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Ratchening up Paris

Thomas Stoerk, John E. Roemer and Humberto Llavador

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Ratcheting up Paris*

Humberto Llavador† John Roemer‡ Thomas Stoerk§

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Abstract

The Paris Agreement is designed to increase climate ambition gradually through a process of ratcheting up. What is the plausible endpoint of this process? We develop a tractable integrated assessment model in which countries interact through a decentralized general equilibrium and negotiate unanimously over a global carbon budget, with all mitigation implemented via a global carbon price. We prove existence and uniqueness of a unanimous international agreement on global emissions, in which carbon pricing revenues are redistributed across countries in proportion to marginal climate damages. In a quantitative application for 154 countries, the resulting equilibrium limits global mean surface temperature change to 1.51°C, at a carbon price of 320 USD/tCO_2. The associated international transfers of carbon pricing revenue are progressive toward lower-income countries and amount to about 0.8% of global GDP annually - an order of magnitude larger than the Paris Agreement's climate finance target.

Keywords: Paris Agreement, climate policy, international environmental agreement, climate economics

JEL: Q54, Q56, Q58, F35, F53.

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†Universitat Pompeu Fabra and Barcelona School of Economics. Corresponding author: humberto.llavador@upf.edu.
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‡Yale University.

§National Bank of Belgium, LSE, and CEPR.

1 Introduction

In the 2015 Paris Agreement, the world committed to limiting climate change to 2°C, and to pursuing policies to limit it to 1.5°C. Nevertheless, the world is currently on track to 2.8°C (Mobir et al., 2025). The IMF estimates that existing climate targets achieve only 20% of required cuts in greenhouse gas emissions by 2030 (Black, Parry and Zhunussova, 2023), illustrating the lack of legislated climate ambition. This mismatch between aspiration and current reality is by design. The Paris Agreement is a cooperative agreement. Instead of relying on a sanctioning mechanism, the Paris Agreement is designed to work through a virtuous cycle: stricter mitigation targets by one party should make it easier for other parties to commit to stricter mitigation targets in turn.

This logic stands in contrast to standard international environmental agreement theory, which predicts underprovision of mitigation without enforcement (Barrett, 2003, Nordhaus, 2015). Nonetheless, post-Paris mitigation pledges have tightened, suggesting scope for "ratcheting up". Before the signing of the Paris Agreement in 2015, 3.7°C of warming was the likely outcome (Stavins, 2021). Now, projected warming by end of century has dropped by nearly 1°C (Mobir et al., 2025), which gives room for cautious optimism about humanity's ability to limit dangerous anthropogenic interference with the climate system.

Parties to the Paris Agreement regularly compare ambition through their nationally determined contributions (NDCs) as well as the mid-century strategies. Ratcheting up of climate policy ambition is further institutionalized through the global stocktake, a regular review process to compare ambition across parties to the Paris Agreement. The first global stocktake started in November 2021 and concluded in the Global Stocktake Decision at COP28, which highlighted the need to invest ca. US$ 4.3 trillion per year until 2030 into decarbonized energy.[1]

In this paper, we abstract from this *process* and instead ask what the *end result* of such a virtuous circle could look like. If Paris kept tightening its ambition through repeated negotiations, where would it plausibly converge?

To answer this question, we build a tractable integrated assessment model which couples a general-equilibrium and a unanimity-negotiation model to endogenize (i) global emissions, (ii) temperature outcomes, (iii) carbon prices, and (iv) international climate finance transfers. Through this model, which mimics the key cooperative dimension of the Paris Agreement, we prove existence and uniqueness of a global unanimity general equilibrium. In equilibrium, emission and abatement decisions are decentralized at the country level, while governments unanimously agree upon the carbon budget, and global carbon pricing revenue is distributed to countries proportional to their marginal climate damages. This equilibrium represents what countries could

[1] Note that the stocktake tries to raise the ambition of both pledges and policies. In this article, we are concerned with what countries will actually do: the policies. For recent work on the Paris process, see Harstad (2023*a*,*b*). More detail on the global stocktake is available from the UNFCCC at https://unfccc.int/topics/global-stocktake.

credibly commit to today through the future, taking into account future climate damages. It thus describes a plausible end game of what ratcheting up of ambition in the Paris Agreement would look like. Carbon pricing moreover acts as a useful policy-relevant instrument benchmark (Aviso et al., 2024).

To obtain quantitative insights, we calibrate our model on IPCC climate science, economic climate impact estimates, and abatement cost estimates along with standard macroeconomic data sources for 154 countries, representing over 98% of the world's population, GDP, and emissions. Solving the calibrated model in Mathematica, we derive two key sets of variables: greenhouse gas emissions that all countries would agree to, as well as the financial flows required to reach this emission level if the agreement were implemented solely through carbon pricing. Together, these estimates allow us to provide an economic estimate for the viability of the Paris Agreement's temperature target, as well as for the magnitude of international climate finance.

We find that there is room for optimism: in our calibration, ratcheting up of the Paris Agreement is feasible. In equilibrium, the increase in global mean surface temperature is limited to 1.51°C, close to the Paris Agreement's 1.5°C ambition and well below its 2°C temperature target. The global carbon price required to reach the necessary mitigation is 320 USD/tCO_2, which yields annual international climate finance flows of 2.3 trillion USD — or 0.8% of global GDP, which is ca. 20 times the often overlooked climate finance ambition of the Paris Agreement.[2] Overall carbon pricing revenue yields 7 trillion USD per year, the same order of magnitude that is considered necessary for mitigation investments towards climate neutrality. Moreover, climate finance is progressive overall, implying fiscal transfers from higher-income to lower-income countries on average, despite the absence of an explicit redistributive mechanism or preferences for redistribution. The reason is that climate finance is proportional to marginal climate damages in each country, with lower-income countries bearing greater impacts of climate change. For the same reason, international climate finance benefits lower-income recipient countries relatively more than its cost to higher-income donor countries.

To study the robustness of our results, we show that uncertainty about abatement cost and climate damages has a limited impact about what ratcheting up of Paris could achieve, while uncertainty in climate sensitivity translates to a wider confidence interval in possible warming. We also show that the hypothetical Pareto efficient benchmark would lead to a higher optimal warming of 1.86°C. Lastly, to discuss our findings' implications compared to the previous literature, we show that maintaining a cooperative spirit is crucial to attain these results. Only small deviations from the cooperation assumption can be accommodated before the agreement breaks down. With larger deviations, the model reproduces the less optimistic insights from the previous literature that guided thinking prior to the signing of the Paris Agreement.

[2] Moreover, international climate finance is difficult to measure in practice. In our estimates, we only look at direct transfers or grants, whereas official statistics often include loans, not all of which are on preferential terms.

1.1 Related literature

The novelty of our work is in describing endogenous unanimity agreements inside a general equilibrium system, which, we argue, fits the Paris Agreement's *de facto* institutional setting. Our work contributes to active strands of research in climate and environmental economics on international environmental treaties (or international environmental agreements (IEAs), as they are known in the research literature).

Our work complements, in both method and outlook, the existing game-theoretic literature, which has focused mostly on participation. Abstracting from the participatory process, we focus instead on what the end result could look like. That literature has studied how to design international treaties for effectiveness in achieving a specific environmental outcome. It originated in the early 1990s (Barrett, 1994, Carraro and Siniscalco, 1993), and has since grown to be substantially extended and refined (for overviews see, e.g., Barrett (2003) or Buchholz and Sandler (2021)). Earlier work started based on the assumption of narrow cooperation, seen through the lens of the pursuit of individual self-interest under the expectation of self-interested behavior of the other parties (Barrett, 2003). In these cases, dynamics known from prisoner's dilemma types of situations ensue: cooperation breaks down without external enforcement. In a 2018 *Science* editorial, Scott Barrett summarizes the key predictions of this literature for the Paris Agreement (Barrett, 2018): the Paris Agreement will fail to reduce greenhouse gas emissions sufficiently because of its reliance on voluntary cooperation. Recent research in this literature is similarly pessimistic (Maggi and Staiger, 2023).

Related economics research on climate clubs — international climate treaties that can impose sanctions on countries outside the coalition — is more cautiously optimistic. Nordhaus (2015) finds, for instance, that even small trade penalties imposed by coalition members would lead to substantial and stable participation while achieving substantial emissions cuts. These findings are generally accepted in the literature to date (Clausing and Wolfram, 2023, Farrokhi and Lashkaripour, 2025) and have consequently inspired substantial policy discussions in international forums such as the G7 and by institutions such as the International Monetary Fund (Parry, Black and Roaf, 2021). However, ambitious mitigation still requires a sanctioning mechanism.

A more recent literature has found, theoretically, the possibility of self-enforcing agreements through partial cooperation in a pledge-and-review bargaining game (Harstad, 2016, Caparrós, 2020, Harstad, 2023*a*,*b*). Investment in technology (as a commitment mechanism) and uncertainty (about the possibility of rejection and consequent delay of an agreement) can explain different breadth and depth of the agreements, with results strongly depending on the nature of investment costs (Eichner and Schopf, 2024).One take-away from this literature is that international climate action is either broad-based and unambitious, or limited to a smaller subset of ambitious countries.

By abstracting from the participatory process and focusing on the possible end result, our methods place our work into an emerging climate-macro literature (Hassler and Krusell, 2012, Hassler, Krusell and Olovsson, 2024). Our contribution is to study international climate policy from a cooperative perspective that takes the design of the Paris Agreement as given. Since its signing in 2015, stated mitigation targets captured in Nationally Determined Contributions (NDCs) and long-term (or mid-century) strategies have significantly strengthened. The world is now plausibly on a course toward 1°C less than it was when the Paris Agreement was adopted (Mobir et al., 2025), and participation in the Paris Agreement has been nearly universal and relatively stable. Both observations are at odds with the aforementioned non-cooperative economic literature. Rather than study treaty formation, we therefore focus on what ratcheting up the Paris Agreement could lead to. For that purpose, we build a tractable integrated assessment model that abstracts from the *process* by which an international climate treaty is formed and instead analyzes the plausible *end result*. Following Carattini and Löschel (2021), we impose unanimity as a real-life constraint rather than as a desirability criterion for the outcome, since unanimity rules apply to all international agreements in the Westphalian system of sovereign countries.

Our work is also closely related to a nascent economics literature that studies cooperation in international climate treaties. Carattini, Levin and Tavoni (2019) provide a recent overview of this literature. Cooperation more generally builds on insights from Ostrom (2010), who posits conditional cooperation: individuals are willing to cooperate if they expect others to do the same. This concept has been formalized in economics as a Kantian equilibrium (Roemer, 2010). A nascent literature has applied such tools to international environmental treaties. Eichner and Pethig (2024) analyze how standard international environmental treaty results change when countries partially follow a Kantian moral compass. Similarly, Grafton, Kompas and Van Long (2017) introduce a symmetric Kant–Nash equilibrium framework to analyze how agents motivated by Kantian ethics interact with traditional Nashian actors in the context of climate change. The study demonstrates that an increased population share of Kantians leads to superior environmental outcomes and higher welfare for all. Our concept of equilibrium is both Nashian and Kantian. Countries are Nashian, pursuing their personal interests when deciding their production and abatement levels, and so are governments when deciding their optimal amount of global emissions. On the other hand, unanimity on international negotiations is equivalent to a strict form of Kantian reasoning in which all agents' recommended actions must coincide. Cooperation is built on the acceptance of participation in the international negotiations and the unanimity rule.

Lastly, our work is of practical relevance to international climate finance negotiations. A recent policy-facing literature argues that large fiscal transfers across countries are not only required to finance mitigation efforts needed by the Paris Agreement, but also that such transfers can be in donor countries' self-interest, given climate damages (Adrian, Bolton and Kleinnijenhuis, 2022, Bolton, Kleinnijenhuis and Zettelmeyer, 2024). Our work contributes to the conversation of how to bring about this change by showing a benchmark equilibrium and quantifying the resulting international climate finance flows at the country level, thus informing real-world policy discussions.[3]

The remainder of the paper is organized as follows: Section 2 presents the building blocks of our integrated assessment model and the equilibrium concept, and proves existence and uniqueness. In Section 3, we calibrate the model for 154 countries, and compute the global unanimity equilibrium that would result from ratcheting up Paris. Section 4 provides the main economic, temperature, and international climate finance results. Section 5 studies the robustness of the results. Section 6 concludes.

2 Model and equilibrium concepts

We simulate a world whose countries negotiate an international climate agreement. As in the Paris Agreement, there is no external enforcement, and greenhouse gasses emissions are presumed to reach net-zero for a climate-neutral world after the second half of this century (Article 4 of the Paris Agreement, 2015). Our model is static and represents countries' decisions when choosing their preferred climate target or carbon budget.

We model the global economy as one with a single good, produced in all countries according to country-specific production functions, which use labor and capital as inputs, and emit carbon dioxide according to country-specific carbon intensities. Abatement and emission decisions are decentralized at the firm level. Capital and output operate in standard competitive markets. Mitigation takes place via carbon pricing. At the economic equilibrium, given the globally agreed-upon amount of emissions, firms maximize profits, and prices clear the capital and emission markets.

Governments decide by unanimity on the global level of carbon dioxide emissions, implicitly setting a temperature target. Carbon pricing revenues are returned to each country according to pre-established national shares. In choosing its desired global level of emissions, each government maximizes its carbon revenue net of climate damages. A unanimous international agreement is reached when all governments agree upon the desired global carbon budget.

Finally, we define a global unanimity general equilibrium as an emission target, a share rule of carbon revenues, and a vector of prices and factor allocations, such that they constitute an economic equilibrium and a unanimous international agreement. Our theoretical model is built upon Llavador, Roemer and Stoerk (2022), and substantially expands it, introducing investment in abatement and country-specific capital shares of output, as well as a richer objective function that considers direct and indirect impacts of carbon budgets.

[3]Our work abstracts from climate finance to help adaptation and to compensate for loss and damages from climate change. For this latter literature, see Clarke et al. (2023).

2.1 The economy

Consider a global economy with J countries, indexed by $j = 1, \ldots, J$. Each country is endowed with labor ($\bar{L}_j$), capital ($\bar{K}_j$), and a representative firm. Firm j chooses capital K_j, emissions e_j, and an abatement rate $\mu_j \in [0,1]$ to maximize profits. The production function $G_j(K_j)$ is strictly increasing, strictly concave, and satisfies $\lim_{K\to\infty} G'_j(K) = 0$. Emissions are proportional to output $e_j = (1-\mu_j)\eta_j G_j(K_j)$, where $\eta_j > 0$ is the carbon emission intensity and $\mu_j \in [0,1]$ is its "control" rate or fraction of emissions abated, where we assumed that firms cannot abate more than 100% of their emissions. Abatement is costly. The abatement cost is $C_j(\mu_j)G_j(K_j)$, where C_j, representing the cost of abatement as a fraction of output, is strictly increasing and convex ($C'_j > 0,\ C''_j > 0$).

There are three markets in the economy: for the produced good, with price p normalized to 1; for capital, with interest rate r; and for carbon emissions, with price c. Given a vector of relative prices (r, c), the profit maximization program of firm j is

$$\begin{array}{ll} \max_{K_j, e_j, \mu_j} & \Pi_j := G_j(K_j) - rK_j - c\, e_j - C_j(\mu_j)G_j(K_j) \\ \text{s.t} & e_j = (1-\mu_j)\, \eta_j G_j(K_j) \\ & \mu_j \leq 1 \end{array} \tag{1}$$

To summarize, firms' profit-maximizing choices determine the demand for capital and emission. The supply of capital is the global available capital ($\bar{K} \equiv \sum_j \bar{K}_j$), while the global supply of emissions E will be decided through an international agreement described later. At an economic equilibrium, firms maximize profits and prices clear markets.

Definition 1 For a given level of global emissions E, an **economic equilibrium** is a vector of relative prices (r, c), and an allocation $(K_1, \ldots, K_J,\ \mu_1, \ldots, \mu_J,\ e_1, \ldots, e_J)$ such that:

1. for each country j, (K_j, μ_j, e_j) maximizes the firm profit maximization program (1); and
2. all markets clear

$$\sum K_j = \sum \bar{K}_j \equiv \bar{K}, \text{ and} \tag{2a}$$

$$\sum e_j = E. \tag{2b}$$

We can show that for any E below the unregulated emission level, an economic equilibrium exists, and it is unique.

Proposition 1 *Given E below the unregulated emission level, there exists a unique economic equilibrium.*

Before providing the proof, it is convenient to define the unit net revenue function

$$W_j(c) := \max_{\mu_j \in [0,1]} \{1 - c\eta_j(1-\mu_j) - C_j(\mu_j)\}\,; \tag{3}$$

and prove the following lemma:

Lemma 1 *W_j is strictly decreasing and strictly convex in c. The optimal unit emission rate $\varepsilon(c) := (1 - \tilde{\mu}_j(c))\eta_j$ is strictly decreasing in c.*

Proof of Lemma 1. By the Envelope Theorem, $W_j'(c) = -\eta_j(1-\tilde{\mu}_j(c)) = -\varepsilon(c) < 0$. The FOC for abatement is $C_j'(\mu_j) = c\eta_j$. Differentiating with respect to c yields $\frac{d\mu_j}{dc} = \frac{\eta_j}{C_j''(\mu_j)} > 0$ by the strict convexity of C_j. Thus, $\varepsilon'(c) = -\eta_j \frac{d\mu_j}{dc} < 0$. Since $V_j''(c) = -\varepsilon'(c) > 0$, $V_j(c)$ is strictly convex. ■

Proof of Proposition 1.

Existence. For any $c \geq 0$, the FOC for capital is $G_j'(K_j) = r/W_j(c)$. Let $K_j(r,c) = (G_j')^{-1}(r/V_j(c))$. The aggregate capital demand $D_K(r,c) = \sum K_j(r,c)$ is strictly decreasing in r. By the Inada conditions, for any c, there exists a unique $r(c)$ such that $D_K(r(c),c) = \bar{K}$. Note that $r(c)$ is strictly decreasing in c to maintain the equality as $V_j(c)$ falls.

Define the aggregate emission function $\tilde{E}(c) = \sum \varepsilon(c) G_j(K_j(r(c),c))$. Since $\varepsilon(c)$, G_j, and K_j are continuous, $\tilde{E}(c)$ is continuous. By assumption, $\tilde{E}(0) > E$. As $c \to \infty$, $\varepsilon(c) \to 0$, hence $\tilde{E}(c) \to 0$. By the Intermediate Value Theorem, there exists c^* such that $\tilde{E}(c^*) = E$.

Uniqueness. It suffices to show $d\tilde{E}/dc < 0$. Differentiating $\tilde{E}(c)$:

$$\frac{d\tilde{E}}{dc} = \sum_j \varepsilon'(c) G_j(K_j) + \sum_j \varepsilon(c) G_j'(K_j) \frac{dK_j(\tilde{r}(c),c)}{dc} \tag{4}$$

The first term is the *abatement effect*, which is strictly negative as $\varepsilon'(c) < 0$. For the second term, differentiate the capital market clearing condition $\sum K_j(r,c) = \bar{K}$ to find:

$$\frac{dK_j}{dc} = \frac{1}{W_j(c) G_j''(K_j)} \left(\tilde{r}'(c) - \tilde{r}(c)\tau_j\right), \quad \text{where } \tau_j = \frac{\varepsilon(c)}{W_j(c)}. \tag{5}$$

Setting $\sum dK_j/dc = 0$ yields $r'(c) = r\bar{\nu}$, where $\bar{\nu}$ is the weighted average $\sum \nu_j \tau_j / \sum \nu_j$ with weights $\nu_j = (W_j G_j'')^{-1}$. The second term (*reallocation effect*) becomes:

$$-r^2 \sum \nu_j \tau_j (\tau_j - \bar{\tau}) = -r^2 \mathrm{Var}_\tau(\nu_j) \leq 0 \tag{6}$$

Since the abatement effect is strictly negative and the reallocation effect is non-positive, $d\tilde{E}/dc < 0$. Thus, c^* is unique. ■

2.2 International agreement on the carbon budget

The global level of emissions $E \in [E_{min}, E_{max}]$ is determined by an international agreement on a target temperature.[4] Governments maximize the quasi-linear utility $V_j(E)$ that depends on the carbon revenue $CR(E)$ received net of climate damages $H_j(E)$. Let the carbon revenue be fully distributed back to the countries according to a vector of shares $(a_1, \ldots, a_n) \in \mathcal{R}^n_+$, $\sum_j a_j = 1$, then

$$V_j(E) := a_j CR(E) - H_j(E), \tag{7}$$

with H_j increasing and convex ($H' > 0$, $H'' > 0$) and $CR(E) := \hat{c}(E) \times E$, where we use a hat on the carbon price to denote its dependence on global emissions.

We define an international agreement as a unanimous decision on global emissions.

Definition 2 Given the vector of revenue shares $(a_1, \ldots, a_J)$, a level of global emissions E^* represents a *unanimous agreement* if $E^*_j = E^*_k = E^* \; \forall j, k$, where $E^*_j = \text{argmax}\, V_j(E)$.

Proposition 2 provides a sufficient condition for the existence and uniqueness of an international unanimous agreement. Furthermore, it shows that at the unique unanimous agreement, carbon revenues are distributed proportionally to marginal climate damages.

Proposition 2 *Let carbon revenue CR be a strictly concave function on global emissions. There exists a unique international unanimous agreement on global emissions E^*. Furthermore, if $E^* \in (E_{min}, E_{max})$, the carbon revenue is distributed proportionally to marginal damages*

$$a_j = \frac{H'_j(E^*)}{CR'(E^*)} > 0, \quad \textit{for all } j.$$

Proof. Since $CR(E)$ is strictly concave and $H_j(E)$ is convex, $CR'(E) - \sum_j H'(E)$ is a strictly decreasing function that will be zero exactly once, where $CR'(E)$ and $\sum_j H'(E)$ intersect. The location of this intersection determines the regime we are in.

- $CR'(E_{min}) - \sum_j H'(E_{min}) > 0 > CR'(E_{max}) - \sum_j H'(E_{max})$.
  Let $E^* \in (E_{min}, E_{max})$ be the unique value with $CR'(E) = \sum_j H'(E_{max})$. Define $a_j = \frac{H'_j(E^*)}{CR'(E^*)} > 0$ for all j. Then $E^* = \arg\max_E a_j CR(E) - H_j(E)$, a_j is proportional to marginal damages, $\sum_j a_j = 1$, and E^* is the unique unanimity agreement.

- $CR'(E_{max}) - \sum_j H'(E_{max}) > 0$.
  Choose $a_j = \frac{H'_j(E_{max})}{CR'(E_{max})} + \epsilon_j$ such that $\epsilon_j > 0$ for all j, and $\sum_j \epsilon_j = 1 - \frac{\sum_j H'_j(E_{max})}{CR'(E_{max})} > 0$. Then

[4] Throughout the text, we use the expressions carbon budget and target temperature interchangeably, based on the approximate linear proportionality of temperature to cumulative carbon emissions (Matthews et al., 2009, 2018, Dietz and Venmans, 2019).

$a_j CR'(E_{max}) > H_j'(E_{max})$ and $E_{max} = \arg\max_E V_j(E)$ for all j. Hence, E_{max} is the unique unanimity agreement.

- $CR'(E_{min}) - \sum_j H'(E_{min}) < 0$.
  Choose $a_i = \frac{H_i'(E_{min})}{\sum_j H_j'(E_{min})} > 0$. Then $V_j'(E_{min}) = H_j'(E_{min})\left(\frac{CR'(E_{min})}{\sum_j H_j'(E_{min})} - 1\right) < 0$ and $E_{min} = \arg\max_E V_j(E)$ for all j. Hence, E_{min} is the unique unanimity agreement.

■

Although carbon revenue often behaves like a concave "Laffer Curve" for emissions (starting at 0, peaking, and returning to 0 at the unregulated limit), proving this would require additional restrictions on the third derivatives of the abatement cost functions and the production functions. Even without imposing such additional structure, our calibrated model in Section 3 confirms that these sufficient conditions are satisfied in practice within the relevant parameter space.

2.3 Global unanimity general equilibrium

Now, we are in a position to define the general equilibrium as an economic equilibrium and an international unanimous agreement. Formally,

Definition 3 A *global unanimity general equilibrium* is a vector of relative prices (r, c), an allocation $(K_1, \ldots, K_J,\ \mu_1, \ldots, \mu_J,\ e_1, \ldots, e_J)$, a share of carbon revenues $(a_1, \ldots, a_J)$, and a global level of emissions E such that,

1. for the global level of emissions E, the allocation $(K_1, \ldots, K_J, \mu_1, \ldots, \mu_J, e_1, \ldots, e_J)$ and the relative prices (r, c) constitute an *economic equilibrium*;
2. for the price of carbon c and the share of revenues $(a_1, \ldots, a_J)$, the global level of emissions E represents a unanimity agreement; and
3. all carbon revenues are redistributed back to the countries: $\sum a_j = 1$, with $a_j \in [0, 1]$ for all j.

Our concept of equilibrium is both Nashian and Kantian (Roemer, 2019). Firms and countries are Nashian, pursuing their personal interests when deciding their production and abatement, and their optimal level of global emissions, respectively. On the other hand, unanimity on international negotiations is equivalent to a strict form of Kantian reasoning in which all agents' recommended actions must coincide. From Proposition 1 and Proposition 2 we can provide a sufficient condition for the existence of a unique global unanimity general equilibrium.

Proposition 3 *Let $\hat{c}(E)$ be the carbon price as a function of global emissions and $CR(E) := \hat{c}(E) \times E$ be the corresponding carbon revenue. If CR is a strictly concave function on global emissions, then there exists a unique global unanimity general equilibrium.*

Proof. Because CR is a strictly concave function, it follows from Proposition 2 that a unique unanimous agreement on global emissions E^* exists for $a_j^* = H_j'(E^*)/CR'(E^*)$, with $a_j > 0$ for all j and $\sum_j a_j = 1$. From Proposition 1 there exists a unique economic equilibrium for E^*. Therefore, there exists a unique global unanimity general equilibrium. ■

Proposition 3 establishes the existence of a vector of carbon revenue shares that induces a unanimous international agreement on a global emission level. Observe that, by functioning as "Lindahl-like" prices, these shares align marginal revenues to marginal costs across governments. Moreover, from Proposition 2 we know that these shares are proportional to marginal climate damages.

3 Quantitative application

We calibrate the model for 154 countries, representing over 98% of the world's population, GDP, and emissions.[5] We endow each country with an annual population, an annual stock of capital, and a carbon intensity parameter calibrated to the average values for 2020-2050 in the SSP5-RCP8.5 scenario. Climate change damages are associated with the temperature change stemming from cumulative emissions and are measured by their present value until the end of the century.

Here, we describe the main steps for calibrating the various functions and parameters: climate damages, production and abatement functions, carbon intensities, and endowments (stocks of capital and population), for each of the 154 countries.

3.1 Economic functions and endowments

The production of country j is represented by a Cobb-Douglas function of labor and capital,

$$G_j(K_j) = A_j(\bar{L}_j)^{1-\alpha_j} K_j^{\alpha_j} \tag{8}$$

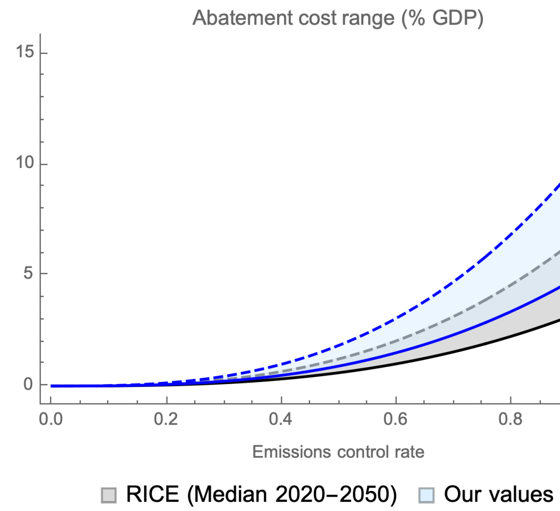
For the capital-to-output ratios, we take the average for the period 2020-2050 for each country's corresponding region, as reported in Leimbach et al. (2017). (See column 6 of Table I.1 in the Appendix.)

We calibrate total factor productivity (TFP) A_j to the average annual values of population, output, and capital stock for the period 2020-2050 in the SSP5-RCP8.5 scenario (columns 3-5 and 7 of Table I.1 in the Appendix). Define $\kappa_j = A_j(L_j)^{1-\alpha_j}$, and write the production function as

$$G_j(K_j) = \kappa_j K_j^{\gamma}. \tag{9}$$

[5] Only countries with incomplete data were excluded from the analysis. The list of 154 included countries is provided in Table I.1 in the Appendix.

Figure 1: Range of abatement costs across all countries. Our parametrization uses 1.5 times the median from 2020 to 2050 in Cline (2011) for the country's corresponding region.



Following Nordhaus (2010), abatement costs are measured as a fraction of GDP and take the following form

$$C_j(\mu_j) = \zeta_j \ \mu_j^{\beta}, \tag{10}$$

where μ_j is the control rate, β represents the degree of nonlinearity in costs, and ζ_j is a country-specific parameter representing heterogeneity in abatement cost across countries. We calibrate the nonlinearity parameter to the RICE model (Nordhaus, 2010) by setting $\beta = 2.8$. To guard against overly optimistic abatement cost curves (Cline, 2011), we choose ζ_j as 1.5 the median for the period of 2020-2050 for the country's corresponding region in Nordhaus (2010), as reported in Cline (2011, Table 4.1).[6] Figure 1 displays the ranges of abatement costs across all countries in RICE and in our study.

Finally, carbon intensities η_j are obtained from a two-step procedure. First, we compute current carbon intensities by using data on all greenhouse gas emissions from EDGAR (Crippa et al., 2021) and 2020 GDP estimates from the SSP database (Riahi et al., 2017). Next, we project counterfactual carbon intensity forward by using each variable's growth rates of the SSP-RCP scenarios, calibrated to SSP5-RCP8.5. Results of this calibration are reported in column 8 of Table I.1 in the Appendix.

3.2 Climate damages and government's utility

The climate damage function maps global annual emissions to present-value, country-specific damages until the end of the century. It is constructed for each country in three steps. The first step maps average temperature increases (as a proxy for climate change) to country-specific damages. The second step maps

[6] The resulting country-specific values are reported in column 9 of Table I.1 in the Appendix. See the robustness analysis in Section 5 for alternative damage and abatement specifications.

cumulative emissions to changes in average temperature. The third step derives cumulative emissions from average annual emissions. We calibrate the parameters to climate damages estimated by Kahn et al. (2021), and to the established linear relationship between temperature change and cumulative emissions (Matthews et al., 2009, 2018, Dietz and Venmans, 2019).

Step 1. Following (Hassler and Krusell, 2012), construct country-specific, exponential climate change damage functions that depend on temperature increases:

$$d_j(\triangle T) = \psi_{1j}\ e^{\psi_{2j} \triangle T}, \tag{11}$$

where temperature change ΔT is measured in degrees centigrade above average pre-industrial levels. The parameters ψ_{1j} can be used to scale damages. The calibration of (11) fits Kahn et al. (2021) annual climate damages (Section II.1 in the Appendix).[7,8]

Step 2. Use the linear proportionality of temperature increases to cumulative carbon emissions (Matthews et al., 2009, 2018, Dietz and Venmans, 2019) to express temperature changes as a function of cumulative emissions:

$$\triangle T_t = \varphi 10^{-3} E_t^{cum}, \tag{12}$$

where φ is the ratio of warming to cumulative CO_2 emissions in °C/TtCO_2, known as the transient climate response to emissions (TCRE), and E_t^{cum} are global cumulative emissions since 1850, in GtCO_2. We take $\varphi = 0.495$°C per TtCO_2 as the best estimate in the literature (IPCC, 2021, Matthews et al., 2018, Gillett et al., 2013). Given the importance of non-CO_2 greenhouse gases such as methane for warming outcomes (Stoerk et al., 2025), we include the adjustment for non-CO_2 greenhouse gas emissions proposed in Dietz and Venmans (2019) that adjusts for these radiative forcing effects.[9]

Step 3. Let E_{00}^{cum} represent historical cumulative CO_2 emissions until 2020. Given the constant annual global emissions E, combine (11) and (12) to express country j's climate damages in year t as[10]

$$D_j(E_{00}^{cum} + tE) = \psi_{1j} e^{\widehat{\psi}_{2j}(E_{00}^{cum} + tE)} \tag{13}$$

where $\widehat{\psi}_{2j} = \psi_{2j}\varphi 10^{-3}$. Finally, letting $n < N$ represent the number of years until a climate-neutral world,

[7] The last two columns of Table I.1 in the Appendix report the values of the estimated parameters.

[8] Climate damage estimates have been almost surely underestimated. Amongst the reasons for underestimation is that estimates currently abstract from tipping points (Dietz et al., 2021) and non-market damages, such as via mortality (Carleton et al., 2022), loss of biodiversity, or ecosystem services. For that reason, Section 5.2 shows a robustness analysis with increased damages. The results are qualitatively similar to those in our preferred specification.

[9] For computational simplicity, we abstract from the short delay between cumulative emissions and the onset of associated temperature change shown in Dietz and Venmans (2019).

[10] Observe that cumulative emissions at year t are historical emissions plus t years of annual emissions E: $E_t^{cum} = E_{00}^{cum} + t \times E$.

compute the present value of climate damages for constant annual global emissions E as

$$H_j(E) \equiv \sum_{t=1}^{N} \rho^t h_j(t,E) = \sum_{t=1}^{n} \rho^t D_j(E_{00}^{cum} + tE) + \sum_{t=n+1}^{N} \rho^t D_j(E_{00}^{cum} + nE). \tag{14}$$

Use (13), after some manipulation (Section II.2 in the Appendix), to obtain:

$$H_j(E) = \theta_{0j} \left(\frac{\theta_j(E) - (\theta_j(E))^{n+1}}{1-\theta_j(E)} + \frac{\rho - \rho^{N-n+1}}{1-\rho} (\theta_j(E))^n \right), \tag{15}$$

where $\theta_{0j} = \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}}$ and $\theta_j(E) = \rho e^{\widehat{\psi}_{2j} E}$; and the first derivative with respect to E

$$H_j'(E) = \theta_{0j} \widehat{\psi}_{2j} \left(\theta_j(E) \frac{1-(n+1)(\theta_j(E))^n}{1-\theta_j(E)} + (\theta_j(E))^2 \frac{1-(\theta_j(E))^n}{(1-\theta_j(E))^2} + n \frac{\rho - \rho^{N-n+1}}{1-\rho} (\theta_j(E))^n \right). \tag{16}$$

The government's utility function, the present value of the returns from carbon revenue net of climate damages, is

$$V_j(E) = \sum_{t=1}^{n} \rho^t \left(a_j CR(E) - h_j(t,E) \right) = \frac{\rho - \rho^{n+1}}{1-\rho} a_j CR(E) - H_j(E). \tag{17}$$

We use an annual discount rate of 1.5% ($\rho = 0.985$).

Summarizing, each country is endowed with a stock of capital and characterized by: a government's utility function with country-specific damages from climate change (17); a production function with country-specific capital-to-output ratio, TFP, population, and carbon intensity parameters (8); and a country-specific abatement cost function (10). All calibrated values are collected in Table I.1 of the Appendix.

3.3 Finding the global unanimity general equilibrium

For a given level of global emissions, the economic equilibrium (Definition 1) can be determined by solving the system of equations comprising the first-order conditions for the firms' profit-maximizing problem (1) and the market-clearing conditions (2a) and (2b). Normalize $p = 1$ and write the equilibrium prices $\hat{c}(E)$ and $\hat{r}(E)$ and the abatement rates $\hat{\mu}(E)$ as functions of the global emissions level. Detailed derivations are provided in Section III of the Appendix.

We program Mathematica to compute the economic equilibrium for a large range of global emission levels $E \in [5, 65]$ in steps of 0.1 and obtain that the fitted carbon revenue function $CR(E) = \hat{c}(E)E$ is a strictly concave function. Hence, there exists a unique international unanimous agreement on global emissions E^* (Proposition 2). Combining the governments' first-order condition for utility maximization and $\sum_j a_j = 1$, the equilibrium can be found as the solution to

$$\sum_j H_j'(E) = \frac{\rho - \rho^{n+1}}{1-\rho} CR'(E). \tag{18}$$

Finally, compute the general equilibrium price of carbon emissions $c^* = \hat{c}(E^*)$, price of capital $r^* = \hat{r}(E^*)$, and abatement rates $\mu_j^* = \hat{\mu}(E^*)$, $j = 1, \ldots, J$. Other values are obtained as follows:

- K_j^* and e_j^*, the stock of capital and the annual emissions for country j, follow from the first-order conditions for profit maximization of the firms

$$K_j^* = \left(\frac{1 - c^*(1-\mu_j^*)\eta_j - \zeta_j(\mu_j^*)^\beta}{r^*} \kappa_j \alpha_j \right)^{\frac{1}{1-\alpha_j}} \qquad j = 1, \ldots, J, \text{ and} \tag{19a}$$

$$e_j^* = (1-\mu_j^*)\eta_j \kappa_j (K_j^*)^{\alpha_j}, \text{ respectively;} \tag{19b}$$

- the share of total revenue for country j follows from its government's first-order-condition for utility maximization

$$a_j^* = \frac{1-\rho}{\rho - \rho^{n+1}} \frac{(H_j^*)'(E^*)}{CR(E^*)}; \text{ and} \tag{20}$$

- the net contribution of country j is $c^*(1-\mu_j^*)e_j^* - a_j^* \, CR(E^*)$.

4 Results of ratcheting up Paris

4.1 Headline results

What temperature outcome could the Paris Agreement converge to eventually? And at what carbon price would such an outcome be achieved? We find that there is room for optimism: Table 1 provides the results of unanimity agreement that emerge endogenously in our integrated assessment model, without external enforcement being present. Cumulative emissions of CO_2 since 1850 would be kept to 3050 $GtCO_2$.[11] Ratcheting up of the Paris Agreement could limit warming to just above 1.5°C, and well below 2°C. Unanimity therefore need not imply weak ambition; with endogenously determined revenue shares, unanimity supports strong mitigation.

The carbon price required to achieve this temperature outcome is 320 USD/tCO_2. As expected, this is substantially larger than current carbon prices in a world on a 2.8°C trajectory. By contrast, this equilibrium carbon price falls well within the modeling estimates for 1.5°C scenarios for the first half of the century reported in the meta-analysis by Dietz et al. (2018). Similarly, European Commission modeling of a climate

[11] Recall that we account for the radiative forcing effects of non-CO_2 greenhouse gases through the temperature correction proposed in Dietz and Venmans (2019).

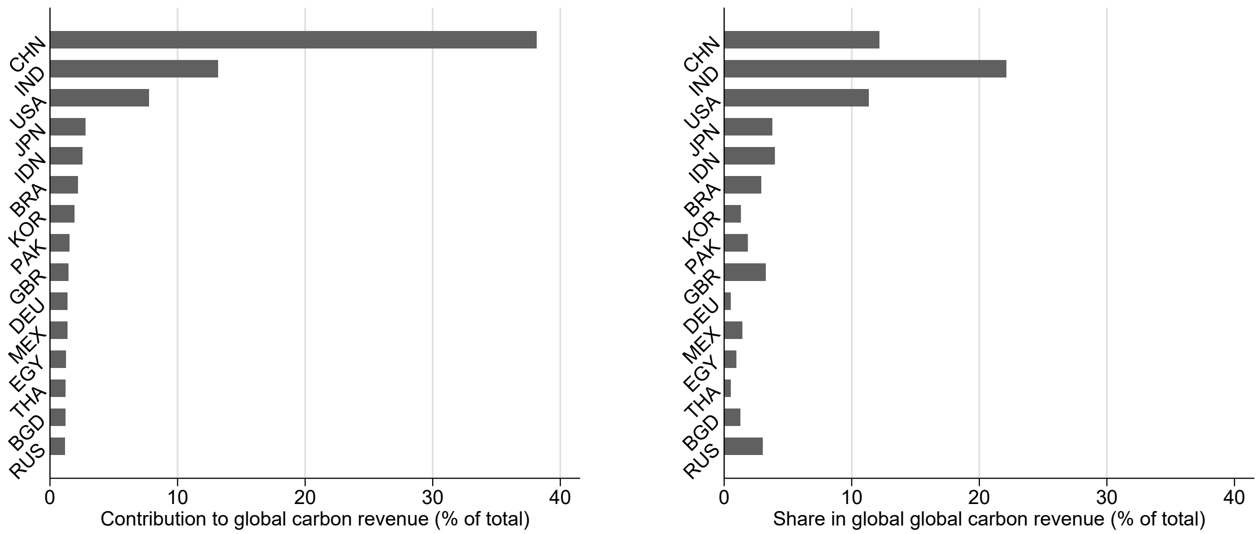
neutrality scenario for 2050 for the European Union found a stylized carbon price of 350 EUR/tCO_2 (European Commission, 2018). Our stylized integrated assessment model can thus reproduce abatement cost estimates of more complex underlying energy systems models, thus reinforcing the real-world informativeness of our quantitative application. Moreover, mimicking policy discussions around the transition required to ratchet up Paris, it is worth highlighting the equilibrium result of our integrated assessment model is achieved through substantial abatement: across all countries, the average abatement rate (μ_j in eq. (10)) is 75%, ranging from a minimum of 30% to several countries that reach 100%.

Overall carbon pricing revenue at this global carbon price amounts to 7 trn USD per annum, or 2.3% of global GDP. Countries contribute to this global carbon revenue differentially, in proportion to the size and carbon intensity of their economies. The left panel in Figure 2 shows the fifteen countries that most contribute. Amongst those, China, India, the US, Japan and Indonesia represent 64% of global carbon revenue. As seen in the right panel, the same countries also receive 53% of global carbon revenue. Across all countries, both contributions to and revenue received from global carbon revenue are strongly correlated between each other (correlation coefficient of 73%), as well as with population (86% and 93%, respectively).

Table 1: Main climate and economic outcomes of ratcheting up Paris. The table shows equilibrium results from the integrated assessment model for global mean surface temperature increase and cumulative emissions by end of the century (from eq. (12)), carbon price (c), global carbon revenue per annum (cE), and international climate finance (computed as $\sum_{j:t_j>0} t_j$, where $t_j = (a_j cE - ce_j)$ represents net transfers).

Climate outcomes	
Temperature by end of century (°C since pre-industrial)	1.51
Cumulative emissions ($GtCO_2$ since 1850)	3050
Economic outcomes	
Carbon price (USD/tCO_2)	319.9
Global carbon revenue	
In trillions of USD per annum:	7.04
As % of global GDP:	2.33
International climate finance transfers	
In trillions of USD per annum:	2.3
As % of global carbon revenue:	32.8
As % of global GDP:	0.76

Figure 2: Top 15 countries by contribution to ($\frac{c \times e_j}{c \times E}$)(left panel) and share in (a_j) (right panel) global carbon revenue.



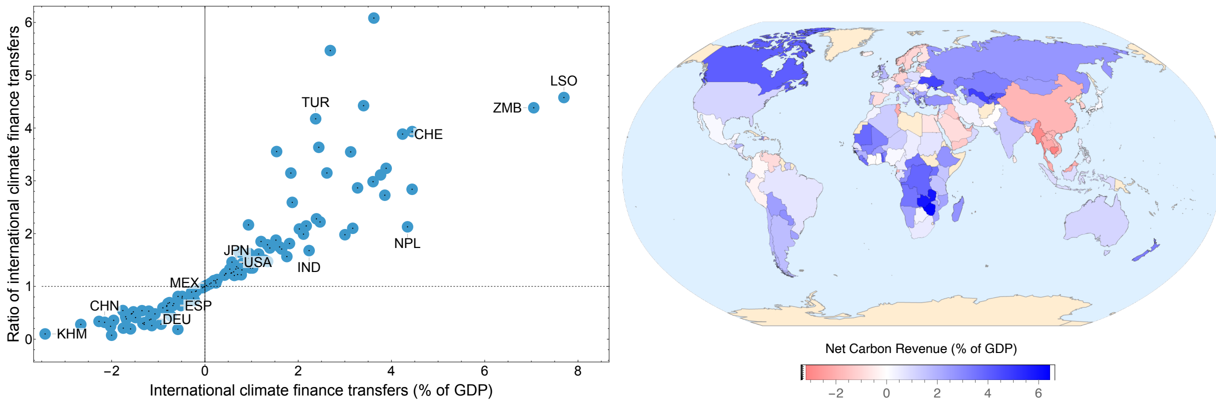
4.2 International climate finance

Not all carbon revenue crosses borders, however. Much of the global carbon revenue stays within the countries in which it originates. A strength of our model is that we can precisely quantify international climate finance transfers at the country level in equilibrium.

We define international climate finance transfers as the part of the global revenue from carbon pricing that is redistributed across country borders. Letting $t_j := a_j cE - ce_j$ represent the net revenue received by a country (the country's share in global carbon revenue minus the carbon revenue raised domestically), international climate finance transfers can be computed as $\sum_{j:t_j>0} t_j = \sum_{j:t_j<0} t_j$; that is, the total amount of transfers received (which must equal the total amount sent). As shown in Table 1, only one third of carbon revenue is redistributed to other countries as international climate finance. Most carbon revenue stays in the country that collects it. Nevertheless, ratcheting up of Paris would lead to substantial flows of international climate finance. Compared to the original international climate finance ambition of the Paris Agreement of 100 billion USD per annum, we find that ratcheting up Paris would lead to international climate finance of more than 20 times this ambition: 2.3 trn USD per annum, or 0.8% of global GDP - an order of magnitude above the COP29 ambition for 300 billion USD per annum.

Our results on international climate finance feature two attractive characteristics which speak to the political plausibility of ratcheting up Paris. Firstly, net donors to international climate finance tend to contribute an outflow of at most 2% of their GDP, with very few exceptions. By contrast, many of the countries that benefit from international climate finance benefit well beyond 2% of their GDP, with many benefiting up to

Figure 3: Magnitude of international climate finance at the country level. Ratio of the amount that a country receives from global carbon revenue ($a_j cE$) divided by the carbon revenue raised domestically (ce_j), plotted over the magnitude of country-level international climate finance transfers in GDP terms (t_j/y_j) (left panel); and donors and recipient countries plotted on a world map (right panel).

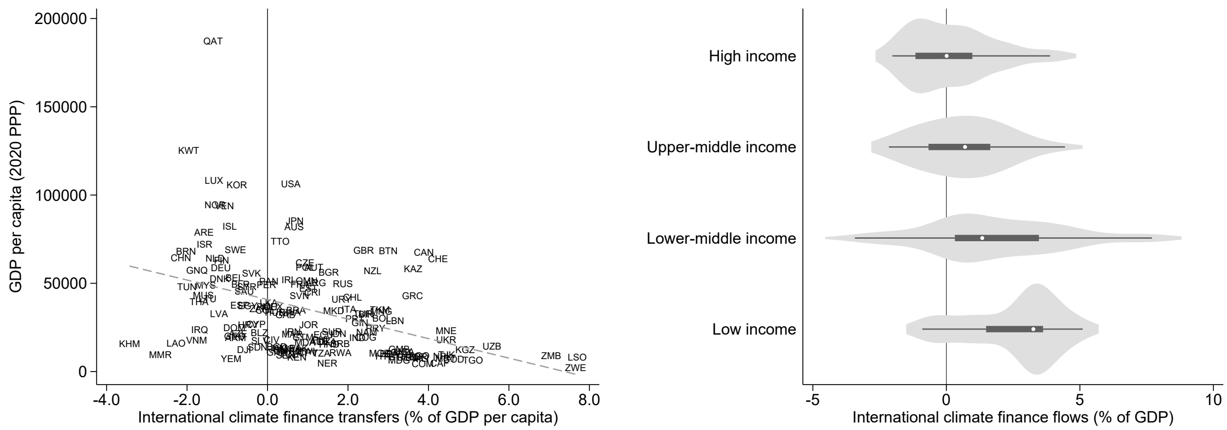


4% and some even 8%. Figure 3 illustrates these magnitudes in the left panel, while the right panel shows net carbon revenue per country plotted on a world map. Countries depicted with a positive percentage receive that much international climate finance, while those depicted with a negative percentage contribute that much, both on net.

While international climate finance serve as implicit side payments necessary for unanimity, it is worth asking whether these transfers would improve or exacerbate existing cross-country inequalities in living standards. If international climate finance tends to flow from higher- to lower-income countries, then ambitious climate policy can unlock synergies for development. Moreover, a globally efficient allocation of mitigation effort might see net flows of international climate finance from higher- to lower-income countries (Glennerster and Jayachandran, 2023).

Figure 4 shows that this is the case. Ratcheting up of the Paris Agreement leads to flows of international finance across countries that are, on average, progressive. As shown in the left panel, we find a quantitatively important, downward-sloping relationship between a country's overall income levels, and international climate finance transfers. That is, higher-income countries tend to contribute relatively more, while the picture is the opposite for lower-income countries. To illustrate this dynamic more explicitly, the right panel shows a violin plot of international climate finance flows with countries grouped by World Bank income levels. As can be seen, nearly all low income countries benefit from international climate finance, while upper-middle and high income countries contribute relatively more. Both high income and upper-middle income contributions to international climate finance are statistically different from low income countries at a 1% significance level. The patterns result not from any built-in redistributive policy, but from the equilibrium result that redistributes international carbon pricing revenue according to marginal damages, coupled with the fact that regions in development are likely to be more adversely affected by climate change. Full country-level results

Figure 4: Relationship between net international carbon finance revenue and country income levels (left panel) and international carbon finance revenue by World Bank income group (right panel). Left panel: Linear regression line with slope coefficient -5526.9 and intercept 40808.3, both significant at 1% level using heteroskedasticity-robust standard errors. Right panel: Statistically significant differences between income groups at 1% significance level: low income vs high income, low income vs upper-middle income, and lower-middle income vs high income. At 5% level: lower-middle vs upper-middle income.



are available in Section IV of the Appendix.

5 Sensitivity analyses and discussion

The main results represent our preferred calibration and model setup. In this section, we explore (i) how changes to parametrization influence results, (ii) whether the end result of ratcheting up Paris exhausts all mutually beneficial reallocations, and (iii) how much the altruism assumption of the Paris agreement can be relaxed before our integrated assessment models replicates the previous literature's less optimistic findings.

5.1 Robustness to different model calibration

We first study how uncertainty about abatement cost and climate damages affect the headline results of ratcheting up Paris. Abatement costs have been a source of heated debate, and uncertainty is two-sided: abatement costs could be lower than we assume, or they could be higher. We therefore report two additional abatement cost calibrations, the first reproducing the original RICE abatement cost calibration, while the second increases RICE abatement cost by a factor of 2 rather than 1.5, as in our preferred calibration. In the first case, because mitigation is now cheaper, lower abatement cost lowers equilibrium end-of-century warming by 3% due to lower cumulative emissions. More importantly, cheaper abatement translates into reducing the required carbon price substantially, by 27%. By contrast, in the second case, higher abatement costs increase both warming by 2% and the equilibrium carbon price by 26%. The sensitivity of the carbon price results speaks to the importance of technological change that helps lower abatement costs. Given the sensitivity of the equilibrium carbon price to abatement cost, global carbon revenue drops with lower abatement cost and increases with higher abatement cost. These changes translate to meaningful differences in the magnitude of international climate finance, which falls by 36% in our lower abatement cost calibration, while it rises by 32% in our higher abatement cost calibration.

We next conduct sensitivity analyses to our climate damages parametrisation. In our preferred calibration, for our equilibrium result of warming of 1.51°C by end of century, climate damages represent 1.7% of GDP. While this magnitude of climate damages at this level of warming is consistent with the current consensus in climate economics (see, e.g., Burke, Zahid and Hsiang (2025) for a recent discussion), it can not be ruled out that climate damages could be be substantially larger than this consensus number. Not accounted-for damages channels such as non-market impacts of climate change or ocean acidification are not included in these estimates, as are most of the effects of tipping points in the climate system (Dietz et al., 2021). Moreover, important methodological challenges about the economic damages of climate change remain (Lemoine, Hausman and Shrader, 2025).

To account for this right-tailed uncertainty in climate damages, we re-compute equilibrium outcomes for damages sensitivity calibrations of 1.5× and 2× of our preferred damages estimation. As expected, this lowers equilibrium temperature by end of century, by 3% and 6%, respectively. The resulting carbon price is 10% and 19% higher. However, global carbon revenue is 6% and 13% lower, indicating that the reduction in emissions more than compensates for the increase in carbon price. International climate finance remains at the same level relative to the size of the economy.

Lastly, climate system uncertainty itself will affect what ratcheting up of Paris can achieve. In our integrated assessment model, climate uncertainty is captured by the plausible lower and upper bounds of the transient climate response to emissions (TCRE) reported in IPCC (2021), adjusted for non-CO_2 greenhouse gas emissions. Climate system uncertainty to date remains large: for a given amount of cumulative emissions, TCRE could be as low as 0.297, or as high as 0.693. As expected, the large uncertainty about climate sensitivity results in drastic changes to warming: if climate sensitivity were as low as is reasonably possible, a warming outcome by end of century of less than 1°C would be reachable. By contrast, if climate sensitivity is high, ratcheting up of Paris could at best hope to keep warming just shy of 2°C. The equilibrium carbon price moves with climate sensitivity, but the overall size of international climate finance with respect to the global economy remains almost constant. The result that moving to the lower and upper bounds of TCRE leads to a 1°C difference in end of century temperature above pre-industrial captures the climate system uncertainty in the IPCC climate models underlying TCRE well: IPCC projections for SSP1-2.6 (IPCC, 2021, Figure SPM.8), for instance, show a confidence interval of around 1°C in end-of-century projected warming. This sensitivity analysis thus serves to confirm confidence in the climate part of our integrated assessment model.

Table 2: Sensitivity of climate and economic outcomes of ratcheting up Paris to changes in model calibration. The table shows equilibrium results from the integrated assessment model for global mean surface temperature increase and cumulative emissions by end of century compared to pre-industrial (from eq. (12)), carbon price (c), global carbon revenue per annum (cE), and international climate finance ($\sum_{j:t_j>0} t_j$, where $t_j := (a_j cE - ce_j)$ represents net transfers).

	Main results	**Robustness checks**					
		Abatement costs		Climate damages		Transient climate response	
		Lower	Higher	×1.5	×2	Lower	Higher
CLIMATE OUTCOMES							
Temperature by end of century (°C since pre-industrial)	1.51	1.46	1.54	1.46	1.42	0.95	1.95
Cumulative emissions (GtCO2 since 1850)	3050	2957	3103	2956	2873	3199	2824
ECONOMIC OUTCOMES							
Carbon price (USD/tCO2)	319.9	234.0	404.4	351.0	380.1	274.5	399.4
Global carbon revenue							
In trillions of USD per annum:	7.0	4.4	9.6	6.6	6.1	7.4	5.8
As % of global GDP:	2.3%	1.5%	3.2%	2.2%	2.0%	2.5%	1.9
International climate finance transfers							
In trillions of USD per annum:	2.3	1.5	3.1	2.2	2.1	2.2	2.1
As % of global carbon revenue:	32.8%	33.4%	32.5%	33.3%	34.3%	29.7%	36.8%
As % of global GDP:	0.76%	0.49%	1.0%	0.73%	0.70%	0.73%	0.70%

Notes:
Abatement costs: Preferred calibration uses 1.5 times ζ_j compared to RICE abatement cost. Lower value uses the specification in RICE, while higher value uses 2 times ζ_j.
Climate damages: Preferred calibration is based on Kahn et al. (2021). The table also reports the outcomes for 1.5 times and 2 times the damages compared to preferred calibration.
Transient Climate Response to Emissions (TCRE): Preferred calibration uses the best estimate in IPCC (2021) adjusted for non-CO_2 greenhouse gases following Dietz and Venmans (2019): TCRE=0.495°/1000 $GtCO_2$. The lower and higher specifications correspond, respectively, to the lower and upper bounds reported in IPCC (2021) with the same non-CO_2 adjustment: $\text{TCRE}_{\text{low}} = 0.297$ and $\text{TCRE}_{\text{high}} = 0.693$.

In summary, as expected, our quantitative results are sensitive to changes in the calibrated values of the parameters. However, our qualitative results remain consistent across the different specifications.

5.2 Comparison to hypothetical Pareto-efficient outcome

We now ask whether the unanimity equilibrium exhausts all mutually beneficial reallocations, or whether further Pareto improvements remain feasible. In our model, ratcheting up of Paris results in a unanimity equilibrium in which countries act as if they held market power regarding the carbon price resulting from the unanimity agreement. As a consequence, the headline result might not be Pareto-efficient. In this section, we characterize in theory and numerically what a hypothetical Pareto-efficient benchmark outcome in the model economy would look like, and how far ratcheting up of Paris is likely to be from that outcome, even if such an allocation is not reachable by the current Paris Agreement institutional setting.

Let us start by defining feasibility and Pareto efficiency, and then find the necessary efficiency conditions. Let the representative agent of country j have quasi-linear utility on the average annual consumption of the single good (x) and climate damages:

$$u_j(x, E) := \frac{\rho - \rho^{N+1}}{1-\rho} x - H_j(E), \tag{21}$$

Then, a consumption and emission allocation is globally feasible if it can be generated with the existing technology and capital. Formally,

Definition 4 An allocation of consumption and emissions $((x_1, e_1), ...(x_J, e_J))$ is *globally feasible* if there is an allocation of capital $K_1, ..., K_J$, abatement rates $\mu_1, ..., \mu_J$, and output $y_1, ..., y_J$ such that:

$$y_j = G_j(K_j), \quad e_j = \eta_j(1-\mu_j)y_j, \quad \sum x_j = \sum (1 - C_j(\mu_j))y_j, \text{ and } \quad \sum K_j = \sum \bar{K}_j. \tag{22}$$

We can now derive the necessary conditions of Pareto efficiency.

Definition 5 A globally feasible allocation is *Pareto efficient* if there is no other globally feasible allocation that gives at least one representative agent higher utility and no representative agent lower utility.

Proposition 4 *Letting* $\hat{\rho} = \frac{\rho - \rho^{N+1}}{1-\rho}$, *the necessary first-order conditions for an allocation to be Pareto efficient are:*

$$\begin{aligned} &(i) \quad (\forall j) \quad \hat{\rho} \geq \eta_j(1-\mu_j)\sum_l H_l'(E) - C_j(\mu_j), \\ &(ii)\ (\forall i,j) \quad \frac{G_i'(K_i)}{G_j'(K_j)} = \frac{\hat{\rho} - \eta_j(1-\mu_j)\sum_l H_l'(E) - \hat{\rho}\ C_j(\mu_j)}{1 - \eta_i(\hat{\rho} - \mu_i)\sum_l H_l'(E) - \hat{\rho}\ C_i(\mu_i)}, \\ &(iii) \quad (\forall j) \quad \text{either } \hat{\rho}\ C_j'(\mu_j) = \eta_j \sum_l H_l'(E) \text{ or } \mu_j = 1. \end{aligned} \tag{23}$$

Proof. The conditions for Pareto efficiency are given by solving the following program:

$$
\begin{aligned}
&\max\ \hat{\rho}\ x_1 - H_1(E) \\
&\quad \text{s.t.} \\
&\quad \hat{\rho}\ x_j - H_j(E) \geq q_j, \quad \forall j > 1 && (\lambda_j) \\
&\quad \sum_j (1 - C_j(\mu_i))\, G_j(K_j) \geq \sum_j x_j && (\alpha) \\
&\quad \bar{K} \geq \sum_j K_j && (\beta) \\
&\quad E \geq \sum_j \eta_j (1 - \mu_j) G_j(K_j) && (\gamma) \\
&\quad \forall j \quad 1 \geq \mu_j && (\zeta_j)
\end{aligned}
\tag{24}
$$

where $\bar{K} = \sum \bar{K}_j$. The program is not convex, because of the global emissions constraint (the functions G_j are concave). Therefore, the Kuhn-Tucker conditions are necessary but not sufficient for the solution of the program in (24). Define $\lambda_1 = 1$. The Kuhn-Tucker conditions are:

$$(\partial x_j) \qquad \alpha = \hat{\rho} \text{ and } \lambda_j = 1 \quad \text{for all } j; \tag{25a}$$

$$(\partial K_j) \qquad \alpha(1 - C_j(\mu_j))G'_j(K_j) - \beta - \gamma\ \eta_j\ (1 - \mu_j)\ G'_j(K_j) = 0 \tag{25b}$$

$$(\partial \mu_j) \qquad -\alpha\ C'_j(\mu_j)G_j(K_j) + \gamma\eta_j\ G_j(K_j) - \zeta_j = 0 \tag{25c}$$

$$(\partial E) \qquad -\sum_j \lambda_j H'_j(E) + \gamma = 0 \tag{25d}$$

From (25a) and (25d), $\gamma = \sum_l H'_l(E)$. Then, from (25b) we get

$$\beta = \left(\hat{\rho}\,(1 - C_j(\mu_j)) - \eta_j (1 - \mu_j) \sum_l H'_l(E) \right) G'_j(K_j), \tag{26}$$

yielding the following conditions:

$$(\forall j) \qquad \hat{\rho} \geq \eta_j (1 - \mu_j) \sum_l H'_l(E) - C_j(\mu_j), \tag{27a}$$

$$(\forall i, j) \qquad \frac{G'_i(K_i)}{G'_j(K_j)} = \frac{\hat{\rho}\ (1 - C_j(\mu_j)) - \eta_j (1 - \mu_j) \sum_l H'_l(E)}{\hat{\rho}\ (1 - C_i(\mu_j)) - \eta_i (1 - \mu_i) \sum_l H'_l(E)}. \tag{27b}$$

Finally, since $\zeta_j (1 - \mu_j) = 0$ for all j, it follows from (25c) the following conditions:

$$(\forall j) \quad \text{either } \mu_j < 1 \text{ and } \hat{\rho}\ C'_j(\mu_j) = \eta_j \sum_l H'_l(E) \quad \text{or} \quad \mu_j = 1. \tag{28}$$

These are the stated conditions in the proposition. ∎

It turns out that the global unanimity equilibrium results in total emissions below the efficient level.

Proposition 5 *Total emissions under a global unanimity general equilibrium are lower than the efficient level.*

Proof. For any country j, the first-order conditions for profit maximization are

$$G_j'(K_j)\,(1 - c(1-\mu_j)\eta_j - C_j(\mu_j)) = r \quad \text{and} \tag{29a}$$

$$c\,\eta_j G_j(K_j) - C_j'(\mu_j) G_j(K_j) = \zeta, \tag{29b}$$

where ζ is the multiplier of the constraint $\mu_j \leq 1$ (see (1)).

From the governments' FOC for $V_j(E)$ (17), and using $\sum a_j = 1$,

$$\sum H_j'(E) = \hat{\rho}(\hat{c}(E) + \hat{c}'(E)E). \tag{30}$$

Substituting this expression into (29a) obtains that, for all countries i, j,

$$\frac{G_j'(K_j)}{G_i'(K_i)} = \frac{\hat{\rho} - (1-\mu_i)\eta_i\,(\sum_l H_l'(E) - \hat{c}'(E)E) - \hat{\rho}\;C_i(\mu_i)}{\hat{\rho} - (1-\mu_j)\eta_j\,(\sum_l H_l'(E) - \hat{c}'(E)E) - \hat{\rho}\;C_j(\mu_j)}. \tag{31}$$

For countries with $\mu_j < 1$, (30) and (29b) yield

$$\hat{\rho}\;C_j'(\mu_j) = \eta_j \sum_l h_l'(E). \tag{32}$$

Comparing (31) to the necessary conditions for efficiency in Proposition 4 we observe that there is an extra term ($\hat{c}'(E)E$) that derives from the impact of the level of emissions on the carbon price. Hence, the outcome is not efficient. ■

This finding is similar to Harstad (2023*a*), whose model of the Paris agreement's pledge-and-review *process* results in an inefficient outcome. Why the inefficiency in our model? Because unanimity confers on each government the power to choose the global level of emissions, and hence the power to set the price of carbon. Suppose instead that governments acted myopically, ignoring the impact of global emissions on prices (as if they were atomistic, acting as price-takers regarding the carbon price). In this case, the utility of government j (17) becomes

$$\tilde{V}_j(E) = \frac{\rho - \rho^{n+1}}{1-\rho} cE - H_j(E). \tag{33}$$

where, notice, the price of carbon is taken as a constant.

The f.o.c for the optimization program of country j's government ($\tilde{V}_j'(E) = 0$) yields

$$\frac{\rho - \rho^{n+1}}{1-\rho} a_j c = H_j'(E). \tag{34}$$

Carbon revenues are still distributed proportional to marginal climate damages

$$a_j = \frac{1}{\frac{\rho - \rho^{n+1}}{1-\rho} c} H_j'(E). \tag{35}$$

Observe that, because the government acts as a price-taker, it ignores the price-impact of changes in global emissions on carbon revenues and its economy, and the outcome is efficient

Proposition 6 *When governments act myopically as price-takers, the global unanimity general equilibrium satisfies the first-order conditions of Pareto efficiency.*

Proof. It follows the proof of Proposition 5. For any country j, the first-order conditions for profit maximization are

$$G_j'(K_j)\left(1 - c(1-\mu_j)\eta_j - C_j(\mu_j)\right) = r \quad \text{and} \tag{36a}$$

$$c\ \eta_j G_j(K_j) - C_j'(\mu_j) G_j(K_j) = \zeta, \tag{36b}$$

where ζ is the multiplier of the constraint $\mu_j \leq 1$ (see (1)).

From the governments' FOC for $\tilde{V}_j(E)$ (33), and using $\sum a_j = 1$,

$$\sum H_j'(E) = \hat{\rho}\ c. \tag{37}$$

Substituting this expression into (36a) obtains that, for all countries i, j,

$$\frac{G_j'(K_j)}{G_i'(K_i)} = \frac{\hat{\rho} - (1-\mu_i)\eta_i \sum_l H_l'(E) - \hat{\rho}\ C_i(\mu_i)}{\hat{\rho} - (1-\mu_j)\eta_j \sum_l H_l'(E) - \hat{\rho}\ C_j(\mu_j)}. \tag{38}$$

For countries with $\mu_j < 1$, (37) and (36b) yield

$$\hat{\rho}\ C_j'(\mu_j) = \eta_j \sum_l h_l'(E). \tag{39}$$

These are the necessary conditions for efficiency in Proposition 4. ∎

We have computed the general equilibrium under these circumstances (Section V in the Appendix). Table 3 displays the outcomes. As can be seen, mutually beneficial reallocations compared to a hypothetical institutional design without market power would move the equilibrium temperature by the end of the century to 1.86°C. Still well below 2°C as per the Paris Agreement's main temperature goal, but far from the 1.5°C target. A less stringent temperature outcome implies a lower carbon price that is only 137 USD/tCO_2, or 43% of the carbon price when ratcheting up Paris. As shown above, the source of the inefficiency derives from the market power in setting the carbon price by choosing the global level of emissions, which is inherent in the unanimity equilibrium.

Table 3: Main climate and economic results for changes in institutional assumptions. The table shows equilibrium results from the integrated assessment model for global mean surface temperature increase by end of century compared to pre-industrial and cumulative emissions by end of century compared to pre-industrial (from eq. (12)), carbon price (c), global carbon revenue per annum (cE) and international climate finance ($\sum_{j:t_j>0} t_j$, where $t_j := a_j cE - ce_j$ represents net transfers). In the hypothetical Pareto-efficient benchmark version of our model, governments are assumed to act as if they were atomistic price-takers in deciding the level of global emissions. In the changed altruism assumption version, we calculate the global unanimity equilibrium for small deviations from the altruism assumption. In this version of our model, governments maximize the present value of income net of climate damages, where economic income is weighted by $\omega = 0.035$. Full altruism, as modeled in our headline results, corresponds to $\omega = 0.0$.

	Main results	**Pareto-efficient benchmark**	**Changed altruism assumption**
CLIMATE OUTCOMES			
Temperature by end of century (°C since pre-industrial)	1.51	1.86	1.52
Cumulative emissions (GtCO2 since 1850)	3050	3760	3065
ECONOMIC OUTCOMES			
Carbon price (USD/tCO2)	319.9	137.1	315.2
Global carbon revenue			
In trillions of USD per annum:	7.0	6.3	7.1
As % of global GDP:	2.3%	2.1%	2.4%
International climate finance transfers			
In trillions of USD per annum:	2.3	2.1	2.5
As % of global carbon revenue:	32.8%	33.2%	35.2%
As % of global GDP:	0.76%	0.69%	0.83%

5.3 Importance of altruism assumption

In our headline results, we find room for optimism: ratcheting up of Paris is possible. This result stands in contrast to previous economic literature that has argued that an international environmental agreement that lacks enforcement will not deliver ambitious mitigation. In this section, we explore how far we can deviate from the altruism assumption built into the design of the Paris Agreement - and thus our model - before ratcheting up of Paris breaks down.

To study this question, we augment our model to accommodate different degrees of altruism. Recall that governments maximize the present value of income net of climate damages. To formally study the importance of the altruism assumption, we modify the utility function of government j to obtain

$$\hat{V}_j(E) = \frac{\rho - \rho^{n+1}}{1 - \rho} \left(\omega_j \ I_j(E) + a_j \ CR(E)\right) + I_j^{\text{net0}} - H_j(E). \tag{40}$$

where now $I_j(E) = \hat{\Pi}_j(E) + \hat{r}(E)\bar{K}_j$ is the annual economic income for $t \leq n$, weighted by $\omega_j \in [0, 1]$, and I_j^{net0} is the present value of economic income after reaching net-zero emissions. Observe that our original model setup is equivalent to $\omega = 0$, and that $(1 - \omega_j)$ can be interpreted as the degree of altruism of government j while participating in the international negotiations on the global level of emissions.

A global unanimity general equilibrium can be computed following the steps in Section 3.3.[12] To study the importance of this altruism assumption for finding a unanimity equilibrium compatible with ratcheting up Paris, we explore how changes to the altruism parameter affect the existence and properties of the unanimity equilibrium in our model. The key question we aim to answer in this sensitivity analysis is whether our model can reproduce the more pessimistic conclusions from the earlier literature.

For simplicity, we assume that all countries share a common degree of altruism: let $\omega_j = \omega$ for all j. Next, we vary ω and study how this affects the result of ratcheting up Pairs. For $\omega = 0$, we obtain our original headline results, reproduced in the left-most column of Table 3. This is by construction. For small deviations from the altruism assumption - or ω strictly positive but close to 0 - a global unanimity general equilibrium still exists. Table 3 shows the outcomes for $\omega = 0.035$. Compared to our headline results, changes are minimal. Ratcheting up of Paris therefore remains possible for small deviations from the altruism assumption.

Significant departures from the altruism assumption, however, change the picture. For $\omega >> 0$ there is no equilibrium with $a_j \geq 0$ for all j. In such a world, ratcheting up of Paris would not be possible. This finding reproduces findings from the earlier literature, by which the lack of enforcement leads to weak mitigation. In this case, to a lack of a unanimity equilibrium in our setting.

A unanimity equilibrium can still be found for a change in institutional setup to the Paris Agreement that includes a penalizing mechanism, similar to the spirit of climate clubs. By allowing negative shares in global carbon revenue - or $a_j < 0$ for some countries - a unanimity equilibrium exists. But the penalties required to sustain this equilibrium would have to be an increasing function on the carbon revenue.

[12]Equation (18) must be substituted by

$$\sum_j H_j'(E) = \frac{\rho - \rho^{n+1}}{1 - \rho} \left(CR'(E) + \sum_j \left(\hat{\Pi}_j'(E) + \hat{r}'(E)\bar{K}_j \right) \right). \tag{41}$$

6 Conclusion

In this research, we construct a tractable integrated assessment model disaggregated at the country level that combines a general-equilibrium description of the world economy with a unanimity-based international agreement mechanism. Its institutional structure reflects the core cooperative logic of the Paris Agreement: countries jointly determine a global emissions constraint without external enforcement. The model endogenously determines global emissions, temperature outcomes, carbon prices, and the associated cross-country financial transfers implied by a cooperative climate policy.

Using this model, we ask: if parties to the Paris Agreement kept tightening ambition through repeated negotiations, where would the Paris Agreement plausibly converge?

We first establish the existence and uniqueness of a unanimous international agreement on the global carbon budget. In equilibrium, countries agree on a single emissions level, and revenues from global carbon pricing are redistributed across countries in proportion to their marginal climate damages. We calibrate the model on climate science, estimates of climate damages and abatement costs, and standard macroeconomic data for 154 countries. Solving the calibrated model yields two central objects: the level of global emissions that all countries would unanimously accept, and the financial flows required to sustain this outcome if mitigation were implemented solely via carbon pricing. These results allow us to assess both the feasibility of the Paris temperature objectives and the implied scale of international climate finance.

We find that there is room for optimism. In equilibrium, global mean surface temperature change is limited to 1.51°C, close to the Paris ambition of 1.5°C and well below the 2°C ceiling. Achieving this outcome requires a global carbon price of 320 USD per ton of CO_2, generating international climate-finance transfers of roughly 2.3 trillion USD per year, or about 0.8 percent of global GDP - an order of magnitude larger than existing commitments. Total carbon-pricing revenue amounts to around 7 trillion USD annually, comparable to estimates of the investment needs for full global decarbonization. Transfers are progressive: poorer countries receive larger net inflows because climate damages rise more steeply with temperature in lower-income regions. Our equilibrium results thus confirm a conjecture in political science after the Paris Agreement was signed that successful ratcheting up would require substantial fiscal transfers from higher- to lower-income countries (Keohane and Oppenheimer, 2016). Overall, we show that unanimity need not imply weak ambition; with endogenously determined revenue shares aligning incentives, unanimity supports strong mitigation.

Although our modeling framework describes a decentralized economy and captures the institutional features of the Paris Agreement, its stylized, static nature imposes inherent limitations. Significant uncertainties persist regarding the parameterization of abatement costs and climate damages. Nevertheless, we demonstrate that "ratcheting up" of ambition remains a plausible equilibrium outcome across the range of plausible parametrizations. We further show, however, that departures from the cooperative framework are sufficient to break down the equilibrium. Thus, ratcheting up of the Paris Agreement is not guaranteed. Overall, our findings offer a basis for cautious optimism, provided that governments ensure the sustained maintenance of international cooperation. Finally, given the static constraints of the current approach, a non-trivial extension for future research would be to incorporate dynamics that account for intertemporal strategic interactions and the evolution of climate-economic feedback loops.

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Supplementary Appendix

I Quantitative application: calibration summary table

Table I.1: Country-specific endowments and parameters

Country		**Endowments**			**Parameters**			**Functions**		
		Population in millions	**GDP** in trn USD	**Capital** in trn USD	Capital share	TFP	Carbon intensity	Abatement	Climate Damages	
ISO3	**Region**				α_j	A_j	in $GtCO_2$/trn USD	Costs: ζ_j	ψ_{1j}	ψ_{2j}
AGO	SSA-M	32.1201	0.490549	4.904375	0.374121	0.030277	0.298697	0.033	0.663855	1.295827
ALB	EEU	3.0917	0.072820	0.499781	0.329297	0.042736	0.216767	0.038	0.425664	0.760779
ARE	MEA-H	15.4761	1.599280	10.055343	0.336316	0.115516	0.239008	0.045	3.218011	0.799823
ARG	LAM-M	44.1786	2.203491	7.703679	0.322620	0.086672	0.321945	0.032	9.910261	0.821100
ARM	CAS	2.6096	0.056536	0.255659	0.307822	0.045063	0.279584	0.038	0.142758	0.817882
AUS	AUNZ	35.3126	2.876563	11.491186	0.370019	0.120297	0.363431	0.039	6.352507	1.059102
AUT	EU15	9.8293	0.737627	4.615634	0.377111	0.098632	0.184717	0.028	1.970056	0.954919
AZE	CAS	10.4627	0.220276	0.707034	0.307822	0.048440	0.414137	0.038	0.120913	1.012850
BDI	SSA-L	14.0770	0.079527	0.085583	0.269137	0.021543	0.389700	0.033	0.122091	1.487283
BEL	EU15	13.1493	0.892799	5.611995	0.377111	0.092158	0.208986	0.028	0.665007	1.002935
BEN	SSA-L	14.5541	0.123916	0.400491	0.269137	0.021132	0.417313	0.033	0.135227	1.410224
BFA	SSA-L	26.4210	0.219907	0.393065	0.269137	0.024829	0.531736	0.033	0.259107	1.384082
BGD	OAS-L	170.2976	2.153193	7.152195	0.360012	0.038057	0.231090	0.057	6.652474	1.092914
BGR	EU12-M	6.6659	0.321475	0.803568	0.319047	0.094847	0.377146	0.038	2.600005	0.753343
BIH	EEU	3.5200	0.103388	0.300753	0.329297	0.066116	0.618597	0.038	0.883196	0.638655
BLR	EEU-FSU	8.6196	0.432345	1.437550	0.292380	0.084881	0.344834	0.038	1.213716	0.761254
BLZ	LAM-L	0.3591	0.007410	0.023733	0.327094	0.049796	0.220057	0.032	0.017857	0.938225

Continued on next page

Table I.1 – continued from previous page

Country		**Endowments**			**Parameters**			**Functions**		
		Population	**GDP**	**Capital**	Capital share	TFP	Carbon intensity	Abatement	Climate Damages	
ISO3	**Region**	in millions	in trn USD	in trilion USD	$\boldsymbol{\alpha_j}$	A_j	in $GtCO_2$/trn USD	Costs: $\boldsymbol{\zeta_j}$	$\boldsymbol{\psi_{1j}}$	$\boldsymbol{\psi_{2j}}$
BOL	LAM-M	11.3964	0.257449	0.492116	0.322620	0.061391	0.583815	0.032	0.699771	1.106691
BRA	BRA	213.8611	7.427980	29.453616	0.355962	0.069421	0.238276	0.032	36.624049	0.806648
BRN	OAS-M	0.5157	0.053250	0.444120	0.407521	0.109325	0.136993	0.057	0.044165	0.782667
BTN	OAS-M	1.0449	0.050235	0.135803	0.407521	0.102927	0.171586	0.057	0.554481	0.912501
BWA	SSA-M	2.4856	0.106310	0.666548	0.374121	0.069537	0.199700	0.033	0.334441	0.874177
CAF	SSA-L	6.0097	0.033592	0.144814	0.269137	0.014672	1.017625	0.033	0.032745	1.461636
CAN	CAN	48.5264	3.616975	16.593108	0.350252	0.106294	0.391281	0.039	16.543985	1.028236
CHE	EFTA	9.5016	0.773052	5.108289	0.414968	0.103573	0.080633	0.028	3.741017	0.967184
CHL	LAM-M	19.2224	0.947584	4.738405	0.322620	0.076356	0.215822	0.032	6.814051	0.774098
CHN	CHN	1,320.3977	72.954953	233.596774	0.379384	0.104981	0.363265	0.049	330.754651	0.581492
CIV	SSA-L	23.9977	0.418892	1.161372	0.269137	0.038406	0.217368	0.033	0.651043	1.136301
CMR	SSA-L	27.0731	0.337166	1.137243	0.269137	0.028195	0.273288	0.033	0.342982	1.270268
COD	SSA-L	108.4180	0.639331	1.231507	0.269137	0.018531	0.451915	0.033	0.871458	1.476348
COG	SSA-L	6.2623	0.141754	0.643534	0.269137	0.039707	0.374862	0.033	0.289565	1.107604
COL	LAM-M	55.3941	1.736132	5.009538	0.322620	0.066795	0.212369	0.032	4.262609	0.973278
COM	SSA-L	0.9354	0.006380	0.058775	0.269137	0.013826	0.189684	0.033	0.008987	1.356314
CPV	SSA-L	0.4746	0.008150	0.087157	0.269137	0.027379	0.158511	0.033	0.023000	0.878666
CRI	LAM-M	5.9730	0.221543	0.538955	0.322620	0.078862	0.141273	0.032	1.362493	0.839846
CYP	EU12-H	1.4783	0.054236	0.378072	0.346988	0.057604	0.162620	0.045	0.122186	0.907303
CZE	EU12-H	12.4521	0.868079	4.192458	0.346988	0.099451	0.316997	0.028	1.141315	1.044299

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Table I.1 – continued from previous page

Country		Endowments			Parameters			Functions		
ISO3	Region	**Population** in millions	**GDP** in trn USD	**Capital** in trilion USD	Capital share $\boldsymbol{\alpha_j}$	TFP A_j	Carbon intensity in $GtCO_2$/trn USD	Abatement Costs: $\boldsymbol{\zeta_j}$	Climate Damages $\boldsymbol{\psi_{1j}}$	$\boldsymbol{\psi_{2j}}$
DEU	EU15	87.3320	6.061797	33.560899	0.377111	0.098852	0.190669	0.028	4.196403	0.943879
DJI	SSA-L	1.1756	0.015208	0.050861	0.269137	0.029381	0.389566	0.033	0.001432	1.094697
DNK	EU15	6.8143	0.436667	2.560072	0.377111	0.091484	0.143824	0.028	0.177784	1.099049
DOM	LAM-M	11.1571	0.333703	1.768104	0.322620	0.053536	0.203391	0.032	0.525651	0.879054
DZA	NAF	43.0687	1.015330	7.234031	0.326126	0.041617	0.477594	0.033	1.205673	0.956071
ECU	LAM-M	17.0799	0.449916	2.654538	0.322620	0.046864	0.265169	0.032	0.795943	1.122346
EGY	NAF	103.7491	2.819394	5.299188	0.326126	0.069532	0.195941	0.033	7.015622	0.980281
ESP	EU15	55.5789	2.791969	18.985312	0.377111	0.074456	0.164351	0.028	2.701105	0.970465
EST	EU12-H	1.3747	0.076059	0.387319	0.346988	0.084778	0.611060	0.038	0.065006	0.997293
ETH	SSA-L	121.0627	1.010478	2.952250	0.269137	0.021725	0.655452	0.033	1.158111	1.355727
FIN	EU15	6.4593	0.436964	2.056553	0.377111	0.102815	0.251003	0.028	0.148319	1.018234
FJI	OAS-L	0.8049	0.011902	0.071859	0.360012	0.035387	0.176834	0.057	0.041478	0.945974
FRA	EU15	80.4784	4.867157	28.872801	0.377111	0.087440	0.134678	0.028	9.189361	1.037462
GAB	SSA-M	1.9724	0.078345	0.459309	0.374121	0.067579	0.288397	0.033	0.177154	0.930777
GBR	EU15	78.0211	5.525648	24.563566	0.377111	0.107589	0.143382	0.028	21.670407	1.009868
GEO	CAS	3.3723	0.098573	0.768212	0.307822	0.046940	0.317479	0.038	0.204408	0.757902
GHA	SSA-L	34.7950	0.440563	1.916844	0.269137	0.026368	0.202010	0.033	0.499057	1.209889
GIN	SSA-L	11.7464	0.229016	0.258740	0.269137	0.054535	0.579021	0.033	0.655017	1.037463
GMB	SSA-L	2.4663	0.027255	0.054649	0.269137	0.030152	0.302150	0.033	0.082243	1.215665
GNB	SSA-L	2.0013	0.017417	0.028446	0.269137	0.026816	0.528647	0.033	0.026082	1.342490

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Table I.1 – continued from previous page

Country		**Endowments**			**Parameters**			**Functions**		
ISO3	**Region**	**Population** in millions	**GDP** in trn USD	**Capital** in trilion USD	Capital share $\boldsymbol{\alpha_j}$	TFP A_j	Carbon intensity in $GtCO_2$/trn USD	Abatement Costs: $\boldsymbol{\zeta_j}$	Climate Damages $\boldsymbol{\psi_{1j}}$	$\boldsymbol{\psi_{2j}}$
GNQ	SSA-M	1.1646	0.077535	0.415038	0.374121	0.097013	0.174501	0.033	0.042660	0.887683
GRC	EU15	12.1370	0.660444	4.118496	0.377111	0.080500	0.204930	0.028	2.977394	0.974468
GTM	LAM-L	18.3634	0.335817	1.074707	0.327094	0.044882	0.224025	0.032	0.867395	1.062756
HND	LAM-L	9.2120	0.146803	0.562160	0.327094	0.038717	0.383791	0.032	0.211450	1.115363
HRV	EEU	4.2289	0.165093	1.309990	0.329297	0.057313	0.211126	0.038	0.529393	0.734810
HTI	LAM-L	10.9101	0.097657	0.371749	0.327094	0.026591	0.486916	0.032	0.126816	1.254806
HUN	EU12-H	10.0469	0.423691	2.520437	0.346988	0.067475	0.217770	0.028	0.549896	1.051758
IDN	IDN	268.2981	7.956108	56.448985	0.364718	0.050231	0.175935	0.057	37.591321	0.896821
IND	IND	1,476.2039	31.401772	135.543017	0.308244	0.042879	0.221032	0.052	167.872970	0.968049
IRL	EU15	6.2883	0.440093	2.999441	0.377111	0.091087	0.238571	0.028	0.612252	1.041274
IRN	MEA-M	85.2439	2.636968	18.283796	0.389528	0.055654	0.282091	0.045	10.797594	0.856496
IRQ	MEA-M	48.8101	0.963120	3.033097	0.389528	0.055338	0.365162	0.045	0.801900	1.135640
ISL	EFTA	0.4804	0.036367	0.148403	0.414968	0.119694	0.274752	0.028	0.011499	1.076069
ISR	MEA-H	13.3153	0.880777	2.733837	0.336316	0.108953	0.260618	0.045	0.716757	1.227302
ITA	EU15	66.8457	3.586034	30.267006	0.377111	0.071537	0.140642	0.028	11.136279	0.928902
JAM	LAM-M	2.4539	0.046213	0.347376	0.322620	0.035779	0.249409	0.032	0.133727	0.800881
JOR	MEA-M	10.5551	0.256441	0.965815	0.389528	0.056791	0.211447	0.045	0.666987	1.164171
JPN	JPN	124.4939	8.249972	33.749537	0.478074	0.122908	0.093386	0.039	41.962027	0.845591
KAZ	CAS	18.3251	1.008906	2.967777	0.307822	0.094929	0.574356	0.038	9.577637	0.707687
KEN	SSA-L	59.9624	0.563760	2.458933	0.269137	0.021237	0.360091	0.033	0.350872	1.320295

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Table I.1 – continued from previous page

Country		**Endowments**			**Parameters**			**Functions**		
ISO3	**Region**	**Population** in millions	**GDP** in trn USD	**Capital** in trilion USD	Capital share $\boldsymbol{\alpha_j}$	TFP A_j	Carbon intensity in $GtCO_2$/trn USD	Abatement Costs: $\boldsymbol{\zeta_j}$	Climate Damages $\boldsymbol{\psi_{1j}}$	$\boldsymbol{\psi_{2j}}$
KGZ	CAS	5.5121	0.067850	0.226401	0.307822	0.032986	0.715172	0.038	0.408922	0.926144
KHM	OAS-CPA	15.0251	0.236315	0.751303	0.291610	0.037622	0.383966	0.057	0.080115	1.026551
KOR	KOR	51.2063	4.330273	15.902750	0.439108	0.139699	0.165934	0.039	15.503304	0.826581
KWT	MEA-H	4.9660	0.608739	2.156381	0.336316	0.155639	0.255561	0.045	1.364384	0.768395
LAO	OAS-CPA	7.2099	0.138767	0.683184	0.291610	0.037361	0.469912	0.057	0.106208	1.066352
LBN	MEA-M	4.6443	0.196636	1.563079	0.389528	0.064270	0.197319	0.045	1.454205	0.802958
LBR	SSA-L	8.3367	0.059751	0.113768	0.269137	0.020898	0.395538	0.033	0.079613	1.465575
LKA	OAS-M	21.6930	0.621885	1.837589	0.407521	0.076438	0.081115	0.057	2.356387	0.862544
LSO	SSA-L	2.4320	0.024430	0.127313	0.269137	0.021810	0.238999	0.033	0.083367	1.286132
LTU	EU12-M	2.8506	0.136977	0.664923	0.319047	0.076847	0.262578	0.038	0.320011	0.689064
LUX	EU15	0.8244	0.094870	0.442817	0.377111	0.144188	0.168743	0.028	0.063072	0.919123
LVA	EU12-M	1.9639	0.096468	0.807783	0.319047	0.064965	0.237694	0.038	0.184262	0.756506
MAR	NAF	32.8484	0.837918	4.454390	0.326126	0.048180	0.197384	0.033	2.624797	0.901241
MDA	EEU-FSU	2.4241	0.049072	0.254296	0.292380	0.041275	0.375306	0.038	0.333028	0.643892
MDG	SSA-L	32.1917	0.189083	0.463372	0.269137	0.017662	0.453075	0.033	0.193348	1.421862
MEX	MEX	126.7431	4.899303	21.341560	0.360502	0.072411	0.244811	0.032	14.337788	0.877960
MKD	EEU	2.2514	0.079249	0.301001	0.329297	0.066906	0.306297	0.038	0.537556	0.812664
MLI	SSA-L	24.9246	0.162262	0.329779	0.269137	0.019987	0.552526	0.033	0.207005	1.422950
MMR	OAS-L	46.9014	0.472737	2.071336	0.360012	0.030719	0.259738	0.057	0.619566	0.894523
MNE	EEU	0.6724	0.019031	0.102736	0.329297	0.051974	0.289768	0.038	0.230109	0.750244

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Country		Endowments			Parameters			Functions		
		Population in millions	**GDP** in trn USD	**Capital** in trilion USD	Capital share	TFP	Carbon intensity	Abatement	Climate Damages	
ISO3	**Region**				$\boldsymbol{\alpha_j}$	A_j	in $GtCO_2$/trn USD	Costs: $\boldsymbol{\zeta_j}$	$\boldsymbol{\psi_{1j}}$	$\boldsymbol{\psi_{2j}}$
MNG	OAS-CPA	3.2689	0.133118	0.622345	0.291610	0.063886	0.972089	0.057	0.501569	0.844227
MOZ	SSA-L	33.1346	0.285854	0.529254	0.269137	0.025434	0.594310	0.033	0.244478	1.466100
MRT	SSA-L	4.9230	0.054588	0.444267	0.269137	0.020435	0.457876	0.033	0.096780	1.176469
MUS	SSA-M	1.3983	0.067920	0.348234	0.374121	0.081244	0.123099	0.033	0.041486	0.806750
MWI	SSA-L	26.4343	0.174556	0.110645	0.269137	0.027852	0.326936	0.033	0.152798	1.557840
MYS	OAS-M	36.9894	1.791153	7.983999	0.407521	0.087578	0.183550	0.057	4.206519	0.879790
NAM	SSA-M	2.9361	0.066569	0.285531	0.374121	0.052848	0.265822	0.033	0.343594	0.939338
NER	SSA-L	29.6041	0.152730	0.592225	0.269137	0.013607	1.052244	0.033	0.020898	1.816972
NGA	SSA-L	262.1136	3.731470	14.579559	0.269137	0.028908	0.197716	0.033	2.920363	1.402884
NIC	LAM-L	5.7727	0.080571	0.320800	0.327094	0.035986	0.447454	0.032	0.025244	0.981439
NLD	EU15	19.4840	1.438742	7.617071	0.377111	0.104089	0.207020	0.028	0.636942	0.989787
NOR	EFTA	7.0449	0.631913	2.728718	0.414968	0.131141	0.174646	0.028	0.323677	1.057014
NPL	OAS-L	39.7481	0.291832	0.868557	0.360012	0.027303	0.318501	0.057	1.269181	1.261848
NZL	AUNZ	5.9319	0.330754	1.279151	0.370019	0.096348	0.434101	0.039	0.854046	1.133746
OMN	MEA-H	3.8689	0.267623	1.752047	0.336316	0.087968	0.354593	0.045	1.124945	0.862039
PAK	PAK	227.8833	2.488940	4.890358	0.289976	0.032746	0.231038	0.057	7.384958	1.187275
PAN	LAM-M	4.3950	0.255341	1.197508	0.322620	0.086050	0.152620	0.032	0.843657	0.812228
PER	LAM-M	29.5770	1.258544	3.348335	0.322620	0.085614	0.169579	0.032	5.079633	0.831679
PHL	OAS-L	121.2246	2.014010	6.925929	0.360012	0.044657	0.151685	0.057	7.153093	1.077318
POL	EU12-H	39.1776	1.964032	5.556504	0.346988	0.098268	0.370741	0.028	2.807408	0.906651

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Country		Endowments			Parameters			Functions		
		Population	**GDP**	**Capital**	Capital share	TFP	Carbon intensity	Abatement	Climate Damages	
ISO3	**Region**	in millions	in trn USD	in trilion USD	α_j	A_j	in $GtCO_2$/trn USD	Costs: ζ_j	ψ_{1j}	ψ_{2j}
PRT	EU15	12.0984	0.553410	4.677475	0.377111	0.064442	0.168240	0.028	1.329884	1.027486
PRY	LAM-M	8.0211	0.192410	0.658518	0.322620	0.051932	0.383795	0.032	0.428242	1.130109
QAT	MEA-H	3.4831	0.750869	3.628145	0.336316	0.208134	0.325972	0.045	2.802821	0.680836
ROU	EU12-M	18.9820	0.755838	3.166391	0.319047	0.070857	0.241593	0.038	3.480223	0.778151
RUS	RUS	140.2211	7.936126	35.231735	0.302251	0.085029	0.396709	0.036	45.571167	0.751186
RWA	SSA-L	16.7974	0.142948	0.232076	0.269137	0.026021	0.193997	0.033	0.256752	1.351780
SAU	MEA-H	45.2847	2.634991	15.813909	0.336316	0.079965	0.245656	0.045	8.681456	0.819022
SDN	SSA-L	65.4370	0.769499	1.445184	0.269137	0.031627	0.362505	0.033	0.299158	1.319775
SEN	SSA-L	17.0589	0.176974	0.736226	0.269137	0.023430	0.292215	0.033	0.135992	1.326163
SLE	SSA-L	8.9653	0.062919	0.077180	0.269137	0.024588	0.352048	0.033	0.109741	1.424454
SLV	LAM-M	5.2291	0.101062	0.446457	0.322620	0.043767	0.168723	0.032	0.420772	0.724389
SRB	EEU	9.7666	0.207741	1.350971	0.329297	0.040447	0.683425	0.038	0.555976	0.773982
SUR	LAM-M	0.5764	0.018849	0.145557	0.322620	0.049786	0.213088	0.032	0.058470	0.934123
SVK	EU12-H	6.0167	0.341974	1.372006	0.346988	0.093834	0.247014	0.028	0.520018	0.899778
SVN	EU12-H	2.3556	0.134299	0.871813	0.346988	0.079353	0.252048	0.038	0.321267	1.009861
SWE	EU15	12.6907	0.932737	4.404272	0.377111	0.107474	0.115377	0.028	0.597342	1.105278
SYR	MEA-M	26.9283	0.692706	1.092182	0.389528	0.085186	0.500070	0.045	0.886966	1.084079
TCD	SSA-L	18.0173	0.139007	0.214101	0.269137	0.024555	1.200245	0.033	0.025657	1.450094
TGO	SSA-L	8.4806	0.058086	0.216986	0.269137	0.017658	0.491042	0.033	0.079231	1.422606
THA	OAS-M	73.8099	2.849190	12.492202	0.407521	0.077344	0.160799	0.057	4.592615	0.917601

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Country		**Endowments**			**Parameters**			**Functions**		
ISO3	**Region**	**Population** in millions	**GDP** in trn USD	**Capital** in trilion USD	Capital share α_j	TFP A_j	Carbon intensity in $GtCO_2$/trn USD	Abatement Costs: ζ_j	Climate Damages ψ_{1j}	ψ_{2j}
TJK	CAS	6.4941	0.097585	0.922520	0.307822	0.027614	0.615379	0.038	0.357133	0.906024
TKM	CAS	5.6190	0.269366	1.817727	0.307822	0.066565	1.271374	0.038	1.226869	0.739689
TTO	LAM-M	1.2531	0.075914	0.178476	0.322620	0.114750	0.621478	0.032	0.123026	0.556911
TUN	NAF	11.8371	0.452089	1.022395	0.326126	0.083625	0.156364	0.033	0.199074	0.746838
TUR	TUR	84.8079	3.635738	22.831798	0.295765	0.062095	0.320811	0.028	10.796536	0.919364
TZA	SSA-L	70.4754	0.701769	1.808814	0.269137	0.025401	0.308142	0.033	0.753688	1.371391
UGA	SSA-L	59.6641	0.532740	0.830967	0.269137	0.026599	0.370002	0.033	0.625072	1.541282
UKR	EEU-FSU	40.8600	1.285124	15.520170	0.292380	0.041012	0.396904	0.038	6.125520	0.886139
URY	LAM-M	3.1644	0.150010	0.728056	0.322620	0.076109	0.366390	0.032	0.000595	0.821100
USA	USA	407.6617	38.026811	116.168465	0.351155	0.142909	0.293611	0.029	87.937129	0.960534
UZB	CAS	29.2209	0.528278	3.004887	0.307822	0.036015	0.725594	0.038	3.050590	0.904492
VEN	LAM-M	35.9640	1.206963	0.497411	0.322620	0.133199	0.238686	0.032	4.389933	0.902427
VNM	OAS-CPA	97.7311	1.885515	7.173995	0.291610	0.040827	0.360085	0.057	3.874289	0.971739
YEM	MEA-M	38.9573	0.304610	1.469655	0.389528	0.026195	0.116981	0.045	0.218068	1.178348
ZAF	ZAF	60.9731	2.081338	7.471443	0.350519	0.069972	0.381636	0.033	2.065736	0.845391
ZMB	SSA-L	20.8157	0.237512	1.382150	0.269137	0.021985	0.254424	0.033	0.555343	1.379893
ZWE	SSA-L	11.2200	0.037709	0.316673	0.269137	0.009153	0.519764	0.033	0.072124	1.339131

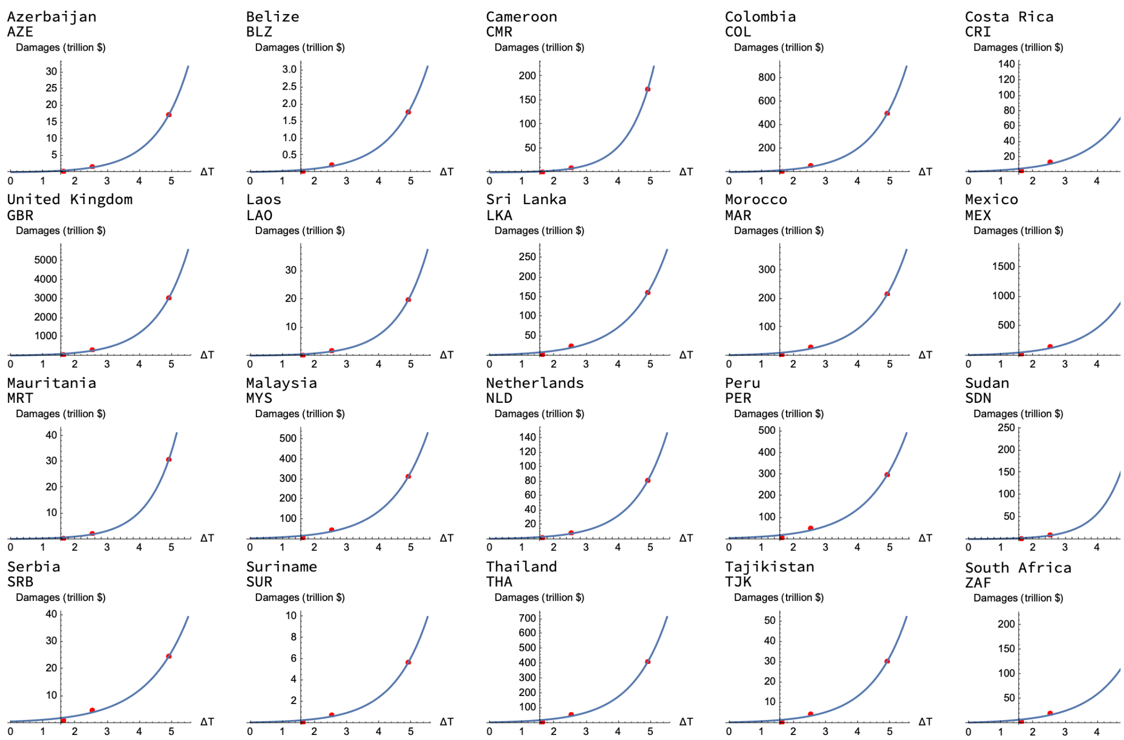
Population, GDP, capital, and carbon intensity represent average values for the period 2020-2050. Sources: Population and GDP from SSP5-RCP8.5; stock of capital from PWT; capital-output ratio from Leimbach et al. (2017); all other values are generated by the authors.

II Country-specific climate damage functions

II.1 Calibration of climate damage as a function of increases in temperature

We fit the exponential damage function specification of our model ($\psi_{1j} e^{\psi_{2j} \triangle T}$) to empirical estimates of climate damages in Kahn et al. (2021). We proxy damages for Uruguay by assuming they account for the same fraction of GDP as Argentina, as the original estimate for Uruguay is an outlier with negative damages. Figure II.1 plots the fitted function and the data points for a random sample of 24 countries.

Figure II.1: Damage functions. Calibrated annual damage functions (blue solid line), and actual data points in Kahn et al. (2021) (red dots) for a random sample of countries. Annual damages measured in trillions of international dollars.



II.2 Present value of climate damages for constant annual emissions: $H_j(E)$

The function $H_j : [E_{min}, E_{max}] \to \mathbb{R}_+$ maps annual global emissions E to the present value of climate damages for country j (expression (15) in the text):

$$H_j(E) = \sum_{t=1}^{n} \rho^t D_j(E_{00}^{cum} + tE) + \sum_{t=n+1}^{N} \rho^t D_j(E_{00}^{cum} + nE), \tag{II.1}$$

where $D_j(E^{cum}) = \psi_{1j} e^{\widehat{\psi}_{2j} E^{cum}}$ are country j's annual climate damages from cumulative emissions (13), n is the number of years until a climate-neutral world, and $\widehat{\psi}_{2j} = \psi_{2j}\varphi 10{-}3$.

We can manipulate (II.1) to obtain expression (15) in the main text as follows:

$$
\begin{aligned}
H_j(E) = & \sum_{t=1}^{n} \rho^t D_j(E_{00}^{cum} + tE) + \sum_{t=n+1}^{N} \rho^t D_j(E_{00}^{cum} + nE) = \\
& \sum_{t=1}^{n} \rho^t \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}} \left(e^{\widehat{\psi}_{2j} E)} \right)^t + \sum_{t=n+1}^{N} \rho^t \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}} \left(e^{\widehat{\psi}_{2j} E)} \right)^n = \\
& \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}} \sum_{t=1}^{n} \left(\rho e^{\widehat{\psi}_{2j} E)} \right)^t + \frac{\rho^{n+1} - \rho^{N+1}}{1-\rho} \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}} \left(e^{\widehat{\psi}_{2j} E)} \right)^n = \\
& \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}} \left(\sum_{t=1}^{n} \left(\rho e^{\widehat{\psi}_{2j} E)} \right)^t + \frac{\rho - \rho^{N-n+1}}{1-\rho} \left(\rho e^{\widehat{\psi}_{2j} E)} \right)^n \right) = \\
& \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}} \left(\frac{\rho e^{\widehat{\psi}_{2j} E)} - \left(\rho e^{\widehat{\psi}_{2j} E)} \right)^{n+1}}{1 - \rho e^{\widehat{\psi}_{2j} E)}} + \frac{\rho - \rho^{N-n+1}}{1-\rho} \left(\rho e^{\widehat{\psi}_{2j} E)} \right)^n \right) = \\
& \theta_{0j} \left(\frac{\theta_j(E) - (\theta_j(E))^{n+1}}{1 - \theta_j(E)} + \frac{\rho - \rho^{N-n+1}}{1-\rho} (\theta_j(E))^n \right),
\end{aligned}
\tag{II.2}
$$

where $\theta_{0j} = \psi_{1j} e^{\widehat{\psi}_{2j} E_{00}^{cum}}$ and $\theta_j(E) = \rho e^{\widehat{\psi}_{2j} E}$.

Using the fact that $\theta_j'(E) = \widehat{\psi}_{2j} \theta_j(E)$, we obtain expression (16) in the text for the first derivative of H_j:

$$
\begin{aligned}
H_j'(E) = & \theta_{0j} \left(\frac{\left(\theta_j' - (n+1)\theta_j^n \theta_j'\right)(1-\theta_j)\left(\theta_j \theta_j^{n+1}\right)\theta_j'}{(1-\theta_j)^2} + \frac{\rho - \rho^{N-n+1}}{1-\rho} n \theta_j^{n-1} \theta_j' \right) = \\
& \theta_{0j} \widehat{\psi}_{2j} \left(\frac{\theta_j - (n+1)\theta_j^{n+1}}{1-\theta_j^n)} + \frac{\theta_j^2 (1-\theta_j^n)}{(1-\theta_j)^2} + \frac{\rho - \rho^{N-n+1}}{1-\rho} n \theta_j^n \right),
\end{aligned}
\tag{II.3}
$$

where, for the sake of clarity, we have written $\theta_j = \theta_j(E)$ and $\theta_j' = \theta_j'(E)$.

III Computing the global unanimity general equilibrium

In the following, we describe the computation of the global unanimity general equilibrium (Definition 3), consisting of an economic equilibrium (Definition 1), a global unanimity agreement (Definition 2), and a vector carbon revenue shares $(a_1, \ldots, a_J) \in \Delta^{J-1}$. First, we compute the economic equilibrium for a given level of global emissions and estimate the carbon revenue as a function of global emissions. Next, we solve the government's optimization program for the estimated carbon revenue function. Finally, we find the equilibrium level of global emissions and obtain the values of all other variables.

III.1 Economic equilibrium

Given relative prices (c and r), the representative firm of country j maximizes profits according to the following program:

$$\begin{aligned}
\max_{K_j, e_j, \mu_j} \; & G_j\left(K_j\right) - rKj - ce_j - C_j\left(\mu_j\right) G_j\left(K_j\right) \\
\text{s.t.} \quad & G_j(K_j) = \kappa_j K_j^{\alpha_j} \\
& e_j = \left(1-\mu_j\right) \eta_j G_j\left(K_j\right) \\
& C_j\left(\mu_j\right) = \zeta_j \mu_j^{\beta_j} \\
& \mu_j \leq 1
\end{aligned} \tag{III.1}$$

The FOC for an interior solution yield

$$(\partial K_j) : \left(1 - c\left(1-\mu_j\right)\eta_j - \zeta_j \mu_j^{\beta_j}\right) \kappa_j \alpha_j K_j^{\alpha_j - 1} = r \tag{III.2a}$$

$$(\partial \mu_j) : c \; \eta_j = \zeta_j \beta_j \mu_j^{\beta_j - 1}. \tag{III.2b}$$

It follows from (III.2a) that

$$K_j = \left(\frac{1 - c\left(1-\mu_j\right)\eta_j - \zeta_j \mu_j^{\beta_j}}{r} \kappa_j \alpha_j\right)^{\frac{1}{1-\alpha_j}}. \tag{III.3}$$

From (III.2b) and $\mu_j \leq 1$ for all j we obtain

$$\mu_j = \min\left\{\left(c \frac{\eta_j}{\zeta_j \beta_j}\right)^{\frac{1}{\beta_j - 1}}, 1\right\}, \qquad j = 1, \ldots, J. \tag{III.4}$$

Substituting (III.3) in the capital market clearing condition ($\sum_j K_j = \sum_j \bar{K}_j \equiv \bar{K}$) yields

$$\sum_j \left(\frac{1 - c\left(1-\mu_j\right)\eta_j - \zeta_j \mu_j^{\beta_j}}{r} \kappa_j \alpha_j\right)^{\frac{1}{1-\alpha_j}} = \bar{K}. \tag{III.5}$$

For a given level of global emissions E, the emission market clearing condition ($\sum e_j = E$) obtains

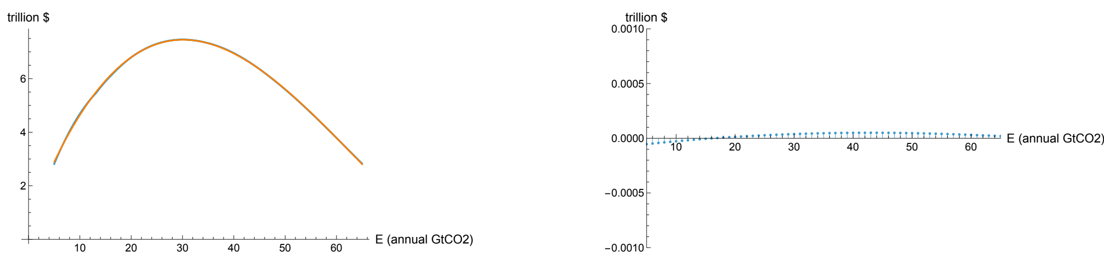
$$\sum_j \left(1-\mu_j\right)\eta_j \kappa_j \left(\frac{1 - c\left(1-\mu_j\right)\eta_j - \zeta_j \mu_j^{\beta_j}}{r} \kappa_j \alpha_j\right)^{\frac{\alpha_j}{1-\alpha_j}} = E, \tag{III.6}$$

where we have used $e_j = (1-\mu_j)\eta_j G_j(K_j)$ and (III.3).

Finally, we obtain $\hat{c}(E)$, $\hat{r}(E)$, and $\hat{\mu}_j(E)$ for $j = 1 \ldots, J$ ($J+2$ unknowns) as the solution to the system of equations (III.4) and the market clearing conditions (III.5) and (III.6) ($J+2$ equations).

We programmed Mathematica to compute the economic equilibrium for a broad range of global emission levels $E \in [5, 65]$, in increments of 0.1. Figure III.2 displays the fitted carbon revenue function $CR(E) = \hat{c}(E)E$ along with its associated residual errors. The function CR is strictly concave, ensuring a unique international unanimous agreement on global emissions E^* (Proposition 2). This equilibrium can be derived by combining the governments' first-order condition for utility maximization with the property $\sum_j a_j = 1$.

Figure III.2: Estimated carbon revenue function and residuals. Left panel: carbon revenue generated from the economic equilibria for different values of E (blue) and its polynomial fit, $0.634568 + 0.504318E - 0.0109408E^2 + 0.0000568606E^3$ (orange). Right panel: residuals from the polynomial fit.



III.2 Unanimity agreement

Governments maximize the present value of their returns from carbon revenue net of climate damages eq. (17)

$$V_j(E) = \frac{\rho - \rho^{n+1}}{1 - \rho} a_j CR(E) - H_j(E). \tag{III.7}$$

From the FOC condition of the government's program we obtain

$$a_j = \frac{H_j'(E_j^*)}{\frac{\rho - \rho^{n+1}}{1-\rho} CR'(E_j^*)}, \tag{III.8}$$

where E_j^* is the optimal global emission level for country j. In a unanimous agreement, $E_j^* = E^* - k$ for all j, k, which, combined with the carbon revenue balance condition $\sum_j a_j = 1$, implies

$$\sum_j H_j'(E) = \frac{\rho - \rho^{n+1}}{1 - \rho} CR'(E), \tag{III.9}$$

where H' is the first derivative of the damage function (16) and CR' is the first derivative of the estimated carbon revenue function obtained from the economic equilibria (Figure III.2).

The international unanimous agreement on global emissions E^* is obtained as the unique solution to (III.9) (which is condition (18) in the main text).

III.3 Global unanimity general equilibrium

Use the unanimous global emission level E^* to compute the general equilibrium price of carbon emissions, price of capital, and abatement rates as, respectively, $c^* = \hat{c}(E^*)$, $r^* = \hat{r}(E^*)$, and $\mu_j^* = \hat{\mu}(E^*)$. Other values are obtained as follows: the stocks of capital follow from the first-order condition for profit maximization of the firm (III.3)

$$K_j^* = \left(\frac{1 - c^*(1-\mu_j^*)\eta_j - \zeta_j(\mu_j^*)^\beta}{r^*} \kappa_j \alpha_j \right)^{\frac{1}{1-\alpha_j}} \qquad j = 1, \ldots, J;$$

the annual country emissions are

$$e_j^* = (1-\mu_j^*)\eta_j \kappa_j (K_j^*)^{\alpha_j} \qquad j = 1, \ldots, J;$$

and, finally, the shares of total revenue follow from the governments' first-order condition (III.8)

$$a_j^* = \frac{1-\rho}{\rho - \rho^{n+1}} \frac{H_j'(E^*)}{CR(E^*)} \qquad j = 1, \ldots, J;. \tag{III.10}$$

IV Country-level outcomes in the global unanimity general equilibrium

Table IV.1: Country-level outcomes. Average annual values. A positive (negative) *redistribution* value represents a net recipient (donor).

Country	GDP_{pc}	Revenue received	Revenue raised	Redistribution	Revenue share	Damages
	y_j/pop_j	$a_j c\ E/y_j$	ce_j/y_j	$(a_j cE - ce_j)/y_j$	$a_j \times 100$	$H_j(E)/y_j$
ISO3	US-$ pc	% GDP	% GDP	% GDP	% revenue	% GDP
AGO	8,987	5.55	1.78	3.77	0.23	2.61
ALB	17,253	3.85	2.57	1.28	0.03	3.22
ARE	78,959	1.44	3.02	-1.58	0.25	1.14
ARG	50,239	2.62	1.42	1.20	0.83	2.02
ARM	19,035	1.67	2.46	-0.79	0.01	1.29
AUS	81,935	2.68	2.02	0.66	1.10	1.57
AUT	58,989	3.03	1.88	1.15	0.25	1.99
AZE	21,464	0.57	1.30	-0.73	0.02	0.35
BDI	8,191	4.34	0.71	3.62	0.07	1.75
BEL	53,149	0.98	1.80	-0.82	0.10	0.61

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Table IV.1 – continued from previous page

Country	GDP_{pc}	Revenue received	Revenue raised	Redistribution	Revenue share	Damages
BEN	8,233	3.74	0.28	3.47	0.06	1.60
BFA	10,010	3.02	0.00	3.02	0.11	1.32
BGD	13,933	3.78	3.54	0.24	1.27	2.14
BGR	56,311	3.26	1.74	1.52	0.17	2.75
BIH	32,527	2.45	0.00	2.45	0.04	2.47
BLR	49,335	1.38	2.05	-0.67	0.08	1.15
BLZ	21,912	1.92	2.12	-0.20	0.00	1.29
BOL	30,303	2.84	0.00	2.84	0.14	1.59
BRA	34,604	2.77	2.06	0.71	2.91	2.18
BRN	68,011	0.65	2.68	-2.02	0.00	0.53
BTN	68,414	6.07	3.07	3.00	0.06	4.19
BWA	33,440	2.79	2.23	0.56	0.03	2.02
CAF	4,861	4.28	0.00	4.28	0.02	1.76
CAN	67,468	5.62	1.74	3.89	2.61	3.41
CHE	63,856	5.71	1.47	4.24	0.49	3.70
CHL	42,029	4.25	2.14	2.11	0.49	3.49
CHN	64,310	1.01	3.16	-2.15	12.17	1.12
CIV	17,931	2.32	2.21	0.10	0.14	1.26
CMR	11,880	2.39	1.97	0.42	0.11	1.15
COD	6,899	4.63	0.00	4.63	0.49	1.88
COG	19,319	3.37	0.93	2.44	0.06	1.88
COL	34,727	2.09	2.14	-0.05	0.57	1.34
COM	4,507	6.09	2.23	3.86	0.00	2.72
CPV	10,759	3.17	2.17	1.00	0.00	2.28
CRI	44,769	3.17	2.05	1.12	0.12	2.39
CYP	26,795	2.38	2.66	-0.29	0.01	1.65
CZE	61,681	1.73	0.80	0.93	0.19	1.03
DEU	58,737	0.71	1.86	-1.16	0.51	0.47
DJ	12,354	0.13	0.71	-0.58	0.00	0.08
DNK	52,553	0.68	1.87	-1.19	0.03	0.38
DOM	24,823	1.34	2.16	-0.82	0.05	0.96
DZA	16,884	1.48	0.00	1.48	0.15	0.97

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Table IV.1 – continued from previous page

Country	**GDP$_{pc}$**	**Revenue received**	**Revenue raised**	**Redistribution**	**Revenue share**	**Damages**
ECU	20,714	3.31	1.91	1.39	0.17	1.82
EGY	37,332	1.74	2.23	-0.49	0.96	1.11
ESP	37,600	1.21	1.90	-0.69	0.36	0.78
EST	47,180	1.02	0.00	1.02	0.01	0.64
ETH	8,376	3.26	0.00	3.26	0.47	1.46
FIN	62,972	0.39	1.53	-1.14	0.02	0.24
FJI	11,705	3.82	3.12	0.70	0.01	2.53
FRA	49,283	2.65	1.84	0.81	1.49	1.59
GAB	32,171	2.31	1.87	0.44	0.02	1.56
GBR	68,679	4.26	1.87	2.39	3.24	2.63
GEO	20,132	1.44	2.26	-0.82	0.01	1.21
GHA	11,025	2.46	2.23	0.23	0.13	1.25
GIN	27,762	2.30	0.00	2.30	0.11	1.38
GMB	12,758	5.03	1.75	3.27	0.02	2.54
GNB	10,820	3.31	0.00	3.31	0.01	1.50
GNQ	57,321	0.46	2.21	-1.75	0.00	0.33
GRC	42,811	5.42	1.82	3.61	0.40	3.48
GTM	19,427	3.00	2.11	0.89	0.15	1.75
HND	15,448	2.14	0.60	1.54	0.04	1.19
HRV	26,640	2.08	2.57	-0.49	0.03	1.80
HTI	8,701	2.87	0.00	2.87	0.04	1.40
HUN	33,497	1.95	1.76	0.19	0.09	1.15
IDN	21,454	4.87	3.11	1.76	3.98	3.42
IND	19,100	5.53	3.29	2.23	22.12	3.58
IRL	52,091	2.16	1.63	0.53	0.10	1.29
IRN	22,668	3.67	3.04	0.63	1.01	2.71
IRQ	23,803	1.05	2.74	-1.69	0.17	0.57
ISL	82,345	0.37	1.31	-0.94	0.00	0.22
ISR	72,177	1.48	3.05	-1.56	0.20	0.74
ITA	35,295	3.89	1.86	2.02	1.30	2.63
JAM	13,204	2.27	2.01	0.26	0.01	1.80
JOR	26,433	3.97	2.94	1.02	0.16	2.10

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Table IV.1 – continued from previous page

Country	GDP_{pc}	Revenue received	Revenue raised	Redistribution	Revenue share	Damages
JPN	85,306	2.51	1.83	0.68	3.78	1.87
KAZ	58,313	3.62	0.00	3.62	0.55	3.27
KEN	8,145	1.86	1.13	0.73	0.13	0.86
KGZ	12,327	4.91	0.00	4.91	0.05	3.33
KHM	15,633	0.38	3.80	-3.43	0.01	0.23
KOR	105,769	1.71	2.47	-0.76	1.31	1.31
KWT	125,131	1.09	3.04	-1.96	0.10	0.90
LAO	15,927	1.15	3.42	-2.27	0.02	0.67
LBN	28,639	6.05	2.88	3.17	0.11	4.78
LBR	8,422	4.38	0.62	3.75	0.04	1.79
LKA	38,871	1.87	1.84	0.03	0.22	1.37
LSO	8,173	9.85	2.15	7.70	0.03	4.67
LTU	41,276	1.03	2.52	-1.49	0.02	0.96
LUX	108,135	0.57	1.90	-1.33	0.01	0.39
LVA	32,723	1.36	2.57	-1.20	0.01	1.15
MAR	21,186	2.85	2.23	0.62	0.28	1.99
MDA	16,563	2.69	1.76	0.93	0.02	2.68
MDG	6,289	3.27	0.00	3.27	0.09	1.39
MEX	36,772	2.16	2.03	0.13	1.43	1.55
MKD	34,322	3.97	2.33	1.65	0.04	3.10
MLI	7,468	3.82	0.00	3.82	0.10	1.62
MMR	9,481	1.03	3.69	-2.66	0.07	0.73
MNE	23,237	6.86	2.42	4.44	0.02	5.82
MNG	34,274	2.83	0.00	2.83	0.04	2.12
MOZ	10,241	2.78	0.00	2.78	0.13	1.14
MRT	7,631	4.43	0.00	4.43	0.02	2.32
MUS	43,106	0.39	1.98	-1.60	0.00	0.30
MWI	11,644	2.46	1.51	0.95	0.11	0.94
MYS	48,776	1.65	3.18	-1.53	0.42	1.18
NAM	22,156	4.49	2.02	2.47	0.04	3.00
NER	4,665	1.49	0.00	1.49	0.03	0.48
NGA	12,899	2.81	2.23	0.57	1.35	1.21

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Table IV.1 – continued from previous page

Country	**GDP$_{pc}$**	**Revenue received**	**Revenue raised**	**Redistribution**	**Revenue share**	**Damages**
NIC	13,274	0.32	0.00	0.32	0.00	0.20
NLD	64,141	0.51	1.81	-1.30	0.09	0.32
NOR	94,270	0.59	1.89	-1.30	0.06	0.35
NPL	8,545	8.19	3.85	4.34	0.40	3.97
NZL	57,058	3.83	1.22	2.62	0.18	2.09
OMN	51,458	3.78	2.80	0.97	0.11	2.77
PAK	13,294	4.32	3.54	0.78	1.86	2.24
PAN	51,258	2.14	2.10	0.03	0.07	1.67
PER	49,124	2.12	2.15	-0.03	0.44	1.62
PHL	18,097	4.20	2.85	1.34	1.31	2.42
POL	58,913	0.93	0.00	0.93	0.31	0.65
PRT	30,006	4.07	1.90	2.17	0.21	2.47
PRY	24,386	3.29	0.60	2.69	0.09	1.80
QAT	187,286	1.58	2.93	-1.35	0.15	1.49
ROU	36,686	2.55	2.56	-0.01	0.25	2.08
RUS	49,781	3.05	1.18	1.87	3.02	2.59
RWA	10,656	4.05	2.23	1.81	0.10	1.82
SAU	45,501	2.46	3.03	-0.58	0.72	1.90
SDN	13,892	0.85	1.09	-0.24	0.11	0.39
SEN	9,156	2.29	1.84	0.45	0.05	1.05
SLE	9,700	4.35	1.23	3.13	0.05	1.84
SLV	17,525	1.96	2.15	-0.18	0.03	1.73
SRB	15,869	1.81	0.00	1.81	0.04	1.48
SUR	22,671	3.74	2.14	1.60	0.01	2.52
SVK	55,592	1.17	1.57	-0.40	0.06	0.82
SVN	43,018	3.34	2.55	0.79	0.05	2.06
SWE	68,885	0.96	1.75	-0.80	0.12	0.54
SYR	48,026	0.90	1.42	-0.51	0.17	0.52
TCD	9,801	0.54	0.00	0.54	0.01	0.22
TGO	6,279	5.11	0.00	5.11	0.04	2.16
THA	39,442	1.25	2.95	-1.70	0.52	0.86
TJK	9,470	4.45	0.00	4.45	0.04	3.09

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Table IV.1 – continued from previous page

Country	**GDP$_{\mathbf{pc}}$**	**Revenue received**	**Revenue raised**	**Redistribution**	**Revenue share**	**Damages**
TKM	35,098	2.80	0.00	2.80	0.08	2.41
TTO	73,634	0.32	0.00	0.32	0.00	0.37
TUN	48,094	0.16	2.16	-2.00	0.01	0.14
TUR	32,591	3.12	0.75	2.37	1.23	2.14
TZA	10,479	3.04	1.70	1.34	0.32	1.34
UGA	11,294	4.40	0.99	3.40	0.42	1.70
UKR	18,135	5.96	1.52	4.44	0.63	4.24
URY	40,813	2.70	0.86	1.84	0.05	2.08
USA	106,177	1.84	1.26	0.58	11.33	1.20
UZB	14,281	5.58	0.00	5.58	0.33	3.88
VEN	93,840	0.99	2.06	-1.07	0.47	0.69
VNM	17,829	2.09	3.85	-1.76	0.52	1.35
YEM	7,338	1.32	2.22	-0.90	0.05	0.69
ZAF	35,421	0.61	0.83	-0.22	0.19	0.45
ZMB	8,909	9.14	2.08	7.05	0.24	4.00
ZWE	2,286	7.66	0.00	7.66	0.03	3.47

V Computing the global unanimity general equilibrium with myopic governments

In this scenario, governments choose the level of global emissions that maximizes their utility, myopically ignoring the impact of global emissions on prices. That is, they act as *price-takers* with utility as in (33):

$$\tilde{V}_j(E) = \frac{\rho - \rho^{n+1}}{1-\rho} cE + -H_j(E). \tag{V.11}$$

where, notice, the price of carbon is taken as a constant.

The FOC ($V_j'(E) = 0$) yields (expression (35)):

$$a_j = \frac{1}{\frac{\rho-\rho^{n+1}}{1-\rho} c} H_j'(E). \tag{V.12}$$

Summing over j and using $\sum_j a_j = 1$ we obtain expression (34) in the text:

$$\sum_j H_j'(E) = \frac{\rho - \rho^{n+1}}{1-\rho} c. \tag{V.13}$$

The economy is as in the main model (Section III.1). But, in this case, there is no need to estimate the carbon revenue function. We can compute the global unanimity general equilibrium by solving the system of $J+3$ equations (V.11), (III.4)-(III.6) for the price of capital r, the price of carbon emissions c, the total level of emissions E, and the abatement rates $\mu_j, j = 1, \ldots, J$. Other values can be obtained as described in Section III.3.