lower elasticity of intertemporal substitution, implying that households are less willing to adjust consumption over time in response to changes in interest rates or income.

The institutional parameter Ω_t plays a critical role in shaping the labor supply decision within the utility function with consumption and the temperature components. The institutionally adjusted disutility of labor can be expressed as:

$$\frac{L_t^{1+\frac{1}{\epsilon_f}}}{1+\frac{1}{\epsilon_f}}(1+\Omega_t)^{-\gamma_{\text{inst}}} \tag{3}$$

where the labor supply at time t is denoted by L_t. The Frisch elasticity of labor supply, represented by $\epsilon_f > 0$, makes the term more dynamic.[9] The institutional parameter Ω_t acts as a moderator on the entire disutility term. As institutional quality Ω_t gets higher, it reduces the overall negative impact of labor on a household's welfare. It does not alter the curvature but instead scales the total disutility up or down. The parameter Ω_t reflects the quality of institutions such as laws, policies, and social systems—that influence economic transactions and productivity (Acemoglu, 2005). Strong institutions (higher Ω_t) imply lower transaction costs (e.g., measurement and enforcement costs), which in turn reduces uncertainty, leading to greater prosperity and efficiency in labor markets.

The household faces the following budget constraint:

$$C_t + \rho_t B_{t+1} + K_{t+1} \leq w_t(1-\tau_{lt})L_t + \{1+(r_t-\delta)(1-\tau_{kt})\}\, K_t + B_t + \Pi_t + G_t^T \tag{4}$$

where B_{t+1} denotes government bond purchases for the next period, ρ_t is the price of one-period bonds, K_{t+1} is the capital holdings of the household in period $t+1$, w_t is the gross wage, τ_{lt} and τ_{kt} are linear taxes on labor income and capital income respectively, r_t is the return on capital, δ is the depreciation rate, Π_t are profits from energy production, and G_t^T are government transfers to households. Moreover, capital holdings cannot be negative: $K_{t+1} \geq 0$.

The Lagrangian function for the household's optimization problem is given by:

$$\begin{aligned}\mathcal{L} = \sum_{t=0}^{\infty} \beta^t & \left[\frac{(C_t(1+\Omega_t)^{\alpha_{\text{inst}}})^{1-\sigma} - 1}{1-\sigma} - \frac{L_t^{1+\frac{1}{\epsilon_f}}}{1+\frac{1}{\epsilon_f}}(1+\Omega_t)^{-\gamma_{\text{inst}}} - \theta T_t^2 (1+\Omega_t)^{-\kappa_{\text{inst}}} \right] \\ & + \sum_{t=0}^{\infty} \gamma_t \left(w_t(1-\tau_{lt})L_t + \{1+(r_t-\delta)(1-\tau_{kt})\}K_t + B_t + \Pi_t + G_t^T - C_t - \rho_t B_{t+1} - K_{t+1} \right)\end{aligned} \tag{5}$$

where, γ_t is the Lagrange multiplier on the budget constraint at time t.

The first-order conditions (FOCs) for the household's problem are as follows:

[9] The Frisch elasticity of labor supply, denoted by ϵ_f, measures how labor supply responds to wage changes while holding the marginal utility of wealth constant. As emphasized by Prescott (1986), it is a key structural parameter in economics. In this model, ϵ_f governs the curvature of the labor disutility function, ensuring its convexity and capturing the elasticity of labor supply.

FOC with respect to Consumption, C_t:

$$\frac{\partial \mathcal{L}}{\partial C_t} = \beta^t \frac{\partial U}{\partial C_t} - \gamma_t = 0 \implies \gamma_t = \beta^t \frac{\partial U}{\partial C_t} \tag{6}$$

$$\gamma_t = \beta^t (1+\Omega_t)^{\alpha(1-\sigma)} C_t^{-\sigma} \tag{7}$$

FOC with respect to Labor, L_t:

$$\frac{\partial \mathcal{L}}{\partial L_t} = \beta^t \frac{\partial U}{\partial L_t} + \gamma_t w_t (1-\tau_{lt}) = 0 \implies -\frac{\partial U/\partial L_t}{\partial U/\partial C_t} = w_t(1-\tau_{lt}) \tag{8}$$

$$\implies \frac{\partial U}{\partial L_t} = \beta^t L_t^{\frac{1}{\epsilon_f}} (1+\Omega_t)^{-\gamma} \tag{9}$$

Substituting the marginal utility of consumption and labor from equations (7) and (9), respectively, yields the labor supply condition:

$$\frac{L_t^{1/\epsilon_f}(1+\Omega_t)^{-\gamma}}{C_t^{-\sigma}(1+\Omega_t)^{\alpha(1-\sigma)}} = w_t(1-\tau_{lt}) \tag{10}$$

Alternatively, from equations (8) and (10);

$$-\frac{\partial U/\partial L_t}{\partial U/\partial C_t} = -\frac{U_{L,t}}{U_{c,t}} = \frac{L_t^{1/\epsilon_f}(1+\Omega_t)^{-\gamma}}{C_t^{-\sigma}(1+\Omega_t)^{\alpha(1-\sigma)}} = w_t(1-\tau_{l,t}) \tag{11}$$

The lhs of eq. (10) represents the marginal rate of substitution (MRS) between leisure and consumption, and the household supplies labor until this disutility of additional work equals the after-tax real wage.

The economic intuition behind the labor supply condition is that it balances the household's trade-off between leisure and consumption against the after-tax wage. The left-hand side of eq. (10) quantifies the disutility of an additional unit of labor relative to the utility derived from consumption. An increase in institutional quality (Ω_t) reduces the disutility of labor through $(1+\Omega_t)^{-\gamma}$ and enhances the effective utility of consumption via $(1+\Omega_t)^{\alpha}$, leading to a higher labor supply for a given after-tax wage $w_t(1-\tau_{l,t})$. This effect captures institutional capacity to improve labor market efficiency, such as through better governance, reduced bureaucratic frictions, or stronger property rights, making work less burdensome and consumption more rewarding. The Frisch elasticity ϵ_f governs the responsiveness of labor supply to changes in wages and institutional quality, with higher ϵ_f amplifying effects. Households thus adjust labor effort until the marginal welfare cost of working equals the after-tax return, integrating both economic and institutional incentives.

FOC with respect to Capital, K_{t+1} (Euler Equation):

$$\frac{\partial \mathcal{L}}{\partial K_{t+1}} = -\gamma_t + \gamma_{t+1}\{1 + (r_{t+1} - \delta)(1 - \tau_{k,t+1})\} = 0 \tag{12}$$

This gives the Euler equation for capital accumulation:

$$\gamma_t = \gamma_{t+1}\{1 + (r_{t+1} - \delta)(1 - \tau_{k,t+1})\} \tag{13}$$

Substituting the expression for γ_t from eq. (7), we get:

$$\beta^t(1+\Omega_t)^{\alpha(1-\sigma)}C_t^{-\sigma} = \beta^{t+1}(1+\Omega_{t+1})^{\alpha(1-\sigma)}C_{t+1}^{-\sigma}\{1 + (r_{t+1} - \delta)(1 - \tau_{k,t+1})\} \tag{14}$$

$$\implies 1 = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{1+\Omega_{t+1}}{1+\Omega_t}\right)^{\alpha(1-\sigma)}\{1 + (r_{t+1} - \delta)(1 - \tau_{k,t+1})\} \tag{15}$$

FOC with respect to Bonds, B_{t+1}:

$$\frac{\partial \mathcal{L}}{\partial B_{t+1}} = -\gamma_t\rho_t + \gamma_{t+1} = 0 \tag{16}$$

$$\implies \rho_t = \frac{\gamma_{t+1}}{\gamma_t} \tag{17}$$

Substituting for γ_t and γ_{t+1} from eq. (7) gives:

$$\rho_t = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{1+\Omega_{t+1}}{1+\Omega}\right)^{\alpha(1-\sigma)} \tag{18}$$

2.2 Firm

The model consists of two production sectors: the final goods sector, indexed as 1, and the energy sector, indexed as 2. Energy is used as one of the inputs to produce final capital-consumption goods. The environmental damage function, $D(T_t)$, is exponential and has been adopted from Nordhaus (2008). The technology that produces this good satisfies the standard Inada conditions and has constant returns to scale for all inputs. Energy production emits pollution, which in turn leads to environmental degradation that affects both economic productivity and households' utility. As in Barrage (2020), emissions can be reduced through abatement activities, though these come at a great cost. Labor and capital are allocated between sectors 1 and 2. Both production factors are mobile across sectors and are paid according to their marginal productivity.

2.2.1 Final good sector

The output in sector 1 is given by;

$$Y_{1,t} = (1 - D(T_t))A_{1,t}F_1(K_{1,t}, L_{1,t}, E_t) \tag{19}$$

The damage function according to Nordhaus (2008) for global temperature is defined as:

$$1 - D(T_t) = \frac{1}{1 + \theta_1 T_t^2}, \tag{20}$$

where T_t represents the average global temperature increase relative to pre-industrial levels, and hence $\theta_1 = 0.0021$. The term $\theta_1 T_t^2$ in the denominator ensures that the function exhibits convexity for lower values of T_t. This implies that for small temperature increases, the damage grows at an accelerating rate. At higher values of T_t, the function transitions to concavity, meaning the damage increases at a decelerating rate. This behavior arises because the function is bounded above by 1, ensuring that the damage never exceeds 100%.

The first-order conditions are:

$$r_t = (1 - D(T_t))A_{1,t}F_{1K,t} \tag{21}$$

$$w_t = (1 - D(T_t))A_{1,t}F_{1L,t} \tag{22}$$

$$p_{E,t} = (1 - D(T_t))A_{1,t}F_{1E,t} \tag{23}$$

2.2.2 Energy sector

The energy sector, indexed by 2, produces energy E_t using labor $L_{2,t}$ and capital $K_{2,t}$ with a constant returns to scale technology.

$$E_t = A_{2,t}F_2(K_{2,t}, L_{2,t}) \tag{24}$$

A fraction of energy, $\mu \in (0, 1)$, from clean technology is provided by energy producers, albeit at an additional cost $\Theta_t(\mu_t E_t)$. In the model, the government provides subsidies $\phi_t(\mu_t E_t)$, where $\phi_t \in [0, 1]$ represents the fraction of total energy production subsidized for clean energy generation. This mechanism reflects the idea that climate change must be addressed through market-based incentives that encourage agents to adopt cleaner technologies (Acemoglu et al., 2012). This creates an additional burden on the government treasury; however, it reduces output losses due to temperature rise and increases the utility derived by households. A carbon tax and a clean energy subsidy can be viewed as two complementary levers that influence emissions reduction in different ways. The carbon tax operates as a punitive instrument, raising the cost of carbon-intensive energy and thereby discouraging its use (Pigou, 2017;

Pindyck, 2019). In an intertemporal framework, the optimal tax rate, τ_t, equals the marginal social cost of carbon (SCC), reflecting the discounted value of future damages caused by an additional unit of emissions (Tol, 2019). This linkage is captured in the model through the influence of the temperature anomaly, T_t, on household utility. In contrast, a clean energy subsidy serves as an incentive, reducing the effective cost or increasing the profitability of producing clean energy. By improving returns on clean technology and increasing the share of clean energy, μ_t, the subsidy encourages producers to voluntarily shift their energy mix toward cleaner sources.

When subsidies make clean energy more attractive, the baseline level of carbon emissions declines. With a lower emissions baseline, the carbon tax can be set at a less stringent level while still achieving the same environmental objectives, such as keeping the temperature anomaly on a sustainable trajectory. The strength of this substitution effect depends on the size of the subsidy. A small subsidy, such as $\phi = 0.1$, results in only a minor change in the energy mix, leaving most of the mitigation burden to the carbon tax. In contrast, a larger subsidy, such as $\phi = 0.3$, induces a substantial shift toward clean energy, lowering baseline emissions and thereby reducing the optimal carbon tax. This reveals a clear dose–response relationship, where stronger subsidies lead to weaker requirements on taxation to achieve the same climate target (Espa and Rolland, 2015).

Profits earned by the energy-producing sector are thus given by:

$$\Pi_t = (p_{E,t} - \tau_{I_t})E_t + \phi_t(\mu_t E_t) - [(1-\mu_t)E_t]\tau_{E_t} - w_t L_{2,t} - r_t K_{2,t} - \Theta_t(\mu_t E_t) \tag{25}$$

The symbol τ_{I_t} denotes the excise tax on intermediate goods encompassing all energy types, including both clean and carbon-based energy. Meanwhile, τ_{E_t} signifies the excise tax levied specifically on carbon emissions.

The first-order conditions are:

$$\begin{aligned} r_t &= \big(p_{E,t} + \phi_t\mu_t - \tau_{I,t} - \tau_{E,t}(1-\mu_t) - \Theta_t\mu_t\big)A_{2,t}F_{2k,t}, \\ w_t &= \big(p_{E,t} + \phi_t\mu_t - \tau_{I,t} - \tau_{E,t}(1-\mu_t) - \Theta_t\mu_t\big)A_{2,t}F_{2l,t}. \end{aligned} \tag{26}$$

The firm hires labor and invests in capital until the value of the marginal product of each factor equals its respective price: the wage rate for labor and the rental cost for the capital.

3 Government

In this framework, the government functions as an intertemporal fiscal authority that must finance its activities entirely through distortionary taxation, consistent with the Ramsey tradition and the formulation used in Barrage (2020). Its overarching objective is to maximize household welfare, subject to the constraints of the resource-rich but distortion-prone economic environment and the forward-looking behavior of private agents (Chari and Kehoe, 1999).

Public spending takes the form of an exogenously specified sequence of government consumption (G_t^C) and household transfers (G_t^T). To these components, our model adds a new expenditure item: a subsidy for clean energy production, $\Phi_t(\mu_t E_t)$, which is introduced to accelerate the green transition. This additional policy instrument increases the fiscal requirements the government must satisfy and heightens the tension between raising revenue efficiently and minimizing economic distortions.

The government's flow budget constraint (GBC) equates its total expenditures with all available sources of revenue. Incorporating the clean energy subsidy, the constraint is written as

$$G_t^C + G_t^T + \Phi_t(\mu_t E_t) + B_t^G = \tau_{lt} w_t L_t + \tau_{It} E_t + \tau_{Et} E_t^M + \tau_{kt}(r_t - \delta)K_t + \rho_t B_{t+1}^G. \tag{27}$$

Thus, public outlays consist of consumption, transfers, the energy subsidy, and the servicing of previously accumulated debt, while revenues are drawn from taxes on labor income, intermediate energy use, carbon emissions, capital income, and the issuance of new government bonds. Although this equality is an accounting identity, it plays a central conceptual role by defining the fiscal space within which optimal policy must be designed.

Because lump-sum taxation is unavailable, the government must rely on distortionary taxes to satisfy the budget constraint. These taxes introduce wedges between private and social returns, generating deadweight losses (Bovenberg and De Mooij, 1994). In a Ramsey setting, the policymaker seeks to choose tax rates—τ_{lt}, τ_{kt}, τ_{It}, and τ_{Et}—so as to raise the required revenue while minimizing the resulting efficiency losses. The Marginal Cost of Public Funds ($MCF > 1$) summarizes the welfare cost of raising an additional unit of revenue in this SB environment (Auriol and Warlters, 2012). When the fiscal burden rises – that is, when the lhs of the GBC increases – tax rates must also rise, which pushes the MCF upward and intensifies welfare losses. The carbon tax embodies this trade-off most clearly: it simultaneously corrects a climate externality and serves as a significant revenue-generating instrument. Consequently, in the second-best world, the optimal carbon tax is smaller than the Pigouvian because using carbon revenue interacts with pre-existing tax distortions.

Institutional quality, Ω, fundamentally influences how binding the government budget constraint becomes. Strong institutions enhance tax administration, improve compliance, reduce transaction costs, and thereby expand the effective tax base (Pampel et al., 2019). In our preference structure, better institutions also improve the welfare productivity of consumption and strengthen labor supply responses to after-tax wages, which lowers the distortionary impact of any given tax rate. On the expenditure side, more effective governance increases the social value of public spending, making programs such as the clean energy subsidy more efficient and better targeted. Taken together, these channels imply that governments operating under high institutional quality face a less restrictive fiscal environment, enabling them to finance the same level of expenditure at lower welfare cost. This mechanism explains the divergence observed in our simulations: in weak institutional settings ($\Omega = 0.1$), the fiscal system is highly distortionary and the MCF_t is elevated, whereas in strong institutional environments ($\Omega = 0.7$), the fiscal constraint is considerably more relaxed, resulting in more efficient and less distortionary tax policy.

4 Carbon cycle and climate sector

From an economic standpoint, anthropogenic carbon emissions represent a classic global, inter-temporal externality, where productive activities generate a harmful byproduct that accumulates over time. The climate model follows the Dynamic Integrated Climate–Economy (DICE) model developed by Nordhaus (1992). It serves as the quantitative core for capturing the physical dynamics of the climate externality, linking current economic decisions to their future climatic consequences. Atmospheric temperature change T_t at time t is assumed to depend on the history of carbon emissions $\{E_s^M\}_{s=0}^t = \{(1-\mu_s)E_s\}_{s=0}^t$, initial conditions S_0 (such as atmospheric carbon stocks or deep ocean temperatures), and exogenous factors $\{\eta_s\}_{s=0}^t$ (e.g., land-based emissions):

$$T_t = f(S_0, E_0^M, E_1^M, \dots, E_t^M, \eta_0, \dots, \eta_t), \tag{28}$$

where:

$$\frac{\partial T_{t+j}}{\partial E_t^M} \geq 0 \quad \text{for all } j, t \geq 0.$$

The general relationship is first expressed as $T_t = f(S_0, E_0^M, \dots, E_t^M, \eta_0, \dots, \eta_t)$, where the temperature increase T_t is the physical measure of harm or damage. The inputs to this function are the history of man-made emissions $\{E_s^M\}_{s=0}^t$, which is the primary choice variable controlled by climate policy; the initial state of the climate system S_0, representing an inherited environmental stock; and exogenous factors $\{\eta_s\}_{s=0}^t$ that act as external shocks. The fundamental constraint, $\frac{\partial T_{t+j}}{\partial E_t^M} \geq 0$, formalizes the economic concept of a stock externality, stating that emissions today cause persistent harm across all future periods, a fact central to calculating the SCC.

Furthermore, to make this framework operational, the model first specifies the dynamics of the externality-generating pollutant. It employs a three-box system to track the movement of carbon between the atmosphere (S_t^{At}), the upper oceans and biosphere (S_t^{Up}), and the deep oceans (S_t^{Lo}). This is governed by the matrix,

$$\begin{pmatrix} S_t^{At} \\ S_t^{Up} \\ S_t^{Lo} \end{pmatrix} = \begin{pmatrix} \phi_{11} & \phi_{21} & 0 \\ \phi_{12} & \phi_{22} & \phi_{32} \\ 0 & \phi_{23} & \phi_{33} \end{pmatrix} \begin{pmatrix} S_{t-1}^{At} \\ S_{t-1}^{Up} \\ S_{t-1}^{Lo} \end{pmatrix} + \begin{pmatrix} E_t^M + E_t^{\text{Land}} \\ 0 \\ 0 \end{pmatrix} \tag{29}$$

In the model's carbon cycle matrix, a zero signifies the absence of a direct physical pathway between two carbon reservoirs. Intuitively, this implies that carbon cannot travel instantly from a source, such as the deep oceans, to a destination like the atmosphere within one time step. Instead, the model requires that carbon first transition through an intermediate reservoir, thereby simplifying the complex environmental dynamics for the purpose of calculation. Economically, this system describes how the 'debt' of carbon emissions, once incurred, persists and depreciates over centuries. The slow transfer of carbon to the deep ocean sink implies that the externality has an extremely long half-life, framing climate change as a profoundly inter-generational problem. The model then translates the atmospheric stock of the carbon, S_t^{At}, into a measure of planetary energy imbalance known as radiative forcing, χ_t, through the relationship:

$$\chi_t = \kappa \left\{ \frac{\ln\left(\frac{S_t^{At}}{S_{1750}^{At}}\right)}{\ln(2)} \right\} + \chi_t^{Ex} \tag{30}$$

The logarithmic nature of this equation is crucial, as it implies diminishing marginal forcing; the initial tonnes of CO_2 have a greater warming impact than later tonnes. This concavity is a key feature that influences the optimal path of the abatement policy.

The final step in the model translates radiative forcing into atmospheric temperature change, incorporating the critical element of thermal inertia from the oceans. This is captured by a two-layer temperature system for the atmosphere (T_t) and the deep ocean (T_t^{Lo}):

$$\begin{pmatrix} T_t \\ T_t^{Lo} \end{pmatrix} = \begin{pmatrix} 1 - \zeta_1\zeta_2 - \zeta_1\zeta_3 & \zeta_1\zeta_3 \\ 1 - \zeta_4 & \zeta_4 \end{pmatrix} \begin{pmatrix} T_{t-1} \\ T_{t-1}^{Lo} \end{pmatrix} + \begin{pmatrix} \zeta_1\chi_t \\ 0 \end{pmatrix} \tag{31}$$

This dynamic structure is economically significant because it creates a substantial lag between the action of emitting and the full consequences of warming. The deep ocean acts as a thermal flywheel, absorbing heat slowly and thus ensuring that past emissions commit the world to future warming. This inertia poses a profound policy challenge, as the costs of abatement are immediate while the full benefits are delayed for generations, elevating the importance of the social discount rate in weighing present costs against future damages.

The credibility of this entire framework hinges on its calibration to robust scientific findings. The model's parameters ($\phi_{i,j}\ (i, j \in \{1, 2, 3\}), \quad \zeta_i\ (i \in \{1, 2, 3, 4\}), \quad \kappa > 0$) are chosen to match a specific Equilibrium Climate Sensitivity (ECS)—in this case, a long-run warming of $3.2°$C to double the atmospheric CO_2. This calibration ensures that the simplified model, designed for economic analysis, accurately reflects the consensus on the magnitude of the climate externality as determined by complex physical models. By doing so, it provides a tractable yet empirically-grounded tool for analyzing the profound inter-temporal trade-offs inherent in global climate policy.

5 Competitive Equilibrium

A competitive equilibrium represents a state of balance in the economy where all agents are simultaneously optimizing their own objectives, and all markets clear. In the context of this climate-economy model, it is a sequence of allocations, prices, and policies over time where no single agent has an incentive to change their behavior. It is the solution to the model, describing the path the economy will follow given its fundamental structure and government policies. The components and conditions together define a state of perfect coordination between households, firms, and the government, all operating within the physical constraints of the planet's carbon cycle. A competitive equilibrium is defined by an allocation $\{C_t, L_{1t}, L_{2t}, K_{1t+1}, K_{2t+1}, E_t, \mu_t, T_t\}$, a set of prices $\{r_t, w_t, p_{E_t}, \rho_t\}$, and a set of policies $\{\tau_{k_t}, \tau_{l_t}, \tau_{E_t}, \tau_{I_t}, \phi_t, B_{t+1}\}$ such that:

i The household maximizes utility, subject to constraints.

ii The firm maximizes profit according to the constraints.

iii The government budget constraint is satisfied in every period.

iv The temperature change satisfies the carbon cycle constraint in all periods.

v Market-clearing conditions are satisfied.

6 Optimal Carbon Tax

The general formula for the Pigouvian carbon tax, representing the marginal external cost of emissions, is the sum of discounted future damages. It can be decomposed into damages affecting production and those directly affecting utility. The general form is taken from Barrage (2020):

$$\tau_{Et}^{\text{Pigou},T} = \underbrace{(-1)\sum_{j=0}^{\infty}\beta^j \frac{U_{c,t+j}}{U_{c,t}}\left[\frac{\partial Y_{t+j}}{\partial T_{t+j}}\frac{\partial T_{t+j}}{\partial E_t^M}\right]}_{\text{Production Damages}} + \underbrace{(-1)\sum_{j=0}^{\infty}\beta^j \frac{U_{T,t+j}}{U_{c,t}}\left[\frac{\partial T_{t+j}}{\partial E_t^M}\right]}_{\text{Utility Damages}} \tag{32}$$

The eq. (32) defines the Pigouvian carbon tax, which is equivalent to the SCC and represents the optimal levy in an economy without other fiscal distortions. It is calculated as the sum of two distinct components that quantify the total future harm from an additional unit of emissions today. The first component, for production damages, calculates the present value of all future economic output that will be lost due to climate change. It does this by using a stochastic discount factor (SDF) $\beta^j\, U_{c,t+j}/U_{c,t}$) to value future losses in today's terms, multiplied by the physical impact of warming on production (e.g., agriculture) and the link between emissions and future temperature. The second component addresses utility damages, which are non-market welfare losses such as the loss of biodiversity. It monetizes this harm by measuring how much current consumption a household would be willing to trade to avoid the direct disutility from a warmer climate in the future. Barrage (2020) uses this formula as a crucial first-best benchmark, arguing that the distinction between production and utility damages is essential because they interact differently with the distortionary taxes found in real-world economies.

The core challenge in extending the framework is to integrate the dynamic institutional quality parameter, $\Omega_t \in (0, 1)$, into the valuation of climate damages, thereby modifying both the marginal disutility of temperature and the economic value of future outcomes as captured by the SDF. This process begins by recognizing that the total Pigouvian tax, $\tau_{E_t}^{\text{Pigou},T}$, which represents the SCC, is composed of two discounted streams of future harm: Production Damages ($\tau_{E_t}^{\text{Pigou},Y}$) and Utility Damages ($\tau_{E_t}^{\text{Pigou},U}$). The institutional influence on the Utility Damages component is dual: first, Ω_t directly scales the marginal disutility of temperature, $U_{T,t} = -2\theta T_t(1+\Omega_t)^{-\kappa_{\text{inst}}}$, meaning that a high institutional resilience parameter ($\kappa_{\text{inst}} > 0$) acts as a 'Climate Shield', dampening the subjective welfare loss from warming and thus lowering this damage component. Second, Ω_t enters the SDF term, $\frac{U_{c,t+j}}{U_{c,t}} = \left(\frac{C_{t+j}}{C_t}\right)^{-\sigma}\left(\frac{1+\Omega_{t+j}}{1+\Omega_t}\right)^{\alpha_{\text{inst}}(1-\sigma)}$, where the Institutional Adjustment Factor (IAF) adjusts the internal rate of substitution based on the consumption multiplier parameter (α_{inst}) and the risk aversion coefficient (σ), thereby altering the present value of all future damages. As this institutionalized SDF is used to discount both $\tau_{E_t}^{\text{Pigou},Y}$ and $\tau_{E_t}^{\text{Pigou},U}$, a growing Ω_t with $\alpha_{\text{inst}} > 0$ and $\sigma > 1$ generally decreases the present value of future benefits, leading to a complex intertemporal trade-off. This yields the final expression for utility damages:

$$\tau_{E_t}^{\text{Pigou},U} = \frac{2\theta C_t^{\sigma}}{(1+\Omega_t)^{\alpha_{\text{inst}}(1-\sigma)}} \sum_{j=0}^{\infty} \beta^j T_{t+j} \frac{\partial T_{t+j}}{\partial E_t^M} \underbrace{(1+\Omega_{t+j})^{-\kappa_{\text{inst}}}(1+\Omega_{t+j})^{\alpha_{\text{inst}}(1-\sigma)}}_{\text{Combined Institutional Scaling}}$$

In the more realistic SB setting, the Optimal Carbon Tax ($\tau_{E_t}^*$) maintains the same component structure ($\tau_{E_t}^* = \frac{\tau_{E_t}^{\text{Pigou},U}}{MCF_t} + \tau_{E_t}^{\text{Pigou},Y}$), but here, the primary institutional influence is through the implied correlation with the Marginal Cost of Public Funds (MCF_t). Since institutional quality (Ω_t) is assumed to be negatively correlated with MCF_t (i.e., $MCF_t = f(\Omega_t)$ with $f'(\Omega_t) < 0$), stronger governance reduces the fiscal distortion created by income taxes. This reduction in the MCF_t lowers the implicit tax discount applied to non-market utility damages ($\frac{\tau_{E_t}^{\text{Pigou},U}}{MCF_t}$), pushing the Optimal Tax closer to the first-best Pigouvian level. Thus, the model concludes that strong institutions are a precondition for efficient environmental policy, as they bridge the gap between the economic ideal and the constrained fiscal reality.

6.1 Production Damages

The stochastic discount factor (SDF) is $\beta^j \frac{U_{c,t+j}}{U_{c,t}}$.

$$\frac{U_{c,t+j}}{U_{c,t}} = \frac{C_{t+j}^{-\sigma}(1+\Omega_{t+j})^{\alpha(1-\sigma)}}{C_t^{-\sigma}(1+\Omega_t)^{\alpha(1-\sigma)}} = \left(\frac{C_{t+j}}{C_t}\right)^{-\sigma}\left(\frac{1+\Omega_{t+j}}{1+\Omega_t}\right)^{\alpha(1-\sigma)}. \tag{33}$$

Thus, the production damage component is:

$$\tau_{Et}^{\text{Pigou},Y} = (-1)\sum_{j=0}^{\infty}\beta^j \left(\frac{C_{t+j}}{C_t}\right)^{-\sigma}\left(\frac{1+\Omega_{t+j}}{1+\Omega_t}\right)^{\alpha(1-\sigma)}\left[\frac{\partial Y_{t+j}}{\partial T_{t+j}}\frac{\partial T_{t+j}}{\partial E_t^M}\right]. \tag{34}$$

6.2 Utility Damages

$$\tau_{Et}^{\text{Pigou},U} = (-1)\sum_{j=0}^{\infty}\beta^j \frac{-2\theta T_{t+j}(1+\Omega_{t+j})^{-\kappa}}{C_t^{-\sigma}(1+\Omega_t)^{\alpha(1-\sigma)}}\left[\frac{\partial T_{t+j}}{\partial E_t^M}\right] \tag{35}$$

$$= \frac{2\theta C_t^{\sigma}}{(1+\Omega_t)^{\alpha(1-\sigma)}}\sum_{j=0}^{\infty}\beta^j(1+\Omega_{t+j})^{-\kappa}T_{t+j}\frac{\partial T_{t+j}}{\partial E_t^M}. \tag{36}$$

The total Pigouvian carbon tax is the sum of the two components:

$$\tau_{Et}^{\text{Pigou},T} = \tau_{Et}^{\text{Pigou},Y} + \tau_{Et}^{\text{Pigou},U}. \tag{37}$$

6.3 Optimal Carbon Tax when Taxes are Distortionary

The Marginal Cost of Public Funds (MCF) is a central concept in public finance that quantifies the total welfare cost to society for each unit of revenue raised by the government through distortionary taxation (Browning, 1976). When taxes on goods or income alter economic decisions, they create a deadweight loss. The MCF captures this efficiency loss, and a value greater than one indicates that raising \$1 for public spending costs households more than \$1 in terms of well-being (Triest, 1990). As in Barrage (2020), the mathematical expression for the MCF is as follows,

$$MCF \equiv \frac{\lambda_{1t}}{U_{ct}} \tag{38}$$

The variables in this equation are defined as follows. MCF denotes the Marginal Cost of Public Funds, while λ_{1t} represents the public marginal utility of consumption. That is, the Lagrange multiplier on the resource constraint in the planner's problem, capturing the social value of an additional unit of the consumption good at time t. U_{ct} is the private marginal utility of consumption, given by the partial derivative of household utility with respect to consumption. Formally, the MCF is defined as

$$MCF = 1 + \frac{\text{Marginal Deadweight Loss}}{\text{Marginal Revenue Collected}}. \tag{39}$$

This implies that the MCF exceeds one whenever taxes distort behavior and create deadweight losses. Under a lump-sum tax, where incentives are unchanged, the deadweight loss is zero and $MCF = 1$. For instance, estimates show that for a typical prime-aged American male earning ten dollars an hour in 1975, the federal income tax created an excess burden exceeding 50% of the revenue collected from that individual (Triest, 1990).

Institutional quality shapes the size of this inefficiency. Strong institutions—through secure rights, efficient markets, and transparent governance—improve an economy's ability to absorb taxation by increasing the utility from consumption and reducing the disutility of labor. This broadens the tax base and lowers the marginal deadweight loss (Arora and Chong, 2018). Weak institutions, in contrast, often require higher tax rates to meet revenue needs, amplifying distortions in work, saving, and investment. The same tax system can therefore impose very different welfare costs depending on institutional strength, making strong governance essential for maintaining a lower and more efficient MCF.

The optimal carbon tax for periods $t > 0$ in an economy with distortionary fiscal policy is implicitly defined by the following expression:

$$\tau_{Et}^{*} = \underbrace{\sum_{j=0}^{\infty} \beta^j \left[\frac{-\partial Y_{t+j}}{\partial T_{t+j}} \frac{\lambda_{1t+j}}{\lambda_{1t}} \right] \left[\frac{\partial T_{t+j}}{\partial E_t^M} \right]}_{\text{Production damages}} + \underbrace{\sum_{j=0}^{\infty} \beta^j \left[\frac{-U_{Tt+j}}{U_{ct}} \frac{1}{MCF_t} \right] \left[\frac{\partial T_{t+j}}{\partial E_t^M} \right]}_{\text{Utility damages}} \tag{40}$$

This formula is derived by combining a social planner's first-order conditions with the profit-maximizing conditions of energy producers. The presence of distortionary taxes drives a wedge between the public and private valuation of damages, a concept captured by the MCF_t. The component for utility damages is divided by the MCF_t, which means that if taxes are distortionary ($MCF_t > 1$), these non-market welfare losses are not fully internalized. In contrast, the valuation of production damages depends on the evolution of the public marginal utility of income over time, $\lambda_{1t+j}/\lambda_{1t}$. This differential treatment arises because mitigating utility damages is analogous to government consumption, while mitigating production damages is analogous to an investment in future output.

7 Calibrating Institutional Quality Parameter Using WGI

This paper represents 'institutional quality' through Ω_t. To quantify this, an appropriate proxy for institutional quality must be constructed. The WGI framework is used for this purpose, as it offers a robust measure of governance quality across more than 200 countries, making it suitable for calibrating the model. It summarizes governance perceptions into six aggregate indicators. Each dimension maps directly to the theoretical channels through which Ω_t affects welfare in our model:

i **Voice and Accountability:** This measures citizen participation and freedoms[10]. High accountability aligns

[10] Acemoglu et al. (2019) provide evidence that a permanent transition to democracy leads to a long-run increase in GDP per capita of about 20–25%. Their analysis further suggests that democracy is not detrimental to growth in poorer countries, though its positive impact is amplified in settings with higher levels of secondary education. Moreover, Heo and Tan (2001), using Granger causality tests for 32 developing nations, find no consistent causal direction, with results varying considerably across the sample. Specifically, they report that economic growth precedes democracy

public policy with citizen welfare, enhancing the value of public goods and ensuring economic gains are broadly shared. This mechanism corresponds to the **consumption channel** ($\alpha_{\textbf{inst}}$), where a higher Ω_t amplifies the utility from consumption, c_t, through the term $(1 + \Omega_t)^{\alpha_{\text{inst}}}$.

ii **Political Stability and Absence of Violence/Terrorism:** This captures the likelihood of political instability. High stability reduces uncertainty, which is crucial for long-term investment and stable labor markets. This stability primarily affects the **labor channel (**$\gamma_{\textbf{inst}}$**)**, reducing the stresses associated with work and lowering the disutility of labor through the term $(1 + \Omega_t)^{\gamma_{\text{inst}}}$.

iii **Government Effectiveness:** This measures the quality of public services and policy implementation. An effective government can build resilient infrastructure, run public health systems, and implement environmental policies efficiently. This has a powerful effect on the **climate resilience channel (**$\kappa_{\textbf{inst}}$**)**, justifying the term $(1 + \Omega_t)^{-\kappa_{\text{inst}}}$, and also strongly supports the consumption channel (α_{inst}).

iv **Regulatory Quality:** This captures the ability of the government to formulate sound policies that promote private sector development. High-quality regulation reduces the burden of compliance, making economic activity less onerous. This maps directly to a lower disutility of labor, corresponding to the **labor channel (**$\gamma_{\textbf{inst}}$**)**.

v **Rule of Law:** This measures confidence in the rules of society, particularly contract enforcement and property rights. A strong rule of law is the bedrock of a low-transaction-cost economy, enhancing both consumption and labor utility. This strengthens both the **consumption channel** ($\alpha_{\textbf{inst}}$) and the **labor channel (**$\gamma_{\textbf{inst}}$**)**.

vi **Control of Corruption:** This captures the extent to which public power is exercised for private gain. Low corruption[11] ensures that public funds are used for their intended purpose (e.g., climate adaptation) and that private transactions are not subject to arbitrary expropriation. This directly impacts the **climate resilience channel (**$\kappa_{\textbf{inst}}$**)** and supports the consumption and labor channels (α_{inst} and γ_{inst}).

To incorporate the empirical WGI scores, which range from -2.5 to $+2.5$, into the theoretical framework, a logistic transformation is applied. This transformation maps the original scores into the interval 0 to 1.

$$\Omega_t = \frac{1}{1 + e^{-\text{WGI}_t}}. \tag{41}$$

This transformation is well-suited for our model for three reasons. First, it is **bounded** and **monotonic**, ensuring that institutional quality improves in a controlled and economically interpretable manner as WGI increases. Second, its

in 34% of cases, democracy precedes growth in 31%, and roughly one-quarter of the countries display no significant causal link. Gerring et al. (2005) emphasize the role of a nation's accumulated democratic experience, or "democratic stock", showing that it has a strong positive effect on economic performance, unlike contemporaneous democratic status. Their estimates indicate that in a country with no prior democratic history, a decade of high-quality democratic governance can raise the annual growth rate by nearly 0.7%.

[11] Strong formal institutions, such as effective laws and governance, help restrain corruption, whereas weak ones often intensify it. In contrast, informal institutions like cultural norms may reinforce corrupt practices. For instance, high collectivism and elevated *power distance*–the acceptance of unequal power hierarchies as legitimate–can normalize authority imbalances and weaken ethical conduct (Boateng et al., 2024).

sigmoidal form embodies **diminishing marginal returns**, reflecting the empirical observation that improvements in weak institutions generate larger welfare gains than marginal reforms in already strong institutional environments. Third, the function is **smooth and differentiable**, a property essential for stable numerical optimization.

Importantly, the logistic transformation is consistent with macroeconomic dynamics where institutional quality evolves gradually and shows persistence, similar to lagged adjustments in GDP or productivity. The S-shaped curve reflects this inertia by allowing slow movements at low and high levels of institutional quality while permitting more responsive changes in the middle range. Using the logistic mapping, therefore, enables the model to match both the empirical scale of the WGI and the temporal pattern of institutional evolution, yielding a measure of Ω_t that is theoretically sound and empirically grounded. The table below presents the parameters employed in the model.[12]

Table 1: Calibrated parameters used in the model

Parameter	**Value**	**Description**
β	0.985	Discount factor determining intertemporal preferences.
σ	1.5	Coefficient of relative risk aversion (CRRA).
ϵ_f	0.78	Frisch elasticity of labour supply.
θ	0.0021	Climate damage coefficient in the utility function.
α_{inst}	0.2	Institutional sensitivity of consumption utility.
γ_{inst}	0.1	Institutional reduction of labour disutility.
κ_{inst}	0.15	Institutional mitigation of climate-related welfare losses.

8 Propositions and Proofs

Proposition 1 (Institutions as a Welfare Multiplier)**:** *For any given allocation of physical consumption and labor, a higher level of institutional quality directly increases societal welfare by amplifying the utility from consumption and mitigating the disutility from labor.*

Authors analyze the components related to consumption and labor for a fixed (C_t, L_t) and prove they are increasing in Ω_t, as stated below:

i. Consumption Component: The utility from consumption, $U(C_t)$, is a function of 'effective consumption', defined

[12] All other parameters used in the model are taken from the calibration values provided by Barrage (2020) and Nordhaus (2008).

as $C_t^{\text{eff}} = C_t(1+\Omega_t)^{\alpha_{\text{inst}}}$. The partial derivative of the consumption utility component with respect to Ω_t is:

$$\frac{\partial U_c}{\partial \Omega_t} = \frac{\partial}{\partial \Omega_t}\left[\frac{(C_t(1+\Omega_t)^{\alpha_{\text{inst}}})^{1-\sigma}-1}{1-\sigma}\right] \tag{42}$$

$$= (C_t(1+\Omega_t)^{\alpha_{\text{inst}}})^{-\sigma} \cdot C_t\alpha_{\text{inst}}(1+\Omega_t)^{\alpha_{\text{inst}}-1} \tag{43}$$

$$= C_t^{1-\sigma}\alpha_{\text{inst}}(1+\Omega_t)^{\alpha_{\text{inst}}(1-\sigma)-1} \tag{44}$$

Assuming $\alpha_{\text{inst}} > 0$, this expression is strictly positive. Thus, the utility derived from any given level of consumption C_t is increasing in Ω_t.

ii. Labor Component: The disutility from labor is given by $D_L(L_t) = \frac{L_t^{1+1/\epsilon_f}}{1+1/\epsilon_f}(1+\Omega_t)^{-\gamma_{\text{inst}}}$. Its partial derivative with respect to Ω_t is:

$$\frac{\partial D_L}{\partial \Omega_t} = \frac{L_t^{1+1/\epsilon_f}}{1+1/\epsilon_f} \cdot (-\gamma_{\text{inst}})(1+\Omega_t)^{-\gamma_{\text{inst}}-1} \tag{45}$$

Assuming $\gamma_{\text{inst}} > 0$, this derivative is strictly negative. This means that an increase in institutional quality Ω_t decreases the disutility associated with any given level of labor supply L_t. Since higher institutional quality increases the utility from consumption and decreases the disutility from labor, it increases the total welfare derived from any non-trivial economic allocation.

Proposition 1 formalizes that governance quality is a core determinant of well-being. Strong institutions—secure property rights, rule of law, and low corruption—enhance both consumption and labor-market conditions. For instance, owning a home (C_t) yields greater welfare when land rights and public services are reliable (high Ω_t), and the same 40-hour work week (L_t) is less taxing under robust labor protections. Institutional quality, therefore, amplifies overall quality of life in ways not captured by income alone.

Proposition 2 (Institutions as a Climate Shield): *The optimal first-best carbon tax, equivalent to the SCC, is a decreasing function of institutional quality.*

How Institutions Mitigate Utility Damages

Climate change directly impacts human well-being through factors such as health effects or disaster-related stress. The model captures this as a direct disutility from rising temperatures, T_t. The instantaneous utility function contains the term for climate disutility, which is dependent on institutional quality, Ω_t:

$$\text{Disutility from Climate Change}_t = -\theta T_t^2(1+\Omega_t)^{-\kappa_{\text{inst}}} \tag{46}$$

where $\theta > 0$ is the climate damage coefficient and $\kappa_{\text{inst}} \geq 0$ captures the sensitivity of this disutility to institutional quality.

To find the marginal harm of a small increase in temperature, consider the partial derivative of the utility function with respect to temperature. The magnitude of this marginal disutility is:

$$|U_{T_t}| = \left| \frac{\partial U_t}{\partial T_t} \right| = \left| -2\theta T_t (1+\Omega_t)^{-\kappa_{\text{inst}}} \right| = 2\theta T_t (1+\Omega_t)^{-\kappa_{\text{inst}}} \tag{47}$$

This equation shows that as institutional quality (Ω_t) increases, the term $(1+\Omega_t)^{-\kappa_{\text{inst}}}$ decreases (assuming $\kappa_{\text{inst}} > 0$). This directly reduces the marginal harm caused by a rise in temperature. The component of the SCC that internalizes these direct welfare losses, τ_E^U, is the present discounted value of all future marginal disutilities, $|U_{T_{t+j}}|$. Since τ_E^U is proportional to $(1+\Omega_t)^{-\kappa_{\text{inst}}}$, it follows that τ_E^U is a strictly decreasing function of Ω_t.

This proposition captures the concept of **institutional resilience**. A physical climate event, like a hurricane, is not equivalent to the resulting economic and social disaster. Strong institutions act as a societal 'immune system' that mitigates the harm. A well-governed country (high Ω_t) can implement effective adaptation measures, leading to less suffering and economic loss from the same physical temperature change (Adom and Amoani, 2021). Since the carbon tax is the price placed on this suffering and loss, a lower level of realized damage justifies a lower tax.

Table 2: Concise Categorization of Climate Damages

Impact Category	**Type**	**Explanation**
Agriculture	Production	Direct impacts on crop yields, livestock, and farm output.
Other Vulnerable Markets	Production	Effects on forestry, fisheries, and energy services.
Sea-Level Rise	Production	Damage to physical capital (buildings, infrastructure).
Supply Chain Disruption	Production	Extreme weather damaging logistics and trade.
Amenity Value	Utility	Loss of enjoyment from pleasant climate or nature.
Ecosystems	Utility	Value of biodiversity and healthy ecosystems.
Human (Re)settlement	Utility	Disutility of forced migration and social disruption.
Loss of Cultural Heritage	Utility	Destruction of historical sites and traditions.
Catastrophic Damages	Mixed	Low-probability, high-impact irreversible events.
Health	Mixed	Productivity loss plus direct suffering and mortality.
Political Instability and Conflict	Mixed	Climate as "threat multiplier," causing unrest.

The SCC captures the marginal external damages from an additional unit of emissions, reflected in both direct utility losses and reduced economic production. We show that stronger institutions lessen the severity of these damages. Table 2 summarizes the key channels through which rising temperatures and broader climate change affect economies and societies: declines in agricultural productivity; vulnerabilities in sectors such as forestry, fisheries, and energy; infrastructure losses from sea-level rise and extreme events; reduced amenity values and ecosystem degradation; disutility from forced migration; and risks to cultural heritage. Mixed categories of damages capture both utility and production losses, such as catastrophic low-probability events, adverse health outcomes involving reduced labor productivity and higher mortality, and political instability where climate acts as a 'threat multiplier', amplifying the risk of social conflict and unrest.[13]

Proposition 3 (Institutions and Fiscal Efficiency): *In a second-best world with distortionary taxation, stronger institutions, by improving fiscal efficiency and lowering the MCF, exert upward pressure on the optimal carbon tax, pushing it closer to the full SCC.*

In a second-best setting where revenues are raised through distortionary taxes, the optimal tax on an externality causing pure utility damage is the first-best Pigouvian value discounted by the MCF.

$$\tau_{Et}^{*,U} = \frac{\tau_{Et}^{Pigou,U}}{MCF_t} \tag{48}$$

The MCF reflects the welfare cost of raising one additional dollar of public funds, and with distortionary taxes, $MCF_t > 1$. Stronger institutions (e.g., lower corruption, efficient administration) reduce tax evasion and the economic distortions required to raise a given amount of revenue. We formalize this as $MCF_t = f(\Omega_t)$, where the function f is decreasing, i.e., $f'(\Omega_t) < 0$. As institutional quality Ω_t increases, MCF_t falls towards its theoretical minimum of 1. Consequently, the discount factor applied to the Pigouvian tax, $1/MCF_t$, increases:

$$\frac{\partial}{\partial \Omega_t}\left(\frac{1}{MCF_t}\right) = -\frac{1}{MCF_t^2}\frac{\partial MCF_t}{\partial \Omega_t} > 0 \tag{49}$$

This implies that for any given Pigouvian value $\tau_{Et}^{Pigou,U}$, a higher level of institutional quality Ω_t justifies a smaller downward adjustment from the first-best tax. The optimal tax $\tau_{Et}^{*,U}$ therefore moves closer to $\tau_{Et}^{Pigou,U}$ as Ω_t improves. This constitutes an upward pressure on the optimal tax level. This proposition highlights the "tax interaction effect". Imposing a carbon tax in an economy with already-high taxes on labor or capital can exacerbate existing distortions, for instance by lowering real wages and shrinking the labor tax base. To account for this harmful interaction, the optimal carbon tax is set below the true cost of the environmental damage. The size of this downward adjustment is determined by the inefficiency of the tax system (as measured by the MCF).

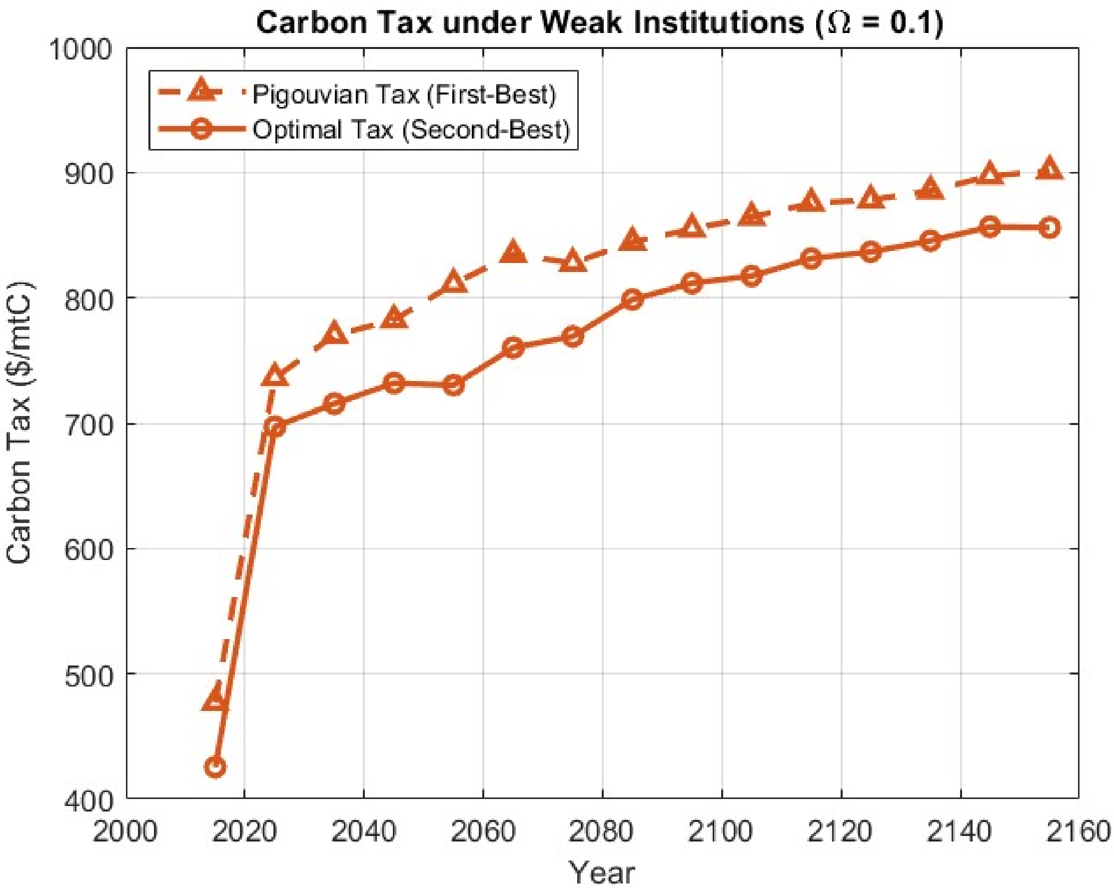
In a country with weak institutions (low Ω_t), the tax system is very inefficient and distortionary (high MCF). Therefore, a larger discount must be applied to the carbon tax to avoid causing excessive collateral economic damage. Conversely, a country with strong institutions (high Ω_t) has an efficient tax system (low MCF). Because its existing taxes are less distortionary, the harmful interaction with a new carbon tax is smaller. This allows the government to set a carbon tax that is much closer to the true environmental cost without fearing excessive economic side effects.

[13] Burke et al. (2015) find that a 1°C rise in local temperature is linked to an average 2.1% increase in interpersonal conflict and an 11.3% increase in intergroup conflict.

9 Illustrative Simulation

Theoretical propositions regarding the structure of optimal carbon taxation can be illustrated through a simulation.[14] Consider an economy characterized by weak institutions, parameterized by a low and constant value of institutional quality, $\Omega = 0.1$. In such an environment, the fiscal system is presumed to be inefficient, leading to a high MCF.

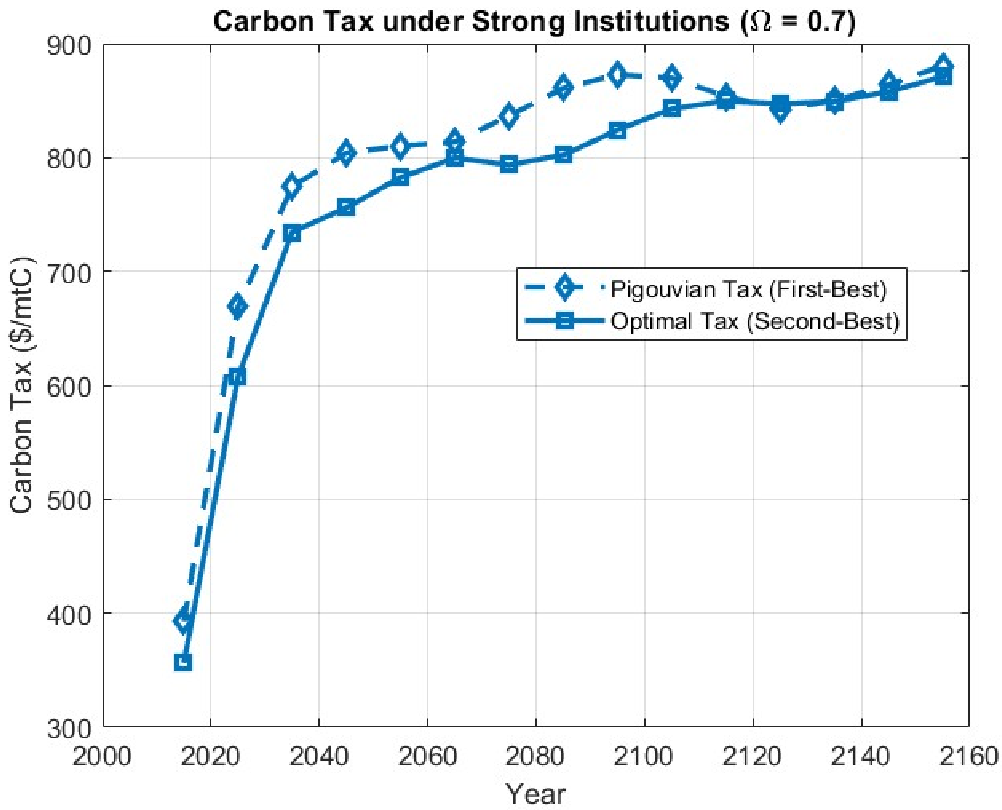
Figure 2: Optimal vs. Pigouvian Carbon Tax Trajectories under Weak Institutions.



Figures 2 and 3, respectively, depict the evolution of the Pigouvian tax (first-best) and optimal carbon tax (second-best) paths for the respective weak and strong institutions. The Pigouvian tax is set precisely at the marginal SCC, representing a theoretical ideal that ignores other economic distortions. In contrast, the optimal tax is set at a lower rate to account for the tax-interaction effect, a real-world phenomenon where a new carbon tax amplifies the efficiency losses of pre-existing taxes (e.g., on income) by reducing the real value of wages. This necessary downward adjustment from the Pigouvian benchmark to mitigate these compounded economic costs is termed the fiscal discount. The magnitude of this fiscal discount is fundamentally determined by institutional quality. Figure 2 depicts the optimal and Pigouvian tax under weak institutions and shows a large and persistent gap between the two tax paths. This is because

[14] A metric ton of carbon (mtC) measures the mass of pure carbon, whereas a metric ton of CO_2 ($mtCO_2$) includes the added weight of oxygen, making it heavier. Thus, prices quoted in \$/mtC should not be confused with those in \$/$mtCO_2$, as 1 mtC = 3.664 $mtCO_2$.

Figure 3: Optimal vs. Pigouvian Carbon Tax Trajectories Under Strong Institutions.



a high MCF makes the tax-interaction effect severe, necessitating a substantial discount to protect economic welfare. Under weak institutional quality ($\Omega = 0.1$), initial carbon taxes are significantly higher, starting near $425/mtC for the SB policy and approximately $480/mtC for the FB. The difference between the two tax paths remains sizable (about $40–$60) over time, and the FB tax reaches nearly $900/mtC by 2150. Conversely, Figure 3 depicts the optimal and Pigouvian tax under the strong institutions, where the low MCF minimizes this negative interaction. In the case of strong institutional quality ($\Omega = 0.7$), the carbon tax in 2015 starts at roughly $360/mtC under the SB policy and about $390/mtC under the FB policy. Both tax paths rise sharply, reaching nearly $600/mtC and $670/mtC, respectively, by 2020. Beyond this point, the gap between the two policy regimes narrows progressively.

9.1 The Economic Dividend of Low Abatement Costs

The total cost of abatement as defined by Barrage (2020) is as follows,

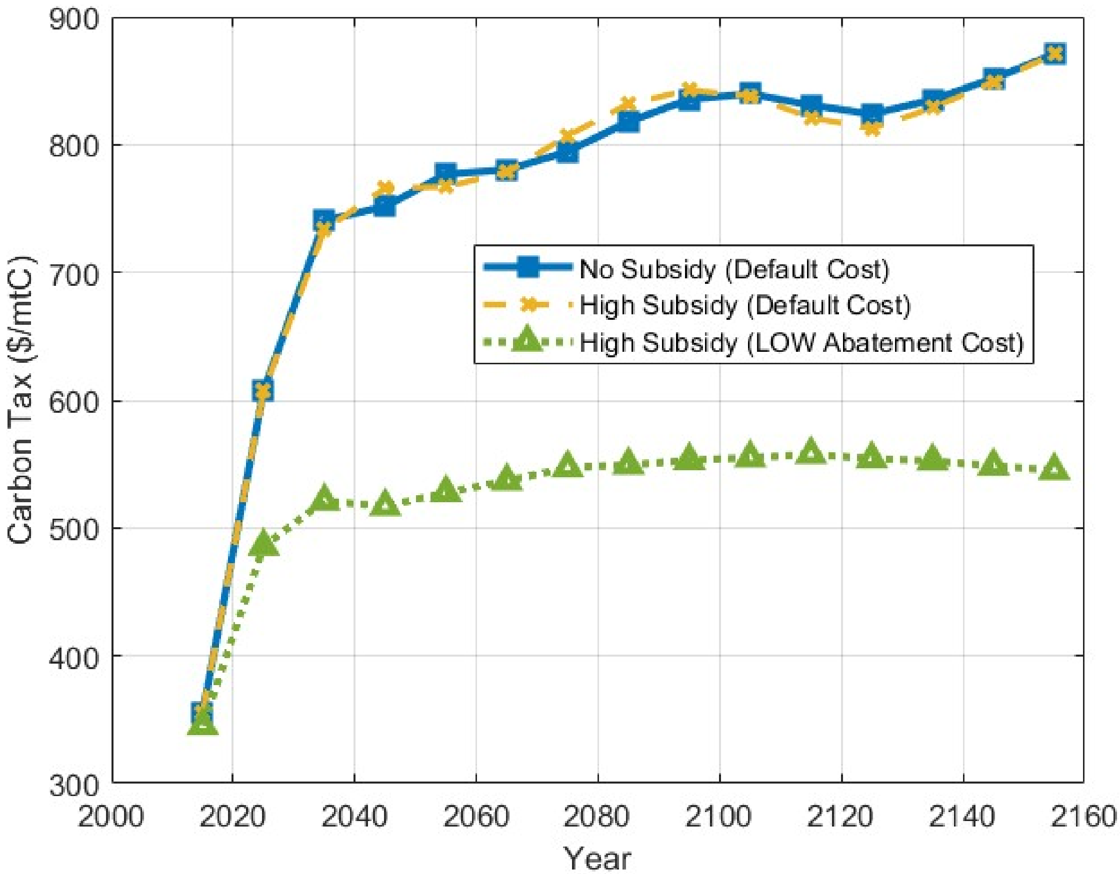
$$\Theta_t(\mu_t E_t) = \frac{a\, P_t^{\text{backstop}}}{1 + a_t \exp\big(b_{0t} - b_{1t}(\mu_t E_t)\big)^{b_2}}\,(\mu_t E_t) \tag{50}$$

The cost of climate change abatement represents a fundamental trade-off for an economy. Within the model's framework, this can be clearly inferred from the economy-wide resource constraint, which dictates that total output must be allocated among competing uses. As specified in the model's formulation, the total cost of abatement, $\Theta_t(\mu_t E_t)$, is directly subtracted from the aggregate resources available in the economy. This expenditure is a necessary defensive investment to mitigate future climate damages, but it comes at an immediate opportunity cost: every dollar spent on abatement is a dollar that cannot be allocated to consumption or welfare-enhancing investment in physical capital. Therefore, a lower abatement cost yields a direct and significant economic dividend. As clean energy technology becomes cheaper and more efficient, a smaller fraction of the nation's total output will be required to meet its climate goals. This efficiency gain frees up substantial economic resources. The immediate consequence is that more output is available for household consumption (C_t), which directly increases utility and, consequently, leads to better standards of living. Concurrently, more resources can be channelled into capital investment, which enhances future productivity and ensures higher levels of consumption for future generations. A **backstop technology** is an innovation, such as advanced solar or nuclear fusion, that can serve as a perfect substitute for fossil fuels (Nordhaus, 2008). Its price, denoted as P_t^{backstop}, is modeled as being initially high but declining over time due to anticipated technological progress—a process that can be accelerated by the stable policy environments and R and D support associated with strong institutions (Alam et al., 2019). The primary economic function of the backstop price is to establish a crucial ceiling on the abatement cost, because a rational economy will not pay more to reduce emissions than the cost of deploying this ultimate clean energy solution. This dynamic ensures that the long-run cost of decarbonization becomes progressively more feasible over time. This mechanism reveals the profound economic benefit of strong institutions (Donges et al., 2023). By fostering an environment that enhances technological progress and productivity, robust institutional frameworks lower abatement costs and facilitate a smoother transition to a more sustainable energy system. The resulting efficiency not only makes climate policy more effective but also materially improves social welfare. A country's ability to sustain high consumption levels while decarbonizing its economy depends on the quality of its institutions. Stronger institutions are consistently linked to higher productivity and innovation, enabling effective decarbonization strategies (Sivaram and Norris, 2016).[15]

A key policy question is whether subsidies for clean technology can serve as a substitute for a direct tax on carbon emissions. The direct R and D subsidies for renewables are the most effective policy, with a one-standard-deviation increase boosting green patents by $\sim 45\%$, outperforming taxes and regulation. The R and D subsidies can help successfully obtain the new green technologies needed in the future to combat climate change (Gugler et al., 2024). Acemoglu et al. (2012) argue that combining (temporary) R and D subsidies with carbon taxes is an effective strategy to steer technological progress towards cleaner innovations. Furthermore, it is critical to understand how the underlying cost of abatement technology influences the optimal carbon price. We explore these interactions through

[15] Institutional robustness has been shown to foster corporate green innovation, highlighting the pivotal role of governments in advancing environmental protection through the enforcement of coercive instruments such as legislation and regulation (Chen et al., 2018).

Figure 4: Impact of Subsidies and Abatement Technology Cost on the Optimal Carbon Tax.

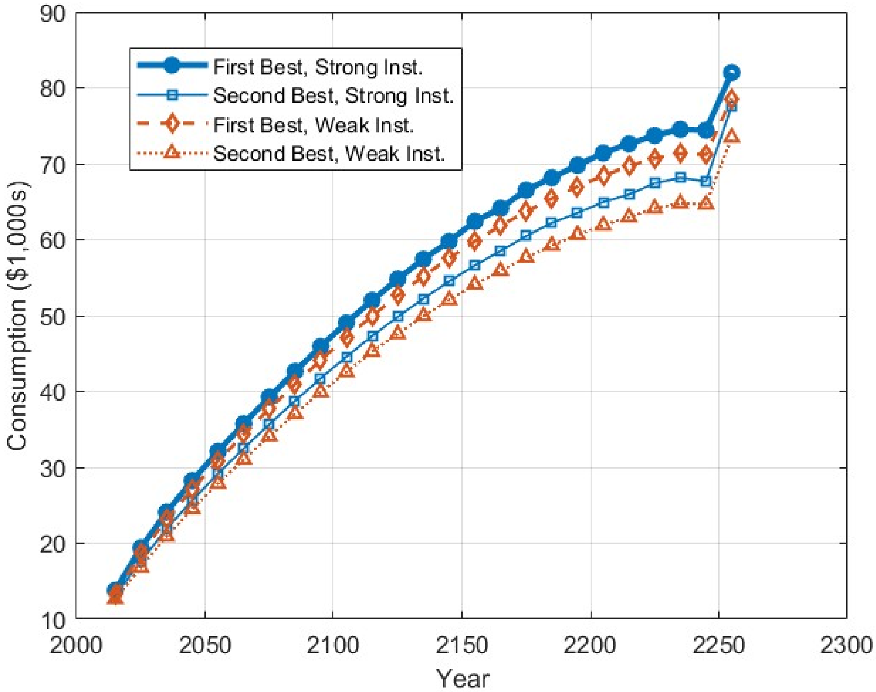


a simulation, comparing the optimal carbon tax path under different policy and cost scenarios. Figure 4 illustrates the optimal carbon tax under three distinct conditions: a baseline with no subsidies, a case with high subsidies for clean energy, and a case that combines high subsidies with low-cost abatement technology. The simulation results yield two key insights. First, a subsidy for clean energy is not a direct substitute for a carbon tax.[16] The optimal tax path remains almost unchanged when a subsidy is introduced, as the tax is still required to internalize the damages from emissions that continue to occur. Second, the cost of abatement technology is a critical determinant of the optimal tax level. Lower abatement technology costs substantially reduce the expense of clean energy production, enabling society to meet emission reduction goals through significantly lower carbon pricing mechanisms. This relationship is clearly demonstrated by the marked variation observed in the third scenario.

Figure 5 depicts an intuitive visualization of long-term economic growth, which plots per capita consumption from

[16] Figure 4 compares three scenarios. The dark line with square markers represents the baseline optimal carbon tax path, assuming default technology costs and no subsidies. The dashed line with x-markers illustrates that introducing a high subsidy for clean energy has a negligible impact on the optimal carbon tax. This illustrates that a subsidy for a substitute good (clean energy) does not eliminate the need to directly price the negative externality of pollution. The dotted line with triangle markers shows that the optimal carbon tax is substantially lower when the cost of abatement technology is low.

Figure 5: Consumption Trajectories Under Different Scenarios

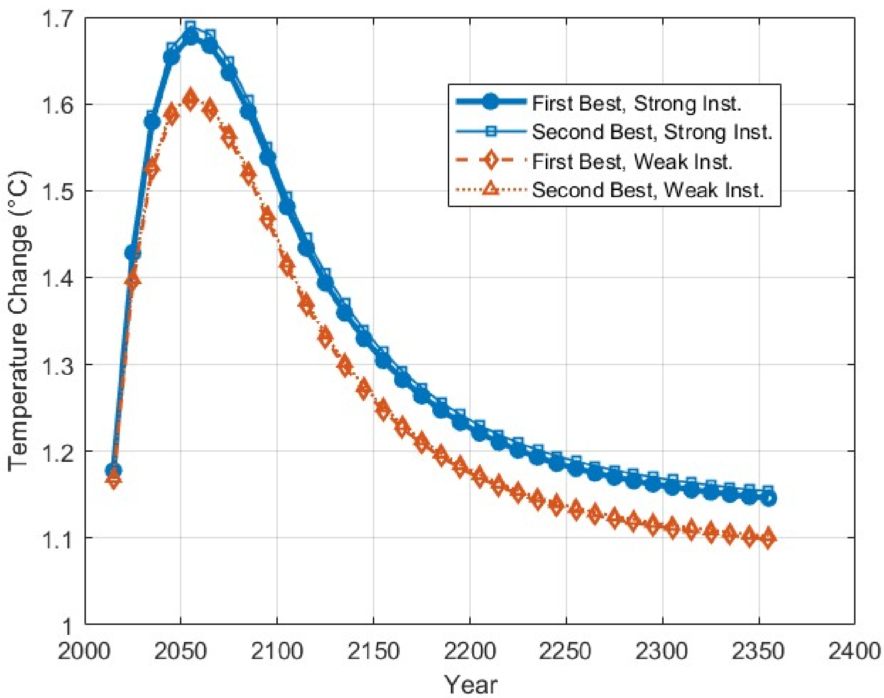


the early 21^{st} century to the mid-23^{rd} century. The figure compares four distinct scenarios based on the quality of institutions (Strong vs. Weak) and the economic policy environment (FB vs SB). Figure 5 presents a unified narrative of long-term economic development, illustrating a clear projection of rising per capita consumption across all four simulated futures, which suggests a fundamental baseline of continuous growth. However, the specific paths diverge significantly, with the quality of governance emerging as a crucial factor in achieving prosperity. At every point in time, both FB and SB consumption levels are consistently higher under strong institutions than under weak ones, clearly demonstrating that effective institutional frameworks foster greater per capita consumption. In parallel, the analysis underscores the importance of the policy environment by contrasting a theoretically ideal FB world with a more constrained SB reality. The consistent gap between the higher FB paths and the lower SB paths highlights the real economic welfare costs imposed by operating with certain economic frictions such as tax imposed on labor income. These two drivers–institutional quality and policy efficiency–compound over the decades. The ever-widening gulf between these best and worst-case scenarios powerfully demonstrates how foundational differences in governance and economic structure can amplify over generations into vast disparities in prosperity.

9.2 Temperature Anomaly

In climate science, a temperature anomaly refers to the deviation from a long-term average or baseline, rather than the absolute temperature. The baseline is typically a multi-decade period from the past, often a pre-industrial period (e.g.,

Figure 6: Projected Temperature Anomaly Above Pre-Industrial Levels



1850-1900), before human greenhouse gas emissions significantly altered the climate. At first glance, the results in Figure 6 might seem counterintuitive: why do scenarios with **strong institutions** lead to a higher peak temperature anomaly than those with weak institutions? The intuition can be inferred by linking climate outcomes to economic activity. Stronger institutions foster more rapid economic growth, which in the short-to-medium term leads to higher energy demand and emissions, causing a greater temperature "overshoot" before climate policies and technological transitions can fully take effect and stabilize the climate. This intuition can be clarified by examining the interaction between economic growth and climate dynamics within the model:

i. **Economic Growth Effect:** As demonstrated in the Figure 5, robust institutional frameworks leads to elevated levels of total consumption. A larger and more productive economy increases its energy demand, which in the early decades (e.g., 2020–2060) is still predominantly satisfied through fossil fuels. Consequently, emissions rise more sharply than in economies with weaker institutions.

ii. **Policy Transition Lag:** The model indicates that all scenarios eventually implement policies to reduce emissions (as evidenced by the peak and subsequent decline in temperature). Yet, these interventions occur with a delay as the capital stock transitions from carbon-intensive to cleaner technologies. During this adjustment, the scale of the strong-institution economy sustains higher emissions, resulting in a more pronounced temperature peak around 2060.

iii. **Eventual Decarbonization:** The post-peak decline in temperature reflects the effectiveness of climate policies in the long run. The shift toward a decarbonized energy system gradually reduces greenhouse gas concentrations, allowing the climate to cool after its peak.

iv. **Long-Term Stabilization:** Strong-institution economies, however, stabilize at a marginally higher long-term temperature. This outcome can be interpreted as a consequence of the initial overshoot, where pushing the climate to a higher peak may trigger feedback mechanisms or lock in a certain degree of warming. Thus, while strong institutions foster greater prosperity, the model highlights a potential risk of more pronounced short-term climate impacts if the transition to a green economy is not immediate.

In fact, the model offers an interesting insight that economic prosperity often precedes environmental improvement. Strong institutions accelerate economic growth so rapidly that the associated emissions temporarily outpace the implementation of climate solutions, leading to a higher but eventually controlled temperature anomaly.

10 Conclusion

A country's ability to build a prosperous and sustainable future eventually depends on the foundation of its institutions. Furthermore, the role of institutions in mitigating the impacts of climate change has emerged as a cornerstone of contemporary research. The analysis collectively models the economic ramifications that stem from the intersection of climate policy design and the quality of governing institutions. Theoretical understanding suggests that a FB (Pigouvian tax) should perfectly internalize the marginal social cost of carbon emissions. In contrast, a SB optimal tax is pragmatically set lower to minimize adverse interactions with pre-existing fiscal distortions, such as labor taxes. The simulation results quantitatively affirm this principle, with the FB carbon tax rate consistently exceeding the SB rate under all conditions. Over time, tax schedules continue to increase, reflecting the growing costs of climate damage. This upward trend stems from the fact that as greenhouse gases accumulate in the atmosphere, the harm they cause becomes progressively more severe, requiring stronger corrective measures.

In a scenario with robust institutions ($\Omega = 0.7$), the carbon tax begins around 2015 at approximately \$360/mtC for the SB policy and \$390/mtC for the FB policy, before undergoing a rapid escalation to \$600/mtC and \$670/mtC respectively by 2020, after which the differential between the two policies gradually decreases. In weak institutional settings ($\Omega = 0.1$), carbon taxes begin at much higher levels—around \$425/mtC under the SB policy and \$480/mtC under the FB. The gap between the two remains substantial (\$40–\$60) throughout the period, with the FB tax climbing close to \$900/mtC by 2150. An analysis of welfare outcomes, measured by per capita consumption, reveals a distinct ranking of prosperity. That is, it shows that a FB policy with a strong institution yields the best possible scenario of the standard of living. Notably, the ordering of the subsequent scenarios highlights the crucial role of institutional quality; when institutions are strong, SB policy delivers better outcomes than a SB policy implemented under weak institutions. The analysis suggests that long-term social welfare is contingent on both institutional quality and the effective implementation of efficient environmental policies. This implication is evident by the growing gap in economic well-being over time: an initial difference of approximately $3,000 in 2025 between the most and least favorable scenarios expands to $17,000 by 2250.

Effectively, the institutional quality is a foundational determinant of a country's capacity to achieve both long-term economic prosperity and effective climate change mitigation. It implies a trade-off, where strong institutions unequivocally foster higher long-term growth and per capita consumption. In consequence, accelerated economic activities can lead to a more pronounced near-term temperature anomaly. Furthermore, it implies that the immense economic capacity unlocked by strong institutions must be proactively directed toward a sustainable trajectory with robust carbon pricing. In fact, the efficient second-best carbon tax must be carefully calibrated below the theoretical Pigouvian benchmark to account for interactions with the existing fiscal system.

Several immediate research questions for future work have emerged, such as – model the heterogenous agent and recalibrate the concept, which can transition from the standard Ramsey model to a Diamond overlapping generations framework, thereby capturing intergenerational dynamics and diverse agent characteristics more effectively. Second, modelling the computational linguistics to examine climate policy discourse, specifically, the use of natural language processing to analyze the sentiment and content of climate-related grievances submitted by various countries within international forums.

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