

Coase Meets Negishi: Property Rights, Welfare Weights, and Distributional Consequences in Climate Economics*

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Abstract

We develop a property-rights based approach for defining welfare weights in economic models of climate change. Whether there is a “right to pollute” or a “right to no pollution” is increasingly contested in legislatures, courts, and international climate negotiations. We show how these notions of property rights can provide the basis for “Coasean welfare weights” that are applicable in multilateral public goods settings. Distributional questions are addressed through positive analysis, conditional on property rights, rather than normative views about redistribution. The implied transfers are consistent with a bargained solution over the net benefits of addressing climate change and reflect the value of property rights over emissions. The approach defines efficient allocations that generate Pareto improvements, in contrast to commonly used Negishi weights. We implement the approach in a global integrated assessment model to quantify what countries have at stake in ongoing political and legal debates about emissions-related property rights.

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1 Introduction

A large and growing body of evidence shows that climate change will cause substantial and highly uneven damages across countries (e.g., Diaz, 2016; Carleton et al., 2022; Hultgren et al., 2025). Less attention has been given to the way that resolving climate change through collective action will also have distributional consequences. These consequences arise not only because of heterogeneity in avoided damages across countries, but also because of differences in abatement costs and the extent to which international transfers may (or may not) occur. Resolving climate change among countries is at its core a global public goods problem (Barrett, 2007; Buchholz and Sandler, 2021), and a seminal insight of Samuelson (1954) is that public goods problems do not, in general, have a unique Pareto efficient solution. Instead, there is a set of efficient allocations that differ in their distributional consequences. Solving public goods problems, such as climate change, therefore requires selecting among allocations on the basis of some criterion beyond efficiency, and how economists make this choice remains an enduring source of debate.

The choice is typically framed as the need for analysts to choose welfare weights across countries or regions for use in a global planner’s social welfare function (Dietz, 2024). A common approach is to use a variant of Negishi weights, where the resulting Pareto efficient allocation is the one that arises without international transfers (Nordhaus and Yang, 1996; Manne and Richels, 2005; Leimbach et al., 2010; Krusell and Smith Jr., 2022; Traeger, 2023; Alsina-Pujols, 2026). The approach is often understood as allowing analysts to separate the problem of climate change from global income inequality, addressing the inefficiency of climate change while sidestepping normative judgments about distributional justice (Nordhaus and Yang, 1996; Hassler and Krusell, 2012; Barrage, 2020). This interpretation is nevertheless criticized for failing to recognize implicit normative assumptions (Stanton, 2011; Kelleher, 2018). The main alternative in the literature is more explicitly normative, whereby analysts use social welfare functions with some degree of inequality aversion (Chichilnisky and Heal, 1994; Tol, 1997, 2002; Dennig et al., 2015; Budolfson et al., 2021; Lang, 2026). These social welfare functions introduce a redistributive motive, but critics of the approach argue that the implied transfers may require more international redistribution than countries are willing to undertake.¹

This paper develops a novel alternative: welfare weights derived from a positive analysis

¹We focus on optimal climate policy in this paper, but the two approaches just described also characterize research that estimates the social cost of carbon (SCC) or evaluates particular climate policies, with some studies explicitly or implicitly using Negishi weights (Hope et al., 1993; Nordhaus, 2010; Rennert et al., 2022; U.S. Environmental Protection Agency, 2023; Conte et al., 2026; Hassler et al., 2026) and others using equity weights (Azar and Sterner, 1996; Fankhauser et al., 1997; Hope, 2008; Anthoff et al., 2009; Anthoff and Emmerling, 2019; Prest et al., 2024; Cruz and Rossi-Hansberg, 2024; Bressler et al., 2026).

of property rights and bargaining, rather than either an assumption of zero transfers or an imposed criterion of distributional equity. The lack of well-defined property rights is a key feature of public goods problems. There are, however, ongoing debates among policymakers and in the courts over attempts to establish the “right to pollute” or the “right to no pollution” with respect to greenhouse gas (GHG) emissions. We show how these standard notions of property rights can provide the basis for what we refer to as Coasean welfare weights. Use of these weights results in efficient allocations that feature transfer payments between countries. But importantly, the transfers are not driven by normative views about global redistribution. Instead, the transfers represent the outcome of a hypothetical bargain over the distribution of surplus obtained by implementing an efficient resolution of climate change, conditional on assignment of property rights. Beyond providing a conceptual basis for Coasean welfare weights, we apply them in a calibrated integrated assessment model (IAM) of global climate change. The quantitative analysis compares the distributional consequences of different allocations and shows what countries or regions have at stake when it comes to questions about emissions-related property rights.

Property rights linked to climate change are increasingly debated and contested in courts, legislatures, and international bodies around the world. In 2025, the International Court of Justice issued an advisory opinion that countries should be held liable for their GHG emissions.² Citizens in a number of countries have sued governments and companies for not doing enough to reduce emissions.³ In the United States, municipalities have sued fossil-fuel companies over liability for climate damages, and several states have enacted or proposed “Climate Superfund” laws that mandate payment for damages or adaptation costs, though the federal government is challenging these cases and laws in court.⁴ Finally, international transfers motivated by liability through “loss and damage” payments have become central to international climate negotiations (UNFCCC, 2015, 2023, 2024).

Despite the increasing salience of questions about property rights, the topic has received relatively little attention among economists regarding how it might affect the design of climate policy. In this paper, we use an intentionally simple theoretical model to illustrate the fundamental ideas of our approach. We consider a static setting where each country’s

²*Obligations of States in Respect of Climate Change*, Advisory Opinion, General List No. 187 (I.C.J. July 23, 2025).

³See, e.g., *Urgenda Foundation v. State of the Netherlands*, ECLI:NL:HR:2019:2007 (Sup. Ct. Neth. 2019); *Juliana v. United States*, 947 F.3d 1159 (9th Cir. 2020); and *Held v. State*, 560 P.3d 1235 (Mont. 2024); *Smith v. Fonterra Co-operative Group Ltd* [2024] NZSC 5, Climate Change Response (Tort Liability) Amendment Act 2026, No. 52 (N.Z.).

⁴See, e.g., *Suncor Energy (U.S.A.) Inc. v. County Commissioners of Boulder County*, No. 25-170 (U.S. argued Oct. 5, 2026); *United States v. New York*, No. 1:25-cv-03656 (S.D.N.Y. filed May 1, 2025); *United States v. Vermont*, No. 2:25-cv-00463 (D. Vt. filed May 1, 2025).

emissions generate a global public bad. Countries can differ according to domestic welfare functions, initial endowments, benefits from their own emissions, and damages from aggregate emissions. A property-rights regime defines an initial, non-cooperative reference allocation. For example, under “right to pollute,” the reference allocation is the Nash equilibrium, since each country is free to emit and chooses its unilaterally optimal level of emissions. In contrast, under “right to no pollution,” the reference allocation is zero emissions, since each country has the right to prevent the emissions of all other countries. A key feature of the setup—unlike standard externality settings with the potential for Coasean bargaining—is that all countries are potential emitters, experiencing both benefits and costs. This means that property rights are not clearly assigned to one set of countries or the other, but rather, to the actions all countries may undertake.

A Coasean solution is then obtained through Nash (1950) bargaining, which defines a particular Pareto efficient allocation, conditional on a given property-rights regime. The allocation is consistent with what countries might choose for themselves through a decentralized and cooperative bargaining procedure in the absence of transaction costs (Rubinstein, 1982; Osborne and Rubinstein, 1990). The Coasean welfare weights consistent with this allocation take a similar form to Negishi weights—the inverse of the marginal utility of consumption—but in this case, the levels of consumption depend on transfer payments that reflect the bargained value of the property rights over emissions. We describe how the resulting transfers accord with a version of the beneficiary pays principle for emissions reductions under “right to pollute,” and the polluter pays principle for emissions increases under “right to no pollution.”

A key result is that Coasean welfare weights always result in a Pareto improvement relative to the corresponding reference allocation, that is, all countries are made (weakly) better off. This feature of the planner’s solution is important because the distributional consequences of resolving climate change are central to the design and political feasibility of international policy. In contrast, Pareto improvements do not necessarily arise with the use of Negishi weights, highlighting their distributional consequences despite their frequent interpretation as being distributionally neutral. We also use our model to identify conditions under which a specific country will make or receive a transfer with Coasean welfare weights, along with the conditions that dictate whether a country prefers one property-rights regime over another.

We use calibrated simulations to illustrate use of Coasean welfare weights and quantify the distributional consequences of different property-rights regimes. We develop a static IAM that draws on RICE (Nordhaus and Yang, 1996) and C-DICE (Nordhaus, 2015). Focusing first on the property-rights based reference allocations, we find that changing property rights

does not meaningfully change inequality across countries, yet it does meaningfully change the level of consumption for certain countries. For example, moving from “right to pollute” to “right to no pollution” causes consumption per capita to increase 15% in Sub-Saharan Africa and decrease 9% in South Africa, while changes in the United States and the European Union are less than 2%. These results imply that changing property rights is not, on its own, fundamentally redistributive in a way that reorders consumption across countries, yet the value of these rights can still be significant for some countries.

When comparing efficient allocations, distributional differences are interpreted as the relative value of property rights conditional on successful Nash bargaining to a cooperative solution. We find that, under “right to pollute,” the efficient allocation features total annual transfers of \$190 billion, whereas under “right to no pollution,” total transfers amount to \$1.03 trillion. Intuitively, countries with large benefits of emissions relative to climate damages prefer “right to pollute” (e.g., Russia, South Africa, China, and Eurasia), whereas countries with large climate damages relative to the benefits of emissions prefer “right to no pollution” (e.g., Sub-Saharan Africa, Brazil, and a large set of other Asian countries). Finally, by comparing reference allocations for one property-rights regime with the efficient allocation for another, we show why countries may sometimes prefer to contest property rights rather than address climate change. In particular, we illustrate how some countries prefer the inefficient allocation under one set of property rights to the efficient allocation under the alternative set.

The overarching contribution of this paper is to show how the choice of welfare weights in climate economics can be grounded in a positive analysis of property rights. The approach differs fundamentally from the use of inequality-averse social welfare functions and associated equity weights, which impose a normative criterion of distributive equity. While we do not prescribe how property rights should be assigned, we note that the choice itself is actively debated and has normative content (Fleurbaey, 2008). Nevertheless, separating consideration of the distributional consequences of property rights from questions about efficiency is familiar territory for analysts of environmental and natural resource problems (Coase, 1960; Libecap, 1990; Deryugina et al., 2021).

The approach is also distinct from the standard use of Negishi weights in climate models, though we argue it is more closely aligned with Negishi’s original formulation with respect to the role of initial endowments. Negishi’s (1960) original analysis applies to a private-goods economy with no market failures, showing a correspondence between the decentralized equilibrium and the appropriately weighted planner’s problem. When applied in climate models, however, the public goods market failure is central, and Negishi weights are typically used to implement an efficient allocation with an assumed no-transfer rule (e.g., Nordhaus and

Yang, 1996). But this rule ignores the distributional consequences based on heterogeneous benefits and costs of addressing climate change, that is, efficient provision of the global public good. Our approach differs in that the public good problem is addressed conceptually by assigning property rights and modeling a decentralized bargaining procedure. The approach thus represents a synthesis of Coasean logic with Negishi’s insight that welfare weights can be chosen to support a decentralized allocation, conditional on a set of endowments.⁵

Our analysis also relates to other strands of the literature. Existing studies examine the way that international environmental agreements can be used to infer implied social welfare weights (Eyckmans et al., 1993; Narita et al., 2010). The extensive literature on emissions trading systems is founded on the notion of establishing partial property rights over the “right to pollute” and allowing agents to buy and sell those rights (e.g., Montgomery, 1972; Tietenberg, 1985; Nordhaus, 1991). A number of papers analyze Nash bargaining solutions to climate change (Howarth, 1996; Tol, 1997; Yang, 2013; Yu et al., 2017; Tulkens, 2019; Yang, 2020), but they consider only the Nash equilibrium as an initial allocation, without explicit consideration of property rights. Finally, while the “right to no pollution” is less studied, Ambec and Ehlers (2016) consider the welfare consequences of polluter-pays liability as the basis for regulation in a multilateral setting, and recent papers by Tavoni et al. (2024) and Burke et al. (2026) estimate loss and damage compensation payments based on historical emissions and the SCC.

The remainder of the paper is organized as follows. Section 2 outlines the basic setup of our theoretical model. Section 3 provides background on and discussion of the standard approach to Negishi weights in climate models. Section 4 develops our property-rights based approach, providing a formal definition of Coasean welfare weights and a discussion of the implications. Section 5 outlines the setup of our climate-economy IAM and reports quantitative results. Section 6 concludes with a brief summary and directions for future research.

2 Basic setup

This section establishes the basic setup of our theoretical model. We keep the setup as simple as possible to focus on novel aspects of our analysis. We assume a standard static setting where each country’s GHG emissions contribute to a global public “bad” through climate change.

Countries are denoted $i = 1, \dots, n$, with wealth endowments w_i . Each country benefits

⁵We note that in Negishi’s original setting, endowments reflect private wealth, and the allocation is consistent with a competitive equilibrium. In our setting, endowments include property rights, and the allocation is achieved conceptually through bargaining.

from its own emissions, e_i , according to the function $b_i(e_i)$, where $b_i(0) = 0$, $b'_i(e_i) > 0$ and $b''_i(e_i) < 0$. A country's benefits of emissions can be interpreted analogously as avoided abatement costs. A country's level of unregulated emissions, defined as $\bar{e}_i$, is the quantity that satisfies $b'_i(\bar{e}_i) = 0$. This means that in the absence of any domestic regulation that limits emissions, each country will emit up to the point where its own marginal benefits are no longer positive. Each country experiences increasing and weakly convex damages of aggregate emissions according to the function $d_i(E)$, where $E = \sum_i e_i$ and $d_i(0) = 0$ for all i . Welfare in each country is an increasing and strictly concave function of consumption, denoted $u_i(x_i)$, and we write each country's resource constraint as $x_i = w_i + b_i(e_i) - d_i(E)$.

We later make use of the Nash equilibrium, so it is helpful to define it here. We write each country's unilateral optimization problem as

$$\max_{e_i} u_i(x_i) \text{ subject to } x_i = w_i + b_i(e_i) - d_i(E). \quad (1)$$

Assuming interior solutions, here and throughout, the first-order condition is simply $b'_i(e_i) = d'_i(E)$ for all i . Each country internalizes the domestic marginal damages when choosing its own level of emissions. A Nash equilibrium is defined as a vector of emissions levels $\{\hat{e}_1, \dots, \hat{e}_n\}$ that satisfies the first-order condition for all countries, and it is straightforward to verify there exists a unique Nash equilibrium with this setup.⁶ A Nash equilibrium also defines a level of private consumption and welfare for each country according to $\hat{x}_i = w_i + b_i(\hat{e}_i) - d_i(\hat{E})$ and $u_i(\hat{x}_i)$. Finally, while each country's problem is written with a choice over its level of emissions, a Nash equilibrium defined over emissions corresponds to abatement levels too, which can be written as $\hat{a}_i = \bar{e}_i - \hat{e}_i$ for all i .

Next we solve for the set of Pareto efficient allocations. We write the global planner's problem as choosing each country's level of emissions and a set of transfers:

$$\begin{aligned} & \max_{\{e_i, t_i\}_{i=1}^n} \sum_{i=1}^n \alpha_i u_i(x_i) \\ & \text{subject to } x_i = w_i + b_i(e_i) - d_i(E) + t_i \text{ for all } i, \text{ and } \sum_{i=1}^n t_i = 0, \end{aligned} \quad (2)$$

where α_i is the welfare weight the planner assigns to each country (normalized to sum to one), t_i is country i 's net transfer, and all transfers must sum to zero. The first-order conditions

⁶Both existence and uniqueness follow immediately using the replacement-function approach to aggregative public good games (Cornes and Hartley, 2007). Each country's best-response function is summarized by a replacement function $f_i(E)$ of aggregate emissions that is weakly decreasing. This gives an aggregate replacement function $\sum_i f_i(E)$ that is also weakly decreasing and continuous on a compact interval, thereby ensuring a unique fixed point that defines the Nash equilibrium.

that define the solution can be written as

$$b'_i(e_i) = \sum_i d'_i(E) \text{ for all } i \quad (3)$$

$$\alpha_i u'_i(x_i) = \alpha_j u'_j(x_j) \text{ for all } i, j. \quad (4)$$

Equation (3) implies that the marginal benefit of emissions (or equivalently the marginal avoided abatement cost) in each country is equal to the global marginal damages of emissions, which can be interpreted as the global SCC at the efficient quantity. A comparison between the first-order conditions of (1) and equation (3) reveals the fundamental market failure of excessive emissions at the Nash equilibrium: each country has a unilateral incentive to internalize only the domestic marginal damages of its own emissions, whereas efficiency requires internalizing the global marginal damages. Equation (4) implies that the weighted marginal utility of consumption is equal across all countries.

We make several further observations about the set of Pareto efficient allocations because they play a central role in the analysis that follows. First, each country's level of emissions, denoted e_i^* (or equivalently as abatement $a_i^* = \bar{e}_i - e_i^*$), is the same across all Pareto efficient allocations. This follows because (3) does not depend on the welfare weights or transfers. Intuitively, the marginal benefits of emissions (avoided abatement costs) are equalized across countries in order to maximize overall benefits for a given level of aggregate emissions. Second, and related, E^* (or equivalently $A^* = \bar{E} - E^*$) remains constant across Pareto efficient allocations, and this helps to make our results sharp in what follows.⁷ Third, welfare weights only affect transfers and the level of consumption in each country, x_i^* , which is increasing in a country's relative weight α_i . Specifically, the planner chooses transfers to equalize weighted marginal utilities.

Finally, and central to our analysis, the setup provides no guidance about how a planner is to choose the welfare weights. The weights nevertheless determine distributional outcomes among Pareto efficient allocations. One way to see this is to note that a planner can rationalize any Pareto efficient consumption vector $\{\tilde{x}_1, \dots, \tilde{x}_n\}$ by choosing weights $\alpha_i \propto 1/u'_i(\tilde{x}_i)$ for all i , which satisfies (4) for the given consumption vector. In the next two sections, we turn to the question of how one might choose welfare weights. We begin with what is

⁷Underlying these first two observations is the way that climate damages are a function of aggregate emissions only, not levels of wealth that may include transfers. This assumption is not as restrictive as it might at first seem, however, since the damage functions have subscripts i , and are thus unique to each country. Damages can therefore vary with endowments or any other country-specific exogenous characteristic. The useful simplification is that damages do not depend on transfers. While generalizing the setup to allow damages to depend on transfers is possible, it adds unnecessary complexity that distracts from the central part of our analysis.

considered the standard approach in economic models of climate change, before focusing on our property-rights based approach in Section 4.

3 Negishi weights: background and perspective

The standard approach for choosing welfare weights in economic models of climate change is to use Negishi weights (Nordhaus and Yang, 1996; Manne and Richels, 2005; Leimbach et al., 2010; Traeger, 2023). In this section, we describe the basic approach and discuss its implications. In doing so, we make a distinction between the distributional consequences of climate policy, and the distributional consequences of transfers to highlight how Negishi weights are not as distributionally neutral as often understood.

Use of Negishi weights is typically justified on the basis that they yield a Pareto efficient allocation conditional on the existing distribution of resources (Nordhaus and Yang, 1996). Accordingly, Negishi weights are often understood as allowing economists a way to address the inefficiency of climate change without addressing global inequality, thereby sidestepping explicit normative judgments about distributional equity. The fundamental idea applied in climate economics is to choose the particular Pareto efficient allocation associated with no transfers.

In the context of our basic setup, this means solving the planner’s problem in (2) with specific welfare weights such that $t_i = 0$ for all i , and this yields a particular solution rather than a set of solutions. We have already established how the first-order conditions in (3) imply that every Pareto efficient allocation has the same E^* and e_i^* for all i . The allocation consistent with no explicit transfers therefore implies consumption in each country equal to $x_i^N = w_i + b_i(e_i^*) - d_i(E^*)$, where we use the superscript N to denote the Negishi solution.

What does the Pareto efficient allocation of $\{x_1^N, \dots, x_n^N\}$ implicitly require of the planner’s welfare weights? The set of first-order conditions in (4) means that this allocation is the solution to (2) if and only if the planner has welfare weights that satisfy $\alpha_i \propto 1/u'_i(x_i^N)$ for all i . These conditions therefore define the Negishi weights, which we denote α_i^N for each country. It is worth emphasizing how the Negishi solution applied in this setting does not start from exogenously specified welfare weights to solve for the Pareto efficient allocation; rather, the no-transfer requirement pins down the allocation, and the Negishi weights are the welfare weights that rationalize this allocation as the solution to the planner’s problem.⁸

⁸It is worth emphasizing that the Negishi weights must be set to the inverse marginal utility of consumption at the Pareto efficient Negishi solution itself. Using consumption levels at some other allocation, such as the Nash equilibrium, will generally not result in an efficient allocation, as the first-order conditions in (4) cannot be satisfied without transfers. Solving for Negishi weights in practice typically necessitates use of a fixed-point method.

Researchers who use Negishi weights in climate economics reference the original Negishi (1960) theorem to argue that the resulting allocation separates questions of efficiency and distribution by replicating a competitive equilibrium with no transfers (Nordhaus and Yang, 1996; Manne and Olsen, 1996). But it is important to recognize that Negishi’s original analysis applies to a perfectly competitive private-goods economy with no market failure. In this case, the decentralized equilibrium is Pareto efficient and coincides with the solution to a particularly weighted planner’s problem. The central feature of climate-economic models, however, is the presence of a market failure, i.e., a global public bad or good depending on the setup. In the absence of policy instruments, therefore, the correspondence between the decentralized equilibrium and the planner’s solution breaks down because only the latter is Pareto efficient.

We argue that in order to analyze the distributional implications of a particular Pareto efficient allocation, an important question to consider is how it compares to an initial inefficient allocation. Consider for a moment the Nash equilibrium as an initial allocation to illustrate the point. When moving from the Nash equilibrium to the Pareto efficient Negishi solution, it is straightforward to construct examples where a country can be made either better or worse off. In our setting, a country will be made better off at the Negishi solution if and only if $x_i^N - \hat{x}_i > 0$, which is equivalent to satisfying $d_i(\hat{E}) - d_i(E^*) > b_i(\hat{e}_i) - b_i(e_i^*)$. The left-hand side is the reduction in climate damages country i experiences with globally efficient emissions, and the right-hand side is the forgone benefits to country i of lowering its own emissions. Intuitively, this inequality is more likely to hold for countries with high marginal climate damages over the relevant range from E^* to $\hat{E}$, and relatively small foregone benefits from reducing their own emissions. It is also more likely to hold when more of the global emissions reduction comes from other countries.⁹

This comparison makes clear that the Negishi solution is not distributionally neutral relative to the Nash equilibrium. In particular, when moving from the Nash equilibrium to the Negishi allocation there are distributional consequences because of differential damage reductions and differential costs of abatement across countries. While others have made this point (e.g., Yang, 2020), it is important to emphasize because we believe it is less well-recognized than deserved and because of the contrast with results later in the paper. That is, the Negishi solution corresponding with use of welfare weights α_i^N for all i in (2) is not necessarily a Pareto improvement relative to the Nash equilibrium that solves (1) for all i .

⁹Some may find this result intuitive upon recognizing that the Negishi solution corresponds with each country imposing the globally efficient carbon tax (or an equivalent quantity-based regulation) and keeping its own tax revenue. In this case, all countries need not be made better off. Yet a country being made worse off requires a degree of asymmetry; for if all countries are identical, they all have the same level of consumption under each allocation, which must be higher at the planner’s solution.

An important implication of this observation relates to the value of using the Negishi approach for choosing among efficient allocations in economic models of climate change. To the extent the models are intended to build consensus over the benefits of addressing climate change, the message is likely to fall short if the focal point is one where some countries are made worse off by collective action. Indeed, Nordhaus (2015) emphasizes how the Westphalian system of international law requires that any agreement between sovereign countries be voluntary, but use of Negishi weights as the standard approach in climate IAMs does not ensure this condition will be met.¹⁰

One solution, of course, is to allow transfers to ensure a Pareto improvement, but there is currently little guidance on how to set transfers without making normative judgments about distributional equity. The challenge is that economists are often reluctant to make such normative judgments, which is one reason for using Negishi weights in the first place. In the next section, we propose an alternative approach for choosing welfare weights that is anchored in property rights rather than notions of distributional fairness. One advantage of the approach, as we show, is that the resulting allocations are always Pareto improvements.

4 A property-rights based approach

We now show how property rights can provide a foundation for welfare weights in a multi-lateral public goods model, applied specifically to climate change. The approach begins with standard notions of “right to pollute” or “right to no pollution” in a Coasean framework, though applied in a novel way to a public goods setting. When combined with Nash bargaining to arrive at a cooperative solution, we show how judgments about property rights imply corresponding Pareto efficient allocations and implicit welfare weights. We discuss distributional consequences of differing property-rights regimes and how the approach relates to and can serve as an alternative to Negishi weights.

4.1 A Coasean logic

The fundamental insight of Coase (1960) applies to settings with externalities: if property rights are well-defined and there are zero transaction costs, Pareto efficient allocations can be obtained through a process of bargaining and transfers. Within the context of environmental economics, and pollution in particular, the assignment of property rights typically occurs over

¹⁰For example, it has been shown that some countries are made worse off at the Negishi solution in the RICE model (Nordhaus and Yang, 1996) and with the setup of the original C-DICE model (Kotchen, 2018). In our quantitative model here, we also find evidence of countries being made worse off at the Negishi solution compared to the Nash equilibrium in Section 5.

the right to pollute or not. In the case of “right to pollute,” pollutees benefit from emissions reductions and pay compensation to polluters for their abatement costs. In the case of “right to no pollution,” polluters benefit from emissions and pay compensation to the pollutees for the damages they experience.

Settings with global public bads or goods—such as emissions contributing to climate change or abatement mitigating it—differ from externalities in ways that limit the applicability of Coasean bargaining. First, property rights are often not well defined, especially at the global level. Second, all agents typically experience the adverse consequences and benefits of the public bad or good, so in the case of GHG emissions, all agents are both polluters and pollutees. This means that even if property rights were assigned over the right to pollute or not, there is no clean partition of rights among agents. Third, tracking the effect of one agent’s actions on another can be difficult in a multilateral setting, where the aggregate effects of all agents are what matters (i.e., cumulative emissions), and damages can be non-linear. Finally, transaction costs can be insurmountably high in cases with large group sizes, as one might expect, for example, with global public bads or goods.

In what follows, we nevertheless show how a thought experiment over the assignment of property rights and Coasean bargaining can lead to different Pareto efficient allocations, and how this can represent the way that a planner might choose among them. The resulting allocation is consistent with a decentralized, frictionless bargaining procedure, and it implies welfare weights that can be used in economies with public bads or goods. Like Negishi weights, the resulting allocation depends on the pre-existing distribution of income, and it does not contain a normative motive for redistribution. But rather than start with the principle of no explicit transfers, we solve for transfers that would arise through cooperative bargaining after the assignment of property rights over emissions.

4.2 Reference allocations

A property-rights regime in our setting determines how much each country has the right to pollute, or equivalently how much each country is required to abate. With the “right to no pollution” the starting point prior to bargaining is zero emissions in all countries. This arises because emissions in any country cause damages to all others, and by definition, no country has the right to impose those damages. This assignment of property rights is sufficient to fully specify an initial allocation. If $e_i = 0$ for all i , it follows that $b_i(0) = d_i(0) = 0$ for all i , and each country’s corresponding consumption is simply its endowment w_i . Clearly, this initial allocation has inefficiently low emissions.

In the case of “right to pollute” property rights, the starting point prior to any bargaining

is a bit more subtle. If each country has the right to pollute, it will do so up to the point where its unilateral net benefits are maximized. In other words, each country solves (1), and the right to pollute induces the Nash equilibrium as the initial allocation, with each country emitting $\hat{e}_i$ and obtaining private consumption $\hat{x}_i$. We note that in this case, the right to pollute inducing the Nash equilibrium as an initial allocation relies on the assumption that all countries are able to overcome potential obstacles to domestic policy and implement unilaterally optimal policies. As discussed previously, the Nash equilibrium has inefficiently high emissions.

We have just described how two different property-rights regimes are associated with initial allocations that are fully characterized by the level of emissions in each country. These will serve as important reference points in our subsequent analysis. At this point, however, we assert a general definition of reference allocations, while underscoring the connection to the two property-rights regimes of interest.

Definition 1 (Reference allocations). *A reference allocation is a vector of emissions for each country, $\mathbf{e}^r = \{e_1^r, \dots, e_n^r\}$, and two special cases of interest are based on property-rights regimes:*

- (i) *Right to no pollution:* $\mathbf{e}^r = \{0, \dots, 0\}$,
- (ii) *Right to pollute:* $\mathbf{e}^r = \{\hat{e}_1, \dots, \hat{e}_n\}$.

The reason for establishing a general definition is to emphasize how the notion of property rights could extend to a broader set of reference allocations. In the absence of transfers, any vector $\mathbf{e}^r$ fully specifies an allocation, since $x_i^r = w_i + b_i(e_i^r) - d_i(E^r)$ for all i , where $E^r = \sum_i e_i^r$. Thus any $\mathbf{e}^r$ immediately gives corresponding levels of consumption for all countries of $\{x_1^r, \dots, x_n^r\}$. Other reference allocations of potential interest might include property rights based on country-specific emission targets. Another example is a variant of “right to pollute” where countries are not able to overcome obstacles to domestic policy and therefore do not implement unilaterally optimal policies. In this case, countries undertake no abatement (i.e., have no domestic regulations), and we have a reference allocation of $\mathbf{e}^r = \{\bar{e}_1, \dots, \bar{e}_n\}$. Throughout the remainder of the paper, however, we focus on the zero-emissions and Nash reference allocations, as these have a clear correspondence to standard notions of property rights in Coasean settings.

4.3 Nash bargaining

The next step of our planner’s thought experiment is to consider how—conditional on a property-rights regime and corresponding reference allocation—countries would engage in

bargaining to reach an efficient allocation. This step solves for the way that surplus is divided among countries that are able to make an efficient, binding agreement.

There are different ways to arrive at a unique cooperative bargaining solution, but we focus here on Nash bargaining (Nash, 1950). Nash bargaining is a standard approach in the context of international agreements because it has a number of desirable properties, including respect for voluntary participation, accounting for outside options, invariance to utility scaling, capturing mutual dependence among countries, and yielding a Pareto efficient allocation. Beyond providing an axiomatic solution concept, Nash bargaining has a strategic basis, meaning that the solution can be interpreted as the equilibrium outcome of a decentralized negotiation process (Rubinstein, 1982; Osborne and Rubinstein, 1990). This interpretation is the reason why Nash bargaining is particularly suited to our thought experiment, where a planner aims to simulate what countries might cooperatively decide themselves through negotiation, conditional on a set of property rights and no transaction costs. In this way, and importantly, our approach is intended to select among Pareto efficient allocations based on positive analysis rather than imposing a normative criterion of distributive equity.

In our setting, the Nash bargaining solution, which is conditional on a particular reference allocation, is obtained by solving the following maximization problem:

$$\begin{aligned} & \max_{\{e_i, t_i\}_{i=1}^n} \prod_i [u_i(x_i) - u_i^r]^{\gamma_i} \\ & \text{subject to } x_i = w_i + b_i(e_i) - d_i(E) + t_i \text{ for all } i, \\ & \sum_i t_i = 0, \\ & u_i(x_i) \geq u_i^r \text{ for all } i, \end{aligned} \tag{5}$$

where $u_i^r = u_i(x_i^r)$, and each country's relative bargaining power is captured with a weight $\gamma_i \geq 0$, normalized to sum to one. The first-order conditions that define the solution can be written as

$$b'_i(e_i) = \sum_i d'_i(E) \text{ for all } i \tag{6}$$

$$\frac{1}{\gamma_i} \frac{u_i(x_i) - u_i^r}{u'_i(x_i)} = \frac{1}{\gamma_j} \frac{u_j(x_j) - u_j^r}{u'_j(x_j)} \text{ for all } i, j. \tag{7}$$

Equation (6) is identical to (3), confirming that the Nash bargaining solution is Pareto efficient, with emissions e_i^* for each country. The set of conditions in (7) determines the net transfer for each country, which we denote t_i^r , where the superscript r indicates dependence on the reference allocation. Together, these results further identify each country's level of

consumption, denoted $x_i^{r*} = w_i + b_i(e_i^*) - d_i(E^*) + t_i^r$, and this fully specifies a particular allocation.

Importantly, the allocation depends on the property-rights regime, the distribution of climate damages and benefits of emissions, and differences in bargaining power across countries. Property rights are reflected through the presence of each country's utility from a particular reference allocation in (7). It is straightforward to see that, all else equal, if a country's consumption at the reference allocation increases, which depends on its benefits and costs associated with the corresponding level of reference emissions, it will obtain a higher level of private consumption at the efficient allocation. This arises because a more favorable reference allocation improves a country's disagreement payoff u_i^r , which is its outside option in the bargaining problem, and therefore part of its implicit bargaining leverage. We emphasize the standard Coasean logic at play here: property rights have distributional consequences without affecting overall efficiency.¹¹ Rather than assume social welfare weights, the property-rights based reference allocation, combined with bargaining weights, pins down a particular Pareto efficient allocation. As discussed more below, we interpret the bargaining weights as positive parameters that could be estimated, similar to abatement costs or climate damages, rather than reflecting normative objectives.

4.4 Coasean welfare weights

We have established how the solution to the weighted Nash bargaining problem in (5) identifies a particular Pareto efficient allocation. We have also shown how the solution depends on the property-rights regime, which defines a reference allocation. We now consider the welfare weights a planner could employ to rationalize the corresponding allocations. This is the final step of the thought experiment that entails a planner choosing welfare weights that implement an allocation consistent with what countries would decide themselves, given an assignment of property rights.

We begin with a definition of what we refer to as Coasean welfare weights, followed by a discussion of their implications.

Definition 2 (Coasean welfare weights). *Coasean welfare weights for each country are defined as the inverse marginal utility of consumption at the solution to the weighted Nash*

¹¹As noted in Section 2, our setup implies that the efficient level of emissions is invariant to the distribution of endowments and therefore transfers, and this implies no income effects of transfers, making the setup similar to a standard setting with Coasean bargaining. While allowing for income effects would make the efficient level of emissions conditional on the assignment of property rights, it would not change the central insights of our analysis.

bargaining problem in (5), such that for all i

$$\alpha_i^r \propto \frac{1}{u'_i(x_i^{r*})} = \frac{1}{u'_i(w_i + b_i(e_i^*) - d_i(E^*) + t_i^r)}. \quad (8)$$

It is important to emphasize how the Coasean welfare weights are dependent on the assignment of property rights, since t_i^r appears in (8). Coasean weights differ from Negishi weights defined in Section 3 only with respect to each country's level of consumption. Here we have α_i^r based on consumption inclusive of transfers t_i^r given by the Nash bargaining solution, whereas the Negishi weights α_i^N are based on consumption at the Pareto efficient allocation where all transfers are zero. What the weights share in common is rationalizing their corresponding allocations as the solution to a planner's problem. We have already shown this for Negishi weights. Showing it for Coasean welfare weights follows immediately by substituting α_i^r into equation (4) to see that x_i^{r*} and e_i^* for all i is the unique solution to the planner's problem when employing these weights. This gives rise to the first part of the following proposition:

Proposition 1. *Use of Coasean welfare weights, α_i^r for all i , to solve the planner's problem in (2) obtains a Pareto efficient allocation corresponding to the Nash bargaining problem in (5). Moreover, the allocation is a Pareto improvement compared to the corresponding property-rights determined reference allocation.*

The second part of the proposition follows directly from the last constraint of the setup to the Nash bargaining problem in (5). The consequences can also be seen in (7), which implies that if utility increases for any country and $\gamma_i > 0$ for all i , it must increase for all countries, and thus $x_i^{r*} \geq x_i^r$ for all i . Intuitively, a country will only agree to the bargain if the resulting allocation makes it better off than its outside option. This feature of our Coasean solution can be especially appealing in the context of using models to highlight potential cooperative agreements between sovereign countries, as it ensures that all countries are made better off by addressing climate change.¹²

It is important to contrast this feature with use of Negishi weights. We discussed in Section 3 how the use of Negishi weights obtains an efficient allocation that need not result in a Pareto improvement relative to the Nash equilibrium. This means that, to the extent current international climate policy resembles a setting in which countries have a de facto

¹²Others have emphasized the importance of Pareto improvements and therefore the role of transfers in similar settings (Chander and Tulkens, 1995; Ambec and Ehlers, 2016; Hillebrand and Hillebrand, 2019). Our analysis is distinct because of the way we systematically consider the role of different property rights as the basis of transfers, along with a general setting with heterogeneous benefits of emissions and non-linear damages.

“right to pollute,” focusing on a Negishi-weighted solution to climate change can make some countries worse off. It can also be shown that the Negishi solution is not guaranteed to generate a Pareto improvement relative to the “right to no pollution” reference allocation, and indeed, we find evidence of both results in Section 5. Intuitively, the restriction on transfers in the Negishi solution—which was originally intended to rule out redistribution—also rules out the possibility of compensation for differential costs and benefits of addressing climate change.

4.5 Coasean transfer payments

We now consider how country characteristics affect the level of transfers received under our Coasean solutions. The analysis illuminates the potential distributional consequences of solving the inefficiency of climate change within a particular property-rights regime. Before proceeding, it is important to keep in mind how the transfers themselves do not arise from a redistributive objective. In this setting, transfers that arise are consistent with a bargained solution over the net benefits of addressing climate change and reflect the value of property rights over emissions.

We begin with a country’s net transfer moving from a property-rights determined reference allocation to the corresponding Pareto efficient allocation. We define a country’s change in consumption as $\Delta x_i^{r*} = x_i^{r*} - x_i^r$. Using the Pareto efficient Negishi solution, which involves no transfers, we can write $\Delta x_i^{r*} = x_i^N + t_i^r - x_i^r$. Solving for the transfer and substituting in terms from each country’s resource constraint, we have for each country and property-rights regime the following transfer:

$$t_i^r = \omega_i^{r*} \sum_{k=1}^n \left([b_k(e_k^*) - b_k(e_k^r)] - [d_k(E^*) - d_k(E^r)] \right) - \left([b_i(e_i^*) - b_i(e_i^r)] - [d_i(E^*) - d_i(E^r)] \right), \quad (9)$$

where $\omega_i^{r*} = \Delta x_i^{r*} / \sum_i \Delta x_i^{r*}$ is country i ’s endogenous share of the aggregate increase in consumption. In general, ω_i^{r*} depends on heterogeneity across countries and the particular property-rights regime, but we can provide a sharp intuition for the first-order effects on ω_i^{r*} by taking a linear approximation of each country’s change in welfare. In this case, it follows simply that $\omega_i^{r*} \approx \gamma_i$, so each country’s share of the aggregate consumption gain is proportional to its bargaining weight, which we assume holds for the discussion in this section.¹³

¹³To see this, take a first-order Taylor series approximation of the change in a country’s welfare so that $u_i(x_i^{r*}) - u_i^r \approx u_i'(x_i^{r*})[x_i^{r*} - x_i^r]$. Substituting this into (7) simplifies the relationships to $\frac{x_i^{r*} - x_i^r}{\gamma_i} \approx$

Equation (9) shows that each country's net transfer can be written as its share of the aggregate consumption gain, minus its own change in consumption moving from the reference to the efficient allocation. Specifically, the first term captures the share of aggregate consumption gain country i receives through bargaining, which is always (weakly) positive by Proposition 1. The second term, which can take either sign, captures country i 's direct change in consumption from the change in its own and others' emissions. It follows that a country will make a transfer if and only if its change in consumption is positive and greater than its share of the aggregate consumption gain, which, as we have shown, depends on its bargaining weight.

In the case of "right to no pollution," each country's direct consumption change from increasing emissions simplifies to $b_i(e_i^*) - d_i(E^*)$, since the corresponding zero-pollution reference allocation implies $b_i(0) = d_i(0) = 0$ for all i . While greater bargaining power increases a country's transfer, further intuition comes from assuming all countries have the same bargaining power. In this case, countries with greater-than-average net benefits of increased emissions, $b_i(e_i^*) - d_i(E^*)$, pay transfers, whereas countries with lower-than-average net benefits of increased emissions receive a transfer. Intuitively, transfers in this case are closely related to the notion of "polluter-pays" compensation, where countries that gain from being allowed to emit compensate other countries for the damages they cause.¹⁴ In our setting, however, all countries experience both damages and benefits from emissions, so it is the net effect of both changes, along with bargaining power, that determines the net transfer.

With "right to pollute," recall that the reference allocation is the Nash equilibrium, where $\hat{e}_i = e_i^r$ for all i . In this case, $b_i(e_i^*) - b_i(e_i^r) - [d_i(E^*) - d_i(E^r)]$ in equation (9) reflects each country's net benefit in terms of consumption from lower global emissions.¹⁵ Assuming again that all countries have the same bargaining power, we find in this case that countries with greater-than-average net benefits of the reduced emissions pay transfers, whereas countries with lower-than-average net benefits receive a transfer. The intuitive interpretation here is "beneficiary pays" compensation, where countries that benefit more from avoiding climate

$\frac{x_j^{r*} - x_j^r}{\gamma_j}$ for all i, j . Then, substituting in for x_i^{r*} and x_i^r , and using the facts that $\sum_i t_i^r = 0$ and $\sum_i \gamma_i = 1$, it is straightforward to see from the resulting expression that $\omega_i^{r*} \approx \gamma_i$, which would hold exactly if each country's welfare function were linear.

¹⁴We note the related notion of "loss and damage" payments in the context of international climate negotiations, where countries are compensated for damages they experience from climate change. Here, however, compensation is based on differences in the overall net benefits of increased emissions rather than damages only. The distinction between net benefits and loss and damage is important when considering the potential of transfers to promote cooperative solutions to climate change (Kotchen, 2020).

¹⁵In general, it is not necessarily the case that emissions fall for each country when moving from the Nash equilibrium to the efficient allocation. That is, despite $E^* < \hat{E}$, it is possible for at least one country to satisfy $e_i^* > \hat{e}_i$, though a necessary condition is that climate damages are non-linear. Regardless, the transfers are still well-defined, and Pareto improvements are still obtained.

change pay countries that benefit less.

4.6 Distributional consequences of different property rights

We have just analyzed how heterogeneity across countries will affect transfers within a given property-rights regime. We now examine how the establishment of one property-rights regime or another can differentially affect countries to create winners and losers. The analysis illuminates what countries might have at stake in current debates about whether nations should have the “right to pollute” or the “right to no pollution.”

We define each country’s transfer under “right to pollute” as t_i^{RP} and under “right to no pollution” as t_i^{RnP} . In what follows, we also adopt the convention of frequently referring to the different property rights as RP and RnP, respectively. Country i will prefer the efficient allocation associated with RP to RnP if and only if $t_i^{RP} > t_i^{RnP}$. To get a sense for when this condition is likely to hold, we compare (9) evaluated under each set of property rights and the linear approximation where $\omega_i^{r*} \approx \gamma_i$. Substituting in the corresponding allocations and rearranging, we find with this approximation that $t_i^{RP} > t_i^{RnP}$ if and only if

$$b_i(\hat{e}_i) - d_i(\hat{E}) > \gamma_i \sum_{k=1}^n [b_k(\hat{e}_k) - d_k(\hat{E})]. \quad (10)$$

The left-hand side is country i ’s net consumption benefit of emissions at the Nash equilibrium, and the right-hand side is country i ’s bargaining-power weighted share of the same benefit in aggregate. The expression depends only on Nash quantities for two reasons. First, each country’s emissions-based net benefit at the RnP reference allocation is zero, since there are no emissions. It follows that $b_i(\hat{e}_i) - d_i(\hat{E})$ gives each country’s net benefit of emissions at the RP reference allocation compared to the RnP reference allocation. Second, all countries experience the same net benefit of emissions at the efficient quantity regardless of whether the reference allocation is based on RP or RnP. The only difference is that with RP, each country gets its Nash-equilibrium share of the net benefits without subjecting them to the bargaining process.

We note that both sides of the inequality in (10) can take either sign. Regardless, the fundamental and intuitive insight holds: a country is more likely to prefer the Pareto efficient allocation associated with RP, compared to RnP, if it has relatively high benefits of emissions, low damages from emissions, or both.

A further insight is that a country’s preference between reference allocations need not translate to the same preference between corresponding Pareto efficient allocations. To see this possibility, consider an example where both sides of Equation (10) are positive, and

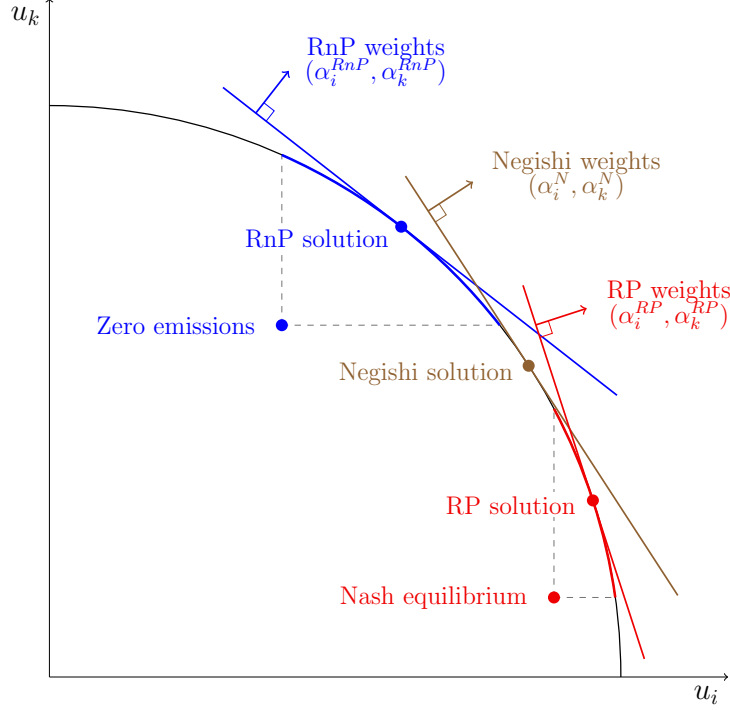


Figure 1: Illustrative example of a Pareto frontier for two countries, including the property-rights reference allocations (the Nash equilibrium for RP and Zero emissions for RnP), the corresponding Coasean-weighted efficient allocations, and the Negishi solution.

$b_i(\hat{e}_i) - d_i(\hat{E}) < \sum_{k=1}^n [b_k(\hat{e}_k) - d_k(\hat{E})]$. It follows that country i prefers RP to RnP when comparing reference allocations (because $b_i(\hat{e}_i) - d_i(\hat{E}) > 0$), but with a sufficiently high γ_i , it will prefer RnP to RP when comparing Pareto efficient allocations. Intuitively, this is a case where the country has sufficiently high bargaining power that it would rather cede the “right to pollute” and negotiate over the larger aggregate surplus under RnP of allowing countries to emit.

Figure 1 uses a Pareto frontier with two countries to illustrate one possible configuration of the results just discussed. The reference allocations are not on the frontier, as they are not Pareto efficient. The colored arcs on the frontier show the set of efficient allocations that would be Pareto improvements from the corresponding reference allocations. These are the set of allocations that could be obtained under each property-rights regime with Nash bargaining and therefore use of Coasean welfare weights. Bargaining weights identify the particular allocations, and possible results are labeled as the RP solution and RnP solution. The position of the Negishi solution, which is Pareto efficient and therefore on the frontier, illustrates that it is not necessarily a Pareto improvement relative to either the RP (Nash) or the RnP (Zero emissions) reference allocation. We have illustrated a case where country i always prefers the RP allocations, and country k always prefers the RnP allocations, but

as discussed above, such a partitioning of preferences need not be the case.

5 Climate model simulations

We now turn to our calibrated IAM to demonstrate the use of Coasean welfare weights and to show quantitative evidence on the distributional implications of different property rights. After describing the basic structure of our model, we begin with a comparison of the reference allocations corresponding to RP and RnP property rights. We then focus on the distributional differences between Pareto efficient allocations, comparing use of Coasean and Negishi welfare weights, along with a set of comparisons between reference and efficient allocations and their implied international transfers.

5.1 Model setup

Our model builds on the standard RICE-2010 (Nordhaus, 2010) and C-DICE (Nordhaus, 2015) models. It contains 15 regions, which we often refer to as countries for expositional ease, although some regions consist of multiple countries.¹⁶ The model is static and calibrated to 2023 data, thereby implementing our conceptual framework for emissions decisions in 2023. Abatement costs and transfers are annual estimates, and climate damages are measured using the SCC, capturing the present value of future damages caused by 2023 emissions. While use of a static model abstracts from dynamic climate and macroeconomic considerations, it is helpful for introducing and focusing on the novelty of Coasean welfare weights. The model captures regional heterogeneity and the implications of different property rights in a relatively straightforward and tractable way, and the results can be readily interpreted and mapped back to the fundamental insights of our conceptual framework.

The benefits of emissions are avoided abatement costs, which differ among regions. We use the functional form of abatement costs in RICE: $c_i(e_i) = \kappa_i \left(\frac{\bar{e}_i - e_i}{\bar{e}_i} \right)^\theta q_i$, where $a_i = \bar{e}_i - e_i$ is abatement, q_i is regional GDP measured in market-exchange-rate dollars, and κ_i is a country-specific abatement cost parameter, calibrated such that the marginal abatement cost at zero emissions (i.e., $a_i = \bar{e}_i$) equals an exogenously set backstop price.¹⁷ We set $\theta = 2.6$, following the DICE-2023 calibration of Barrage and Nordhaus (2024). Thus the benefits of each country's own emissions can be written as $b_i(e_i) = c_i(0) - c_i(e_i)$.

We follow C-DICE in specifying regional damages as $d_i(E) = s_i \phi E$, where ϕ is the global SCC, and s_i is a constant regional share of global damages. We calibrate ϕ to the central

¹⁶Appendix A reports additional details about our model setup and the calibration of all parameters, and the specific country-to-region aggregation is shown in Appendix Table A3.

¹⁷Unless otherwise noted, all dollar values are expressed in constant 2021 USD at market exchange rates.

SCC estimate for 2023 of \$206 from Rennert et al. (2022), and set the regional shares based on RICE and C-DICE.¹⁸ This setup, in parallel with our conceptual model, implies that each country has the same level of emissions in all efficient allocations, and therefore the efficient level of aggregate emissions is the same too. This follows because application of equation (3) implies the efficient level of emissions in each country will always satisfy $b'_i(e_i) = -c'_i(e_i) = \phi$, which is independent of each country's endowment and therefore transfers.

Aggregate consumption in each country is defined in Section 2 as $x_i = w_i + b_i(e_i) - d_i(E) + t_i$, and for application here, we let $w_i = q_i - c_i(0)$, which captures GDP net of full abatement costs. This implies each country's consumption is $x_i = q_i - c_i(e_i) - d_i(E) + t_i$, where we follow the standard C-DICE static convention, representing future climate damages (benefits) with their current consumption-equivalent values. Each country's utility as a function of consumption is given by $u_i(x_i) = l_i \frac{(x_i/(l_i p_i))^{1-\eta}}{1-\eta}$, where l_i is population, and p_i is the country's price level relative to the United States. Thus, $x_i/(l_i p_i)$ denotes purchasing power parity (PPP) adjusted real consumption per capita. The parameter η governs the curvature of utility, and we set $\eta = 1.5$, consistent with RICE-2010. A useful feature of this setup is that transfers have a direct dollar interpretation, while still allowing the welfare value of a dollar to depend on local purchasing power.¹⁹

Bargaining weights, γ_i for each country, are the last set of parameters needed for our application. In our primary simulations, we set bargaining weights proportional to each country's GDP, using the size of an economy as a proxy for international negotiation power. Recall that the aim of our bargaining solution is to mirror the outcome of an agreement that is likely to emerge if regions negotiated among themselves. Thus, the bargaining weights are descriptive parameters of the bargaining environment rather than normative weights. Others have used GDP-based Nash bargaining weights to study international climate agreements (Yu et al., 2017), and political scientists have long emphasized how the size of a country's economy creates bargaining power in international relations (Hirschman, 1945; Keohane and Nye, 1989). In addition to our use of GDP weights, we produce for purposes of comparison a set of comparative results with population weights.

¹⁸We convert the SCC estimate of Rennert et al. (2022) from purchasing power parity (PPP) adjusted international dollars to market-exchange-rate dollars using regional damage shares and price levels, yielding $\phi = \$112/\text{tCO}_2$ in our calibration. Details are provided in Appendix A.

¹⁹We note that our units differ from those in RICE and C-DICE, which express consumption directly in PPP units, but measuring units in market exchange rates gives a ready and familiar interpretation of international transfers (our ultimate focus here) denominated in dollars.

5.2 Comparing reference allocations

We begin with a comparison of consumption levels at the reference allocations associated with RP and RnP. Within-country differences capture the value of changing property rights in the absence of coordination to address climate change. The way that each country's consumption differs across reference allocations is also an important first step for understanding the distributional consequences of property rights for cooperative solutions. The reason, as discussed in Section 4.3, is that a reference allocation determines each country's disagreement payoff, and because this represents an outside option in the bargaining problem, a more favorable reference allocation strengthens a country's bargaining position.

Panel (a) of Figure 2 shows consumption per capita for RP (the Nash equilibrium) and RnP (zero emissions) across all 15 regions. A clear result is that inequality across countries is largely unaffected by the property right. In particular, the rank ordering of consumption per capita across countries is the same under both RP and RnP. In the extreme, consumption per capita is 59 times larger in the United States than in Sub-Saharan Africa under RP, and it is still 50 times larger under RnP. An important consequence for our analysis is that while different property rights can have significant distributional effects for the reference allocation in some countries, as we show next, changing property rights is not fundamentally redistributive in a way that reorders or equalizes per capita consumption across regions.

Panel (b) of Figure 2 shows how consumption differs within regions for the reference allocations associated with RP and RnP. In particular, the figure shows the percentage change in consumption per capita when moving from RP to RnP (i.e., RnP minus RP), along with a decomposition based on changes in abatement costs and climate damages. The net change in consumption per capita is given by the reduction in climate damages (a benefit) minus the increase in abatement costs. Countries differ in whether they are better off at the RP or RnP reference allocation. For example, consumption per capita in Sub-Saharan Africa is 15% higher under RnP than RP. Underlying this difference when changing from RP to RnP is an 18% increase from avoided climate damages, and a 3% decrease from additional abatement costs. On the other hand, China, Russia, South Africa, and Eurasia are considerably better off under RP. In these countries, the abatement costs of moving from RP to RnP are large, outweighing the consumption benefits of lower global emissions.²⁰

²⁰A country's high abatement costs may be driven by either high marginal abatement costs or by the scale of abatement required. Appendix Figure A1 shows that countries with high emissions intensities also tend to have the highest abatement costs relative to GDP.

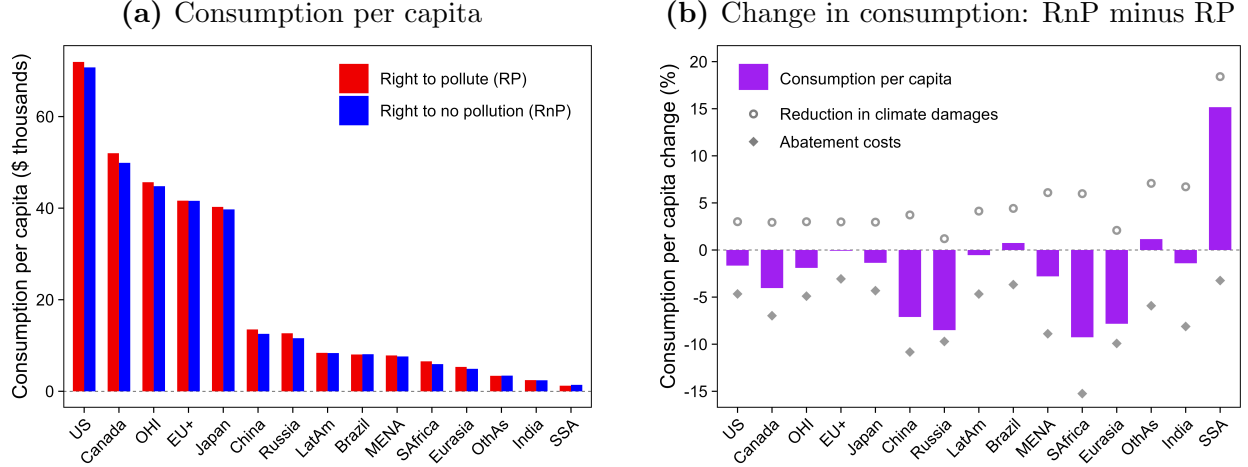


Figure 2: Consumption per capita (USD) at the RP and RnP reference allocations.

Note: Panel (a) is consumption per capita at the reference allocations, and panel (b) is the change in consumption per capita from moving from RP (the Nash equilibrium) to RnP (zero emissions), decomposed into the consumption benefits of reduced climate damages and increased abatement costs. Changes are expressed as percentages of the consumption per capita at the RP reference allocation. The following abbreviations are used in this figure and in tables and figures that follow: Other High Income countries (OHI), European Union and selected non-EU countries (EU+), Middle East and North Africa (MENA), Other Asia (OthAs), Latin America and the Caribbean (LatAm), South Africa (SAfrica), Sub-Saharan Africa (SSA).

5.3 Comparing efficient allocations

We now turn to comparisons among different Pareto efficient allocations. To be clear, the previous subsection showed how property rights affect the reference allocation, and we now consider how property rights affect the efficient allocation. Distributional differences across efficient allocations can be interpreted as the relative value of property rights among regions conditional on successful bargaining to a cooperative solution. In addition to comparisons between RP and RnP, we contrast our results with the familiar Negishi solution as a baseline with no transfers. We begin with differences in regional per capita consumption across efficient allocations, followed by the implied Coasean welfare weights and international transfers induced by different property rights.

How property rights affect the Pareto efficient allocation

We discussed in Section 4.6 the distributional consequences of different property rights on the resulting Pareto efficient allocations. Equation (10) provided a linear approximation to the conditions under which a country would prefer RP to RnP. Figure 3 shows numerical results on differences in consumption per capita between RP and RnP, and relative to the no-transfer Negishi baseline. Panel (a) reports our main results with the Nash bargaining weights

proportional to GDP, and panel (b) shows how the results differ with weights proportional to population.²¹ Recall that all three efficient allocations have the same level of emissions (and therefore abatement) in each region, so differences arise purely due to transfers.

We find large distributional differences across property-rights regimes. Consistent with equation (10), countries prefer RnP to RP if they have relatively low benefits of emissions (i.e., low abatement costs), high climate damages, or both. Countries in this group include the three lowest-income regions in the model—Sub-Saharan Africa, India, and Other Asia—for which high climate damages are the main driver. The European Union plus region, which has low emissions and low abatement costs, also prefers RnP. The effects are largest for Sub-Saharan Africa, reflecting the combination of high climate damages, low emissions, and correspondingly low abatement costs: consumption is 18% higher under RnP than under RP with GDP-based bargaining weights, and 33% higher with population-based bargaining weights. The magnitudes are large not only across property-rights regimes, but also relative to Negishi. For Sub-Saharan Africa, under GDP-based bargaining weights, RnP raises consumption by 11% relative to Negishi, while RP lowers it by 5%.

In contrast, countries that are worse off under RnP tend to have high benefits of emissions (i.e., high abatement costs) relative to avoided climate damages. This can reflect high emission intensity, as in China and South Africa, or relatively low climate damages, as in Russia. In these three countries, consumption is approximately 5–7% lower under RnP than under RP, regardless of the bargaining weights.

For most countries, preferences between RP and RnP are robust to the bargaining weights, despite the large difference between GDP and population shares across countries. This suggests that, even when relative bargaining power is uncertain, many countries have stable preferences over property-rights regimes. Under either set of bargaining weights, the assignment of property rights matters more for the efficient allocation in lower-income countries. In panel (a), we see for example that the difference between RnP and RP results in an 18% change in Sub-Saharan African consumption, whereas the difference is less than 1% for the United States. Underlying these results is the fact that the property rights associated with RP or RnP comprise a larger share of the endowments in low-income countries compared to high-income countries.

A further result that emerges in panel (a) is that, with GDP bargaining weights, consumption at the Negishi solution tends to lie between that for the RP and RnP efficient allocations. For the majority of regions, this means that the sign of the transfer differs between RP and RnP, noting again that the Negishi solution has no transfers and all three

²¹Appendix Figure A2 compares the bargaining weights across regions when based on either GDP or population.

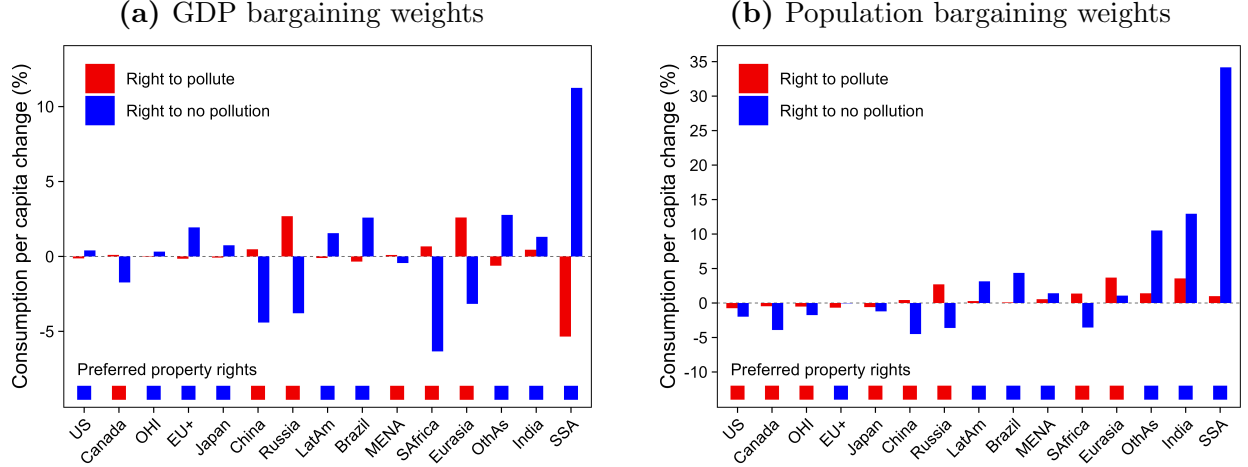


Figure 3: Differences in consumption between the property-rights based Pareto efficient allocations relative to the Negishi solution.

Note: Nash bargaining weights are set proportional to GDP and population in panels (a) and (b), respectively. Note that panels (a) and (b) have different scales on the vertical axis. See Figure 2 note for abbreviations.

allocations have the same emissions in all regions. Importantly, these results imply that for most countries it is the property rights that drive preferences between efficient allocations rather than the GDP bargaining weights.

The same result does not, however, apply under population bargaining weights. In this case, panel (b) shows how consumption per capita for the Negishi solution tends *not* to lie between that for the RP and RnP efficient allocations. The general pattern is that high-income countries prefer the Negishi solution to the assignment of either property right, whereas low-income countries prefer either property right to the Negishi solution. The straightforward intuition for these results is that population bargaining weights have a redistributive consequence. Lower-income regions have higher populations relative to the size of their economies, and this explains why bargaining over surplus when population carries more sway—regardless of the property right—is preferred for these countries compared to the no-transfer Negishi solution. And it is precisely for the same reason, but in reverse, that high-income countries with relatively low populations prefer the Negishi solution to both RP and RnP efficient allocations.

Finally, recall that we observed in Section 4.6 that a country’s preferred property-rights reference allocation need not coincide with its preferred property-rights efficient allocation. The reason is that the efficient allocations depend not just on the property rights, but also on the size and distribution of the total surplus from cooperation. It turns out there are indeed switches in our calibrated analysis, but only from the RP reference allocation to the

RnP efficient allocation. To see why, we note that the consumption gains from cooperation under RnP are 3.9 times larger than under RP. This means that, for any set of bargaining weights, a region’s bargained gain from cooperation is always greater in RnP, so a region that prefers the RnP reference allocation will always prefer the RnP efficient allocation. But regions that prefer the RP reference allocation might prefer the RnP efficient allocation if their bargaining-weighted share of the greater RnP surplus is sufficiently large. Indeed, with GDP bargaining weights, this occurs for most high-income countries, as well as Latin America and India, which can be seen by comparing the preferred property right between the reference allocations in Figure 2 panel (b) with the preferred property rights between the efficient allocations in Figure 3 panel (a).

Coasean welfare weights

Having established the property-rights based efficient allocations, we next examine the social welfare weights that rationalize these solutions. Definition 2 establishes the Coasean welfare weights as the inverse marginal utility of consumption at the efficient allocation corresponding with a given set of property rights. Figure 4 shows the Coasean welfare weights associated with RP and RnP, assuming bargaining weights proportional to GDP, alongside the Negishi weights for purposes of comparison.²²

We find in panel (a) that the Coasean welfare weights are very similar to the Negishi weights across regions in levels. This highlights a key feature of the approach, echoing the observation we made earlier in Figure 2 panel (a): while assigning property rights over RP or RnP has important distributional consequences, these effects are not large enough to fundamentally shift the pattern of global inequality. This applies to the reference allocations, as we have shown, and to efficient allocations too, which is why the ordering of welfare weights remains stable across the RP, RnP, and Negishi scenarios.

Panel (b) of Figure 4 shows that the changes in welfare weights can nevertheless be large when looking at differences across allocations within regions. We note that, all else equal, a region’s welfare weight is increasing in its level of consumption at the efficient allocation, and we see that the qualitative pattern in Figure 4 panel (b) matches that in Figure 3 panel (a). For example, focusing on Sub-Saharan Africa, the region with the largest differences, consumption across scenarios satisfies $x_i^{RP*} < x_i^N < x_i^{RnP*}$, and the corresponding welfare weights satisfy $\alpha_i^{RP} < \alpha_i^N < \alpha_i^{RnP}$, which follows the same ordering. Because the welfare weights are equal to the inverse of the marginal utility of consumption at the corresponding

²²We include a full set of comparable results in Appendix Figures A4–A6 with population-based bargaining weights. As described previously, we focus on GDP bargaining weights as our main proxy for bargaining power, while recognizing that comparisons with population weights, which have more of a redistributive component, might be of interest too.

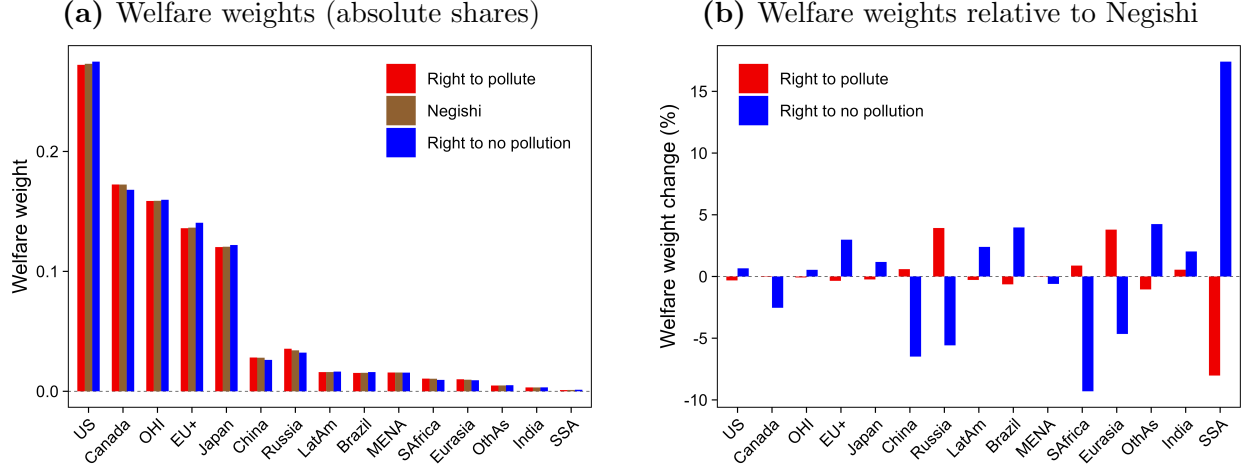


Figure 4: Differences in social welfare weights, assuming GDP bargaining weights.

allocation, the curvature of the utility function also affects their magnitudes. As noted above, we assume an isoelastic utility function with $\eta = 1.5$ as the constant elasticity of the marginal utility of consumption. Results with alternative values of $\eta = 1$ and $\eta = 2$ have smaller and larger effects on the implied welfare weights, yet virtually no effect on the transfers or levels of consumption at the efficient solution (see Appendix Figure A3). Hence more concavity of the utility function simply scales the relative magnitudes of the welfare weights, but the resulting allocations are robust to different values of this parameter.

Implied Coasean transfers

Another way to see the implications of different property rights is to directly examine what gives rise to their respective transfers. We derived in equation (9) an expression for a region's transfer under a given set of property rights, showing how it depends on the difference between two terms: the region's negotiated share of aggregate surplus (which is always positive) minus the region's own change in consumption (which can take either sign). We note that the second term is equivalent to a region's change in consumption moving from a given property-rights based reference allocation to the Negishi solution.²³

We begin with the RP transfers in panel (a) of Figure 5. The majority of countries benefit from the reduction in emissions without transfers, with the exceptions of Russia, South Africa, and Eurasia. This can be seen with these countries having a positive “own surplus

²³Although we have yet to discuss whether a region's net benefit increases or decreases moving from a property-rights based reference allocation to the Negishi solution, the bottom row of Figure 7, which we soon discuss, shows the sign of the effect for each region and scenario based on the change in consumption per capita.

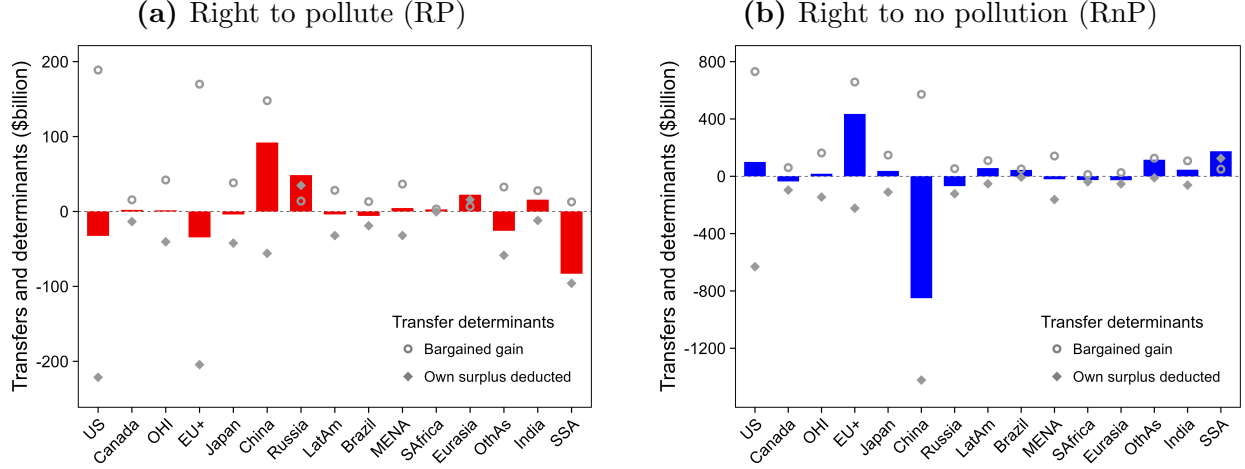


Figure 5: Coasean transfers consistent with the RP and RnP property rights.

Note: Figure shows the international transfers (in \$billions) induced under the RP and RnP efficient allocations. Results are based on GDP bargaining weights. Transfers are exact estimates of equation (9), where “Bargained gain” and “Own surplus deducted” correspond to the first and second terms, respectively.

deducted” in the figure, corresponding to a negative change in own surplus in equation (9). It follows that these countries receive unambiguously positive transfers as compensation for reducing emissions, consistent with a “beneficiary pays” interpretation of the RP property right. For any other region, a positive transfer requires that its share of the aggregate consumption gain be greater than its own surplus without a transfer. China is the largest example satisfying this condition, receiving nearly \$100 billion. Intuitively, regions that pay transfers under RP are those that tend to have a share of the net benefits from reducing emissions greater than their share of the bargaining power. While Sub-Saharan Africa is a clear example, the United States and the European Union plus region are others. Despite having a high share of global GDP, these countries have an even higher share of the net benefits of reducing emissions.

Panel (b) of Figure 5 shows the RnP transfers. Recall that the RnP property right implies an increase in emissions from the reference allocation to the efficient allocation, and transfers are consistent with a “polluter pays” interpretation. For most regions, the sign flips, and the magnitudes are substantially larger because, as noted above, the aggregate consumption gains are 3.9 times larger with RnP than RP. Sub-Saharan Africa is the only region made worse off moving from the RnP reference allocation to the efficient allocation without transfers, and thus it receives a transfer of \$175 billion in the RnP efficient allocation. The European Union plus region receives a relatively large transfer, because its GDP-weighted share of the total consumption gain is substantially greater than its own consumption gain from increased emissions. China—the country with the largest emissions—would make the

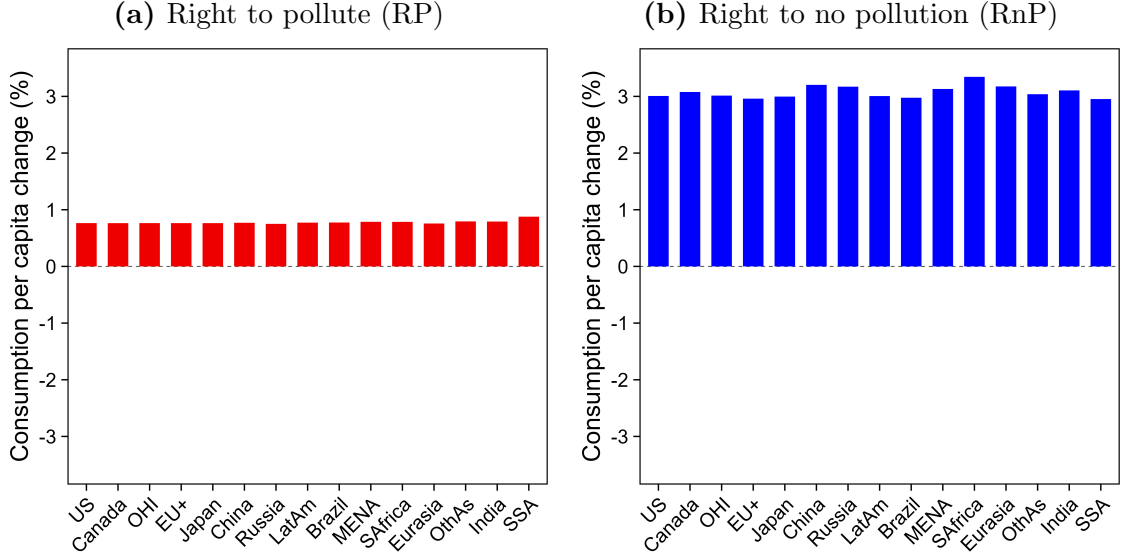


Figure 6: Consumption per capita changes relative to corresponding reference allocations.

Note: Figure shows changes in consumption per capita within the RP and RnP property-rights regimes based on GDP bargaining weights.

largest transfer payment under RnP, totaling \$850 billion. Despite obtaining a large GDP-weighted share of the total gain in consumption, China has exceedingly large benefits of increased emissions and therefore pays a large sum when the property right is based on RnP.

Finally, we note that the total transfer flows under RnP are \$1.03 trillion per year, compared to \$190 billion per year under RP. Interestingly, these numbers are roughly comparable to the magnitudes of existing pledges and demands for climate finance. For example, at the Conference of the Parties in 2024 (COP29), countries agreed to provide \$300 billion a year in climate finance, while developing countries pushed for \$1.3 trillion a year, including more money for loss and damage (UNFCCC, 2024).

5.4 Comparing reference and efficient allocations

Having made comparisons between reference allocations in Section 5.2 and between efficient allocations in Section 5.3, we now compare reference and efficient allocations. Specifically, we consider the resulting Pareto improvements (or lack thereof) when moving from a reference allocation to an efficient allocation, both within and across property-rights regimes.

A key feature of using Coasean welfare weights, as highlighted in Proposition 1, is that moving from a property-rights based reference allocation to the corresponding efficient allocation always results in a Pareto improvement. Figure 6 shows the percentage increase in consumption for each region under both RP and RnP. Panel (a) shows how consumption

per capita increases by approximately 1% across all regions under RP, and panel (b) shows an increase of approximately 3% across all regions under RnP. The reason why the gains are similar across regions on a percentage basis is that GDP bargaining weights are roughly proportional to aggregate consumption across regions.²⁴ RnP results in greater consumption gains because, as discussed above, aggregate consumption gains under RnP are nearly 4 times greater than under RP. This is due to the fact that zero emissions (the reference allocation for RnP) is far from the Pareto frontier. The overarching message of Figure 6 is a quantitative illustration of a key feature of using Coasean welfare weights: conditional on a set of well-defined property rights, the efficient allocation is one that makes every country better off.

We now consider changes in consumption between a reference allocation for one property right and the efficient allocation for another. This exercise is informative because property rights with respect to GHG emissions are contested in practice, and it is possible for a country to be more concerned about establishing the property right than addressing the inefficiency of climate change. For example, in the stylized example in Figure 1, country i would prefer the RP reference allocation (the Nash equilibrium) to the efficient RnP solution.

Panel (a) of Figure 7 shows precisely this result for several countries. South Africa, Russia, Eurasia, China, and Canada all prefer RP^r to RnP^* , where we use the superscripts “r” and an asterisk to denote the reference and efficient allocations, respectively. These are countries with relatively low climate damages and/or high abatement costs. To the extent that current international climate policy resembles RP and the Nash equilibrium, these countries would oppose shifting to RnP property rights, even if it also meant shifting to the efficient RnP^* allocation. Panel (b) shows the converse: countries can be worse off at the RP^* than RnP^r . This is especially true for Sub-Saharan Africa and, to a lesser extent, other Asian countries, both of which are better off in the zero-emissions allocation due to relatively large climate damages. Finally, illustrating a potential outcome discussed in Section 3, panels (c) and (d) of Figure 7 show that the Negishi solution is not a Pareto improvement relative to the reference allocation of either property-rights regime.

Together, these comparisons show why finding a Pareto improvement relative to the reference allocation of one property-rights regime may still be insufficient for global cooperation when property rights over emissions are contested. In particular, they raise a potential concern about what might be perceived as the pragmatic approach within a de facto RP property right. Although moving from RP^r to RP^* is indeed Pareto-improving, it may still

²⁴Assuming population bargaining weights results in a notably different distribution of the consumption gains: dollar gains per capita are approximately equalized across regions, causing greater percentage changes in lower-income regions (see Appendix Figure A6).

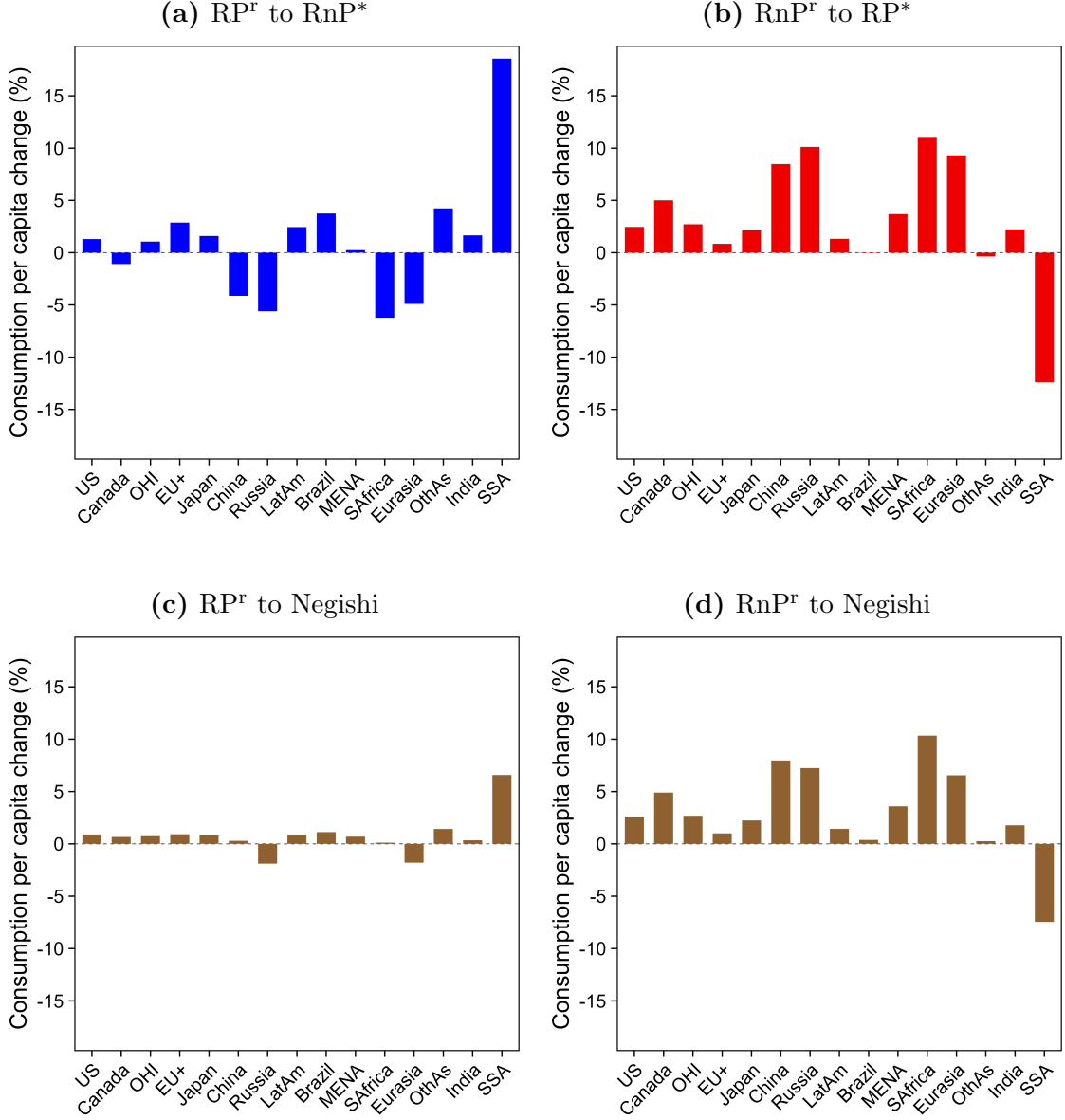


Figure 7: Consumption per capita changes moving from RP and RnP reference allocations to different efficient allocations.

Note: Figure shows changes in consumption per capita based on GDP bargaining weights. Superscripts “r” and an asterisk denote the reference and efficient allocations, respectively, for the corresponding property-rights regime.

be opposed by high-damage countries that do not accept “right to pollute” as the relevant baseline, and would instead prefer RnP^r .

6 Conclusion

This paper develops a property-rights based approach for defining welfare weights in climate economics. We show how familiar notions of the “right to pollute” or the “right to no pollution” can provide the basis for Coasean welfare weights. The approach anchors questions about distributional outcomes among countries in a positive analysis, conditional on property rights, rather than on normative principles of distributional justice. Transfers that arise among countries are not driven by a redistributive motive that a global planner imposes. Instead, they follow the logic of Coasean bargaining, adapted to a multilateral public goods setting, in accordance with the principles of either the “beneficiary pays” for emissions reductions, or the “polluter pays” for emissions increases. In contrast to standard approaches for choosing welfare weights in the literature, our approach obtains a globally efficient allocation that is always a Pareto improvement for all countries, making the solution potentially appealing among sovereign countries.

The framework is novel in the way it connects the insights of several seminal contributions. Samuelson (1954) identifies the initial problem with the inherent need for welfare weights when choosing among Pareto efficient allocations involving provision of a public good. Coase (1960) shows how establishing property rights can resolve externality problems, and we show how the same logic can apply to the global public goods problem of climate change, with property rights over the right to pollute or not. We then show how Nash (1950) bargaining identifies a particular Coasean solution, and calibrating Negishi (1960) weights to the resulting Pareto efficient level of consumption in each country defines a corresponding global social welfare function for potential use in IAMs.

The fundamental difference between Coasean welfare weights and Negishi weights as commonly used in climate economics (e.g., Nordhaus and Yang, 1996) is the level of consumption to which the weights are calibrated. Both approaches respect the initial distribution of private-good endowments. The standard Negishi approach imposes a constraint of no transfers among countries, yet as we make clear, distributional consequences arise because countries differ in the net benefits of changes in emissions. In contrast, Coasean welfare weights imply transfers among countries, but importantly, they are consistent with a decentralized, Pareto-improving bargaining procedure. The standard Negishi approach is often justified as the only way for IAMs to address climate change without simultaneously addressing global income inequality. Our approach, however, provides an alternative, where transfers reflect the value of property rights, rather than normative views about inequality. At the same time, the resulting allocations still depend in part on the initial distribution of endowments, as with Negishi weights, and to the extent there are equity concerns with

initial endowments, there may be equity concerns with the resulting efficient allocations.

We employ a relatively simple IAM and begin to quantify what countries (or regions) have at stake in ongoing debates about emissions-related property rights. While the total transfers that arise under either property-rights regime are not large enough to materially change the distribution of wealth across countries, the magnitudes are large enough to have meaningful effects for certain countries. Underlying many of the results is the way that countries with large benefits of emissions relative to climate damages tend to prefer “right to pollute,” whereas countries with large climate damages relative to the benefits of emissions tend to prefer “right to no pollution.” Cross-country heterogeneity and the resulting distributional consequences of alternative property-rights regimes help to explain why climate-related property rights are sparking growing debate around the world.

Finally, we acknowledge that our quantitative application is relatively simple in order to focus on the fundamental ideas, and future research can further clarify the consequences of Coasean welfare weights compared to other approaches using more detailed IAMs. A natural next step is to implement the approach in a dynamic IAM, one that captures the intertemporal nature of climate change and the potential value of property rights. We also focus throughout on the Nash bargaining solution to simulate a decentralized Coasean bargaining procedure, but alternative solution concepts might be worth considering in future work (e.g., other bargaining approaches or definitions of core stability). Additionally, we consider reference allocations based solely on RP and RnP, but our framework could accommodate other considerations too, such as historical or differentiated responsibilities among countries. Future research might also consider more explicit links to climate policy instruments, as we focus on efficient allocations without regard to policies needed to implement them. For example, one approach would be to implement globally efficient carbon taxes combined with international transfers, but another is an emissions trading system with a particular allocation of permits that reflects the endowments implied here. In these settings, Coasean welfare weights can be used to characterize specific Pareto-improving policy packages.

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Appendix A: Additional calibration details

Section 5.1 describes the model setup consisting of three functions for each region: abatement costs $c_i(e_i) = \kappa_i \left(\frac{\bar{e}_i - e_i}{\bar{e}_i} \right)^\theta q_i$, where $\theta = 2.6$ following Barrage and Nordhaus (2024); regional damages $d_i(E) = s_i \phi E$; and utility $u_i(x_i) = l_i \frac{(x_i / (l_i p_i))^{1-\eta}}{1-\eta}$, where $x_i = q_i - c_i(e_i) - d_i(E) + t_i$, and $\eta = 1.5$ in our primary analysis consistent with RICE-2010 (Nordhaus, 2010).

We aggregate country-level data to regions according to the country-to-region classification (see Table A3). Population l_i is from the UN World Population Prospects 2024 (United Nations, 2024). Data on GDP in purchasing power parity, q_i^{PPP} , and at market exchange rates, q_i , are from the International Monetary Fund (2025). We calculate regional price levels relative to the United States as $p_i = q_i / q_i^{\text{PPP}}$. The first three columns of Table A1 report l_i , q_i , and p_i for each region. The rest of our calibration focuses on the regional damage and abatement cost functions.

Regional damage functions

We obtain an estimate of the global SCC for 2023 by linearly interpolating the estimates for 2020 (Rennert et al., 2022) and 2025 (Funke et al., 2023), resulting in a value of \$206/tCO₂ in 2021 dollars. We calibrate the regional marginal damage shares using the regional marginal-damage estimates in RICE-2010 (Nordhaus, 2014) as our primary source. For model regions not separately identified in RICE-2010—Brazil, South Africa, and Canada—we use the corresponding regional estimates in C-DICE (Nordhaus, 2015); specifically, for these regions, we use the estimates of RICE-2010 that are reported in Appendix Table B-2 of Nordhaus (2015). We construct the shares for Sub-Saharan Africa, Latin America and the Caribbean, and Other High Income countries as residual shares of the encompassing RICE regions: Africa minus South Africa, Latin America minus Brazil, and OHI minus Canada, respectively.

Since the monetary units of RICE-2010 and C-DICE are PPP-adjusted international dollars, we convert the PPP-based damage shares, denoted s_i^{PPP} , to market exchange rate dollars using regional price levels. Specifically, our conversion is to set regional damage shares according to $s_i = \frac{p_i s_i^{\text{PPP}}}{\sum_j p_j s_j^{\text{PPP}}}$, and the global SCC in market exchange rates is $\phi = \sum_j p_j s_j^{\text{PPP}} \phi^{\text{PPP}}$, where $\phi^{\text{PPP}} = \$206$ from above. We report the regional damage shares in the fourth column of Table A1, and $\phi = \$112$.

Table A1: Main model parameters

Region	l_i (millions)	q_i (\$billions)	p_i	s_i	$\bar{e}_i$ (MtCO ₂)	κ_i
US	343	25,456	1.00	0.192	5,067	0.045
OHI	121	5,674	0.75	0.043	1,442	0.048
Canada	39	2,103	0.94	0.016	651	0.068
EU+	534	22,910	0.78	0.172	3,580	0.030
Japan	124	5,157	0.90	0.038	1,020	0.042
Russia	145	1,865	0.32	0.006	1,733	0.096
China	1,423	19,947	0.62	0.185	12,850	0.105
MENA	594	4,935	0.39	0.073	3,512	0.084
Brazil	211	1,772	0.44	0.019	484	0.035
LatAm	435	3,807	0.46	0.039	1,288	0.045
Eurasia	165	895	0.30	0.005	887	0.097
SAfrica	63	438	0.50	0.006	449	0.144
OthAs	1,215	4,401	0.33	0.075	2,313	0.055
India	1,438	3,746	0.28	0.061	3,063	0.076
SSA	1,194	1,726	0.36	0.069	426	0.027

Note: All dollar values are expressed in constant 2021 US dollars at market exchange rates. Reported values are rounded. Parameter definitions, data sources, and calibration procedures are described in the accompanying text.

Regional abatement cost functions

To calibrate regional abatement costs, we need parameter values for κ_i and $\bar{e}_i$. We follow the general approach of Barrage and Nordhaus (2024), though applied at the regional level. Marginal abatement costs, $-c'_i(e_i)$, are calibrated to satisfy two equations. The first is that the marginal abatement cost at zero emissions equals a region-specific backstop price. The second is that the marginal abatement cost at observed emissions equals the observed regional carbon price. This produces two equations and two unknowns for each region, enabling us to solve for κ_i and $\bar{e}_i$ for all i .

Regional backstop prices.— Barrage and Nordhaus (2024) model a global backstop price that implies an estimate for 2023 of \$716/tCO₂ in 2021 PPP-adjusted international dollars, which we denote $\tilde{\tau}_{\text{global}}^{\text{PPP}}$. We derive regional backstop prices in PPP-adjusted international dollars according to

$$\tilde{\tau}_i^{\text{PPP}} = \tilde{\tau}_{\text{global}}^{\text{PPP}} \frac{p_i^{\varphi-1}}{\sum_j \xi_j p_j^{\varphi-1}},$$

where ξ_j denotes region j 's share of observed emissions (see below and Table A2). An implication of this expression is that the emissions-weighted average of regional backstop prices equals the global backstop price in DICE-2023. The parameter φ reflects the extent to which regional differences in backstop prices diverge from regional differences in price

Table A2: Calibration of abatement cost functions

Region	$\tilde{\tau}_i$ (\$/tCO ₂)	τ_i (\$/tCO ₂)	e_i^{obs} (MtCO ₂)	μ_i^{obs} (%)
US	594	2.1	4,918	2.9
OHI	487	5.3	1,357	5.9
Canada	569	31.0	545	16.2
EU+	498	37.5	2,868	19.9
Japan	552	2.3	987	3.3
Russia	268	0.0	1,733	0.0
China	424	3.8	12,172	5.3
MENA	307	0.0	3,512	0.0
Brazil	335	0.0	484	0.0
LatAm	345	1.1	1,253	2.7
Eurasia	255	0.3	874	1.5
SAfrica	365	1.2	437	2.8
OthAs	274	0.1	2,301	0.5
India	243	0.0	3,063	0.0
SSA	289	0.0	426	0.0

Note: Reported values are rounded. Parameter definitions, data sources, and calibration procedures are described in the accompanying text.

levels. In particular, $\varphi = 1$ corresponds to a common backstop price in PPP units, while $\varphi = 0$ corresponds to a common backstop price in market exchange rate units. Young-Brun et al. (2025) implicitly assume $\varphi = 1$, while a comparison of utility-scale solar installations between the US and India, combined with differences in p_i , implies a value of approximately 0.5 (IRENA, 2022). We assume an intermediate value of 0.7, implying that abatement technologies are traded more internationally than the aggregate GDP bundle of goods, while still depending on local non-traded inputs. Finally, we convert the regional backstop prices to market exchange rate units according to $\tilde{\tau}_i = \tilde{\tau}_i^{\text{PPP}} p_i$, which we report in the first column of Table A2.

Observed emissions and carbon prices.— We obtain observed regional emissions in 2023, denoted e_i^{obs} , from the Global Carbon Budget (GCB) 2025 via Our World in Data (GCB, 2025), supplemented with EDGAR (European Commission, Joint Research Centre and International Energy Agency, 2025) where GCB data are unavailable. We construct observed carbon prices in PPP units, denoted τ_i^{PPP} , from the OECD Carbon Pricing and Energy Taxation database (OECD, 2026). When available, we sum each country’s carbon tax and emissions trading permit price. We then obtain a regional estimate by taking an emissions-weighted average over countries within a region for which pricing data are available. Finally, these carbon prices are converted to market exchange rates with $\tau_i = \tau_i^{\text{PPP}} p_i$. We report the values for τ_i and e_i^{obs} in the middle two columns of Table A2.

Calibrated parameters.— Using the fact that marginal abatement costs equal the backstop price at zero emissions, we can write the marginal abatement cost function as $\check{\tau}_i \mu_i^{\theta-1}$, where $\mu_i = (\bar{e}_i - e_i)/\bar{e}_i$ is the emissions-control rate. Calibrating marginal abatement costs to match observed emissions and carbon prices, we obtain $\bar{e}_i = \frac{e_i^{\text{obs}}}{1 - \mu_i^{\text{obs}}}$, where $\mu_i^{\text{obs}} = \left(\frac{\tau_i}{\check{\tau}_i}\right)^{1/(\theta-1)}$, and we report μ_i^{obs} in the last column of Table A2. Finally, given $\bar{e}_i$ and evaluating marginal abatement costs at zero emissions, we can solve directly for $\kappa_i = \frac{\check{\tau}_i \bar{e}_i}{\theta q_i}$. The values for $\bar{e}_i$ and κ_i , which are main model parameters, are reported in the last two columns of Table A1.

Region classification

Table A3: Country-to-region classification

Region	Countries and areas
US	United States
Canada	Canada
OHI	Australia, Taiwan, Hong Kong, South Korea, Macao, New Zealand, Singapore
EU+	Andorra, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Greenland, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
Japan	Japan
Russia	Russia
China	China
MENA	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, State of Palestine, Syria, Tunisia, Türkiye, United Arab Emirates, Yemen
Brazil	Brazil
LatAm	Antigua and Barbuda, Argentina, Aruba, The Bahamas, Barbados, Belize, Bermuda, Bolivia, Cayman Islands, Chile, Colombia, Costa Rica, Curaçao, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Georgia, Kazakhstan, Kosovo, Kyrgyzstan, North Macedonia, Moldova, Montenegro, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
SAfrica	South Africa
OthAs	Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, Fiji, Indonesia, Kiribati, Laos, Malaysia, Maldives, Marshall Islands, Federated States of Micronesia, Mongolia, Myanmar, Nauru, Nepal, Pakistan, Palau, Papua New Guinea, Philippines, Samoa, Solomon Islands, Sri Lanka, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Vietnam
India	India

Continued on next page

Table A3 continued

Region	Countries and areas
SSA	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Republic of the Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Sudan, Sudan, Eswatini, Tanzania, Togo, Uganda, Zambia, Zimbabwe

Note: The table reports the country and area coverage used to aggregate the model's 15 regions. OHI denotes Other High Income countries; EU+ denotes the European Union and selected non-EU countries; MENA denotes Middle East and North Africa; LatAm denotes Latin America and the Caribbean; SAfrica denotes South Africa; OthAs denotes Other Asia; and SSA denotes Sub-Saharan Africa.

Appendix B: Additional Figures

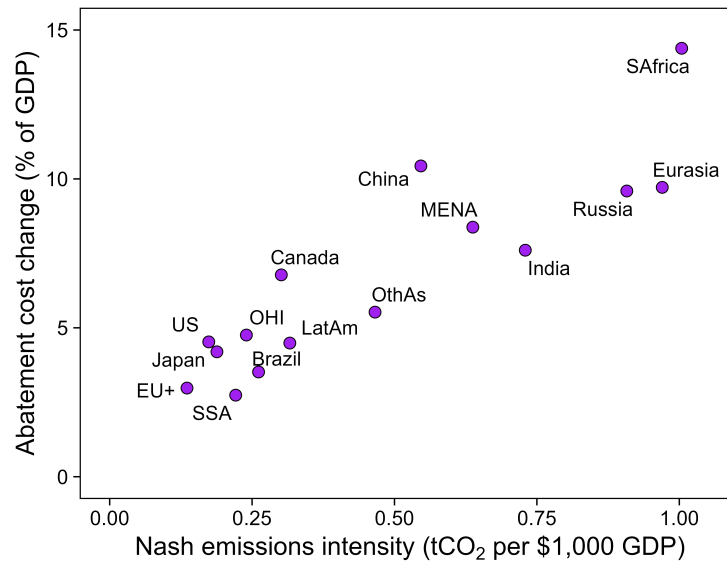


Figure A1: Regional abatement costs of moving from the RP (Nash) to RnP (zero emissions) reference allocation against emissions intensity at the Nash equilibrium.

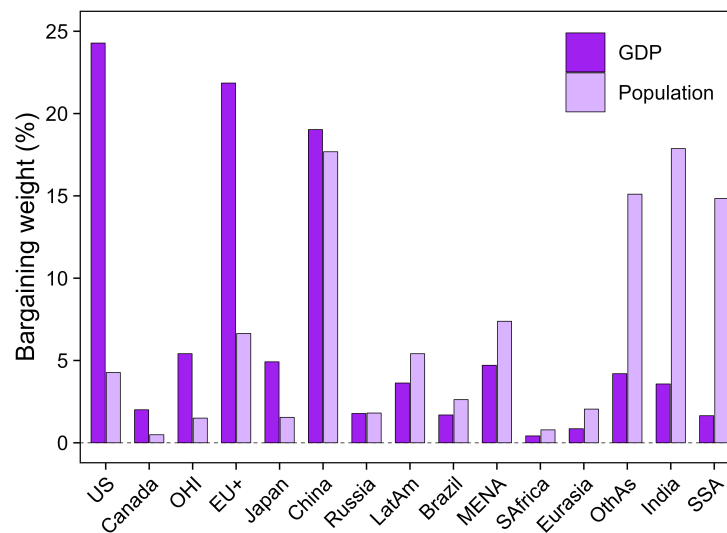
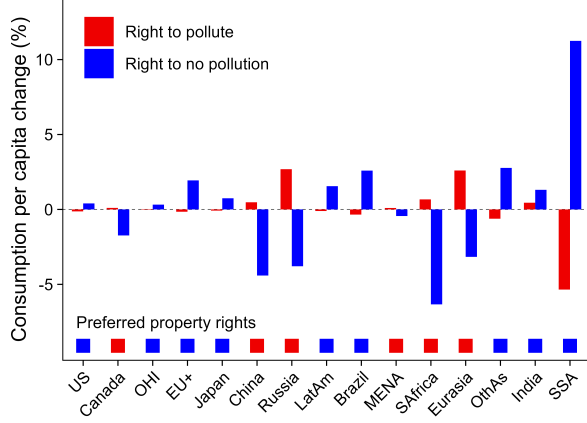
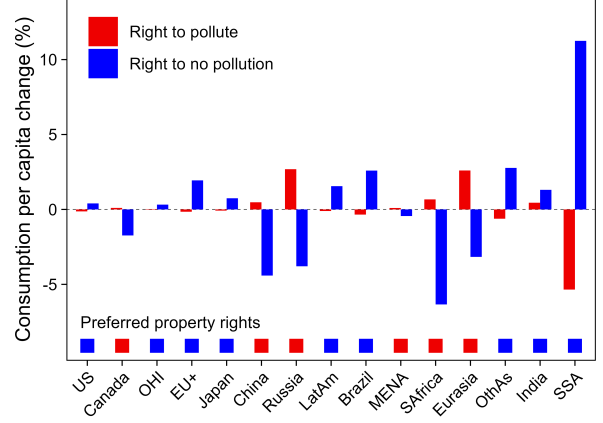


Figure A2: Comparison of bargaining weights based on either GDP or population.

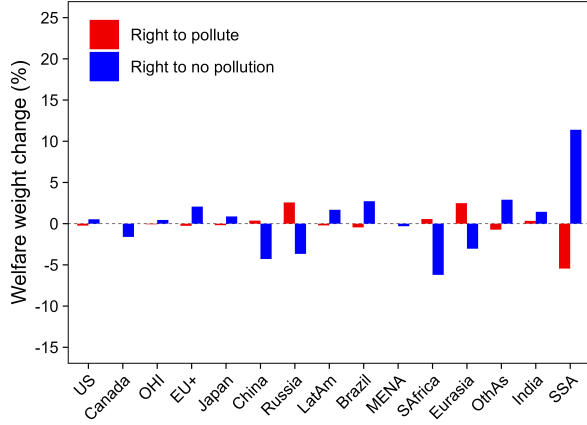
(a) Consumption relative to Negishi ($\eta = 1$)



(b) Consumption relative to Negishi ($\eta = 2$)



(c) Welfare weights relative to Negishi ($\eta = 1$)



(d) Welfare weights relative to Negishi ($\eta = 2$)

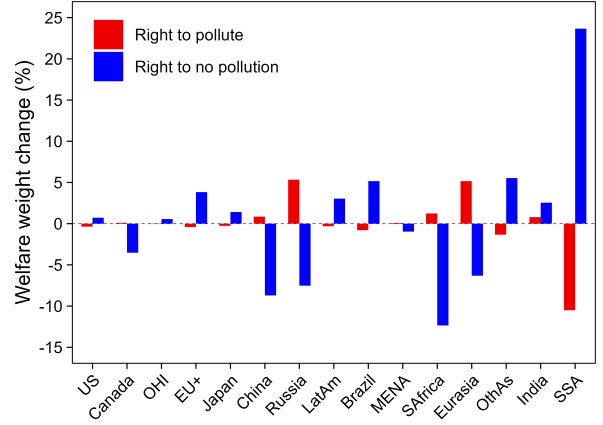


Figure A3: Sensitivity with respect to η (GDP bargaining weights).

Note: This figure shows how consumption per capita at the efficient allocations and the Coasean welfare weights depend on the elasticity of the marginal utility of consumption (η).

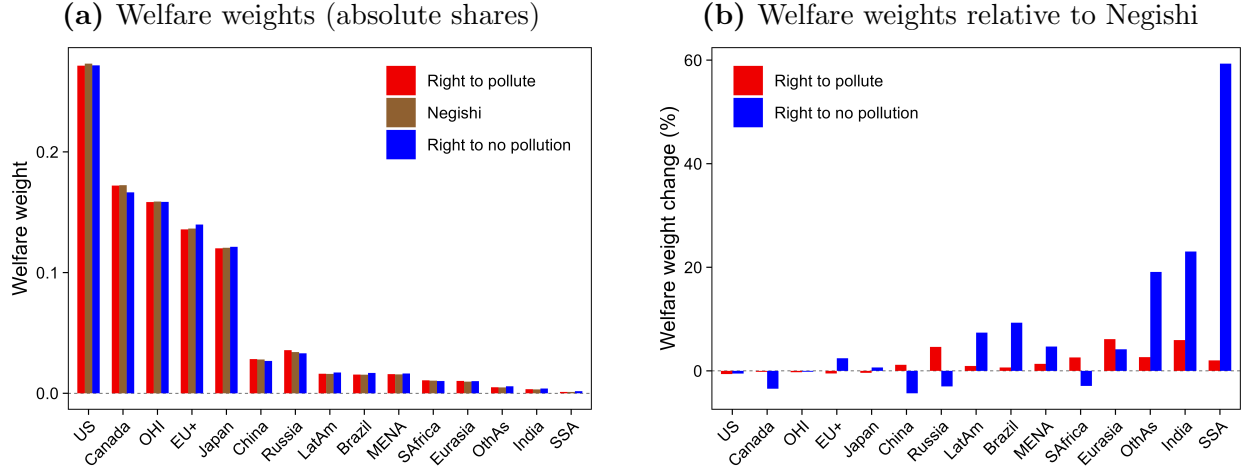


Figure A4: Differences in social welfare weights (population bargaining weights).

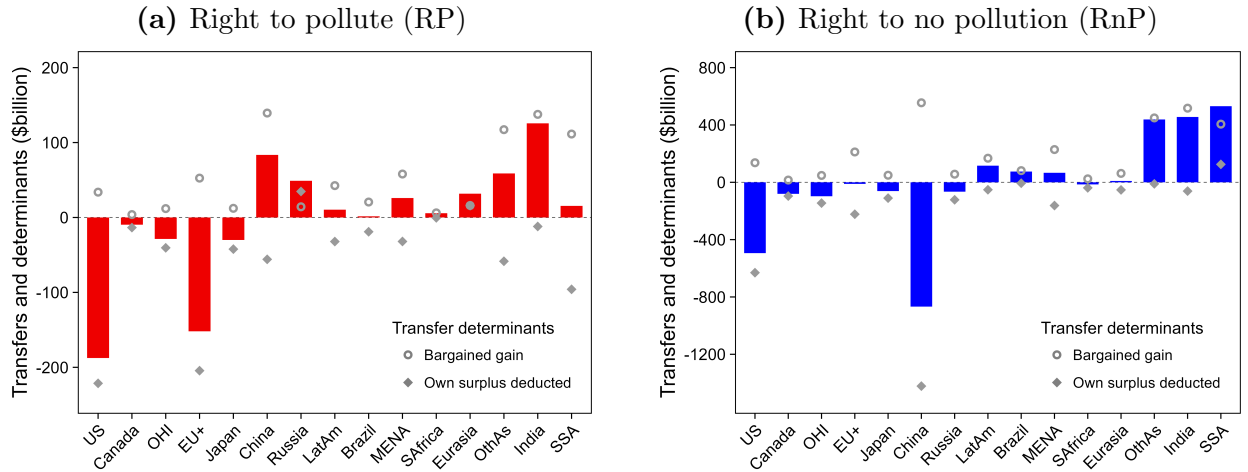


Figure A5: Coasean transfers consistent with the RP and RnP property rights (population bargaining weights).

Note: Figure shows the international transfers (in \$billions) implied by the shift from the RP and RnP reference allocations to the corresponding efficient allocations. Results are based on population bargaining weights. Transfers are exact estimates of equation (9), where “Bargained gain” and “Own surplus deducted” correspond to the first and second terms, respectively.

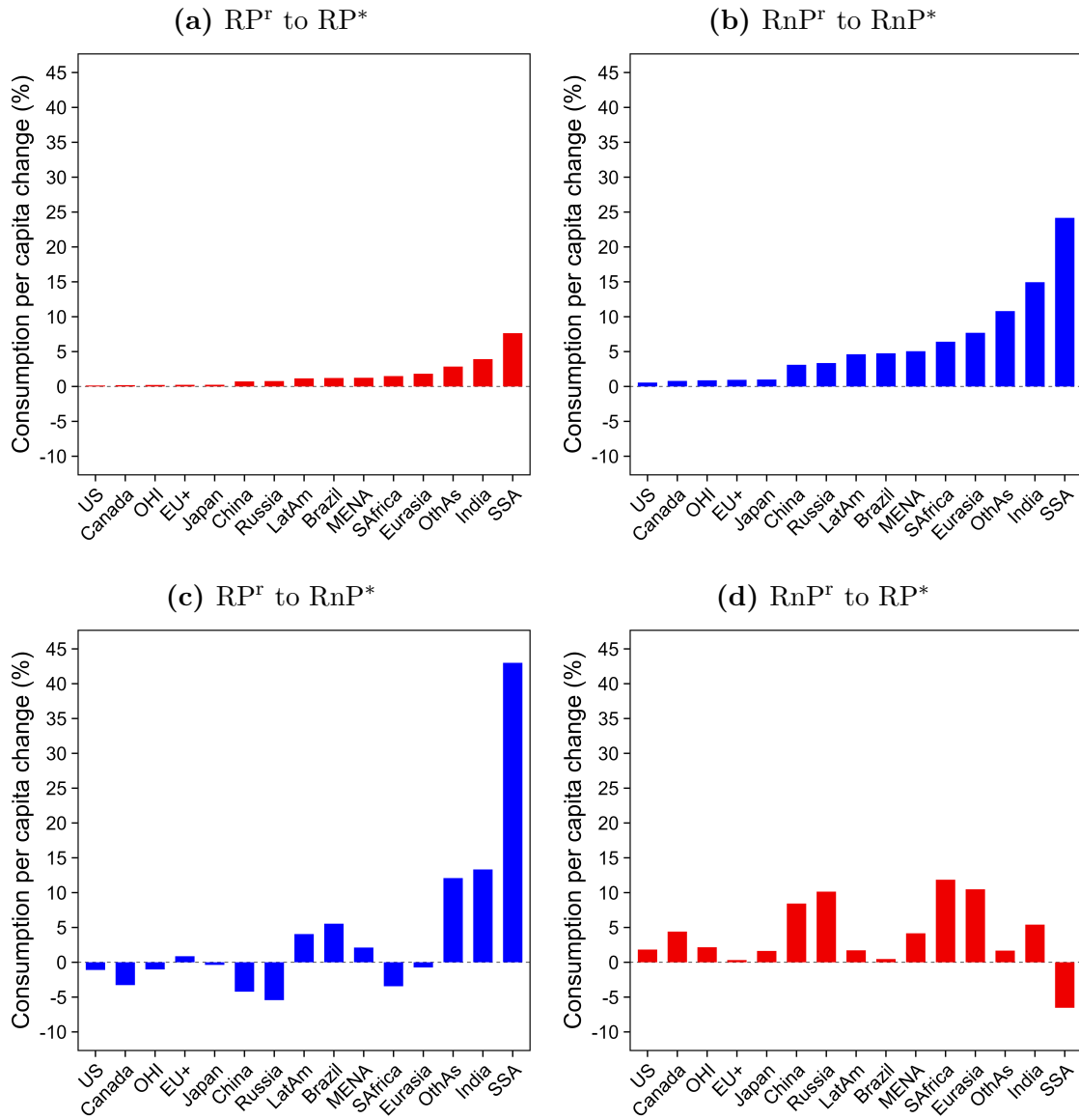


Figure A6: Consumption per capita changes moving from RP and RnP reference allocations to different efficient allocations (population bargaining weights).

Note: Figure shows changes in consumption per capita based on population bargaining weights. Superscripts “r” and an asterisk denote the reference and efficient allocations, respectively, for the corresponding property-rights regime.