

# Global warming, ecosystems and inequality

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## Abstract

Global warming, ecological decline and inequalities are interconnected, yet rarely studied jointly. We investigate how damages to the environment change the social cost of inequalities, and how inequalities influence the social value of ecosystem services. We show that the answer depends on two parameters: inequality aversion, and substitutability between market goods and environmental goods. When both parameters are high, inequality increases the marginal value of the environment. This is not always the case when both parameters are low. We quantify this interaction by building a climate-economy model that includes ecosystem services and features both national and international inequalities. In our main calibration, the presence of national inequality doubles the marginal social cost of damages to the environment, while cross-country inequalities only cause a small increase. Overall, our findings show that the interactions of inequalities and ecosystem services can be quantitatively important for the assessment of conservation, climate, or redistributive policies.

**Keywords:** Climate change, Ecosystem services, Inequality, Integrated assessment models.

**JEL Codes:** D63, Q51, Q54, Q57.

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# 1 Introduction

Environmental crises affect people unequally. Developing countries have already suffered disproportionately from the impacts of global warming, and future damages will be concentrated on the poorest populations (IPCC 2023). Many of the world’s poorest communities live in places where the highest damages to ecosystems are projected (IPBES 2019), while rural, low-income households are the ones who rely most on natural products for subsistence (Angelsen et al. 2014). Understanding the interactions between inequalities and the environment is crucial for policy design; neither can be understood without the other (Drupp et al. 2025).

In this paper, we answer the following questions: Do climate damages to the environment increase the social cost of inequalities? Conversely, how do inequalities change the social cost of damages to the environment? We show that damages to the environment can either increase or decrease the social cost of inequalities, depending on two crucial parameters of the utility function. To quantify this effect, we extend a climate-economy model with national inequalities at the decile level to integrate a flow of ecosystem services from natural capital. In our main calibration, inequality more than triples the social cost of damages to the environment. The largest part of this increase is due to national inequalities. Results are highly sensitive to the model’s parameters, in line with our theoretical predictions.

Our paper brings together three strands of literature: ecosystem valuation, climate change, and inequalities. Economists began valuing ecosystem services in the 1970s and 1980s, with the rise of cost-benefit analysis (Westman 1977; de Groot 1986; Huetting 1987). Valuation methods were refined in the 1990s (Daily 1997), and a first meta-analysis assessed the global value of nature’s services (Costanza et al. 1997). The Millennium Ecosystem Assessment (UNEP 2003) and the Dasgupta review (2021) contributed to establishing ecosystem services as a central topic of environmental economics.

In parallel, the economics of climate change has mostly focused on how climate change impacts the production of market goods. This approach implicitly assumes that the impacts of climate change on welfare can be properly measured as changes in GDP. However, a small but long-running literature has pointed out that many climate damages are likely to be only imperfectly substitutable with manufactured goods, and that this distinction can have first-order implications for the assessment of climate change costs (Tol 1994; Hoel and Sterner 2007; Sterner and Persson 2008; Weitzman 2010; Drupp 2018). Notably, as the economy grows, natural goods become relatively scarcer, and their marginal value increases (Drupp et al. 2024). This concern has motivated efforts to distinguish between natural and manufactured goods in standard climate-economy models (Tol 1994; Hoel and Sterner 2007; Sterner and Persson

2008). For instance, Drupp and Hänsel (2021) calibrate the single-region DICE2016-R2 model (Nordhaus 2018) to account for non-market environmental damage. They find substantial increases in the social cost of carbon and sensitivity to key preference parameters such as the degree of substitutability. Bastien-Olvera and Moore (2021) go further by explicitly representing natural capital in the production function, as well as non-use values of nature in the utility function. Since this prior work has almost exclusively relied on the single-region, globally-representative DICE model, it therefore abstracts from both national and international inequalities. Bastien-Olvera et al. (2024) include ecosystem services in a country-level model that includes international inequalities (the RICE50+ model, from Gazzotti et al. 2021), but still lacks within-country inequalities.

In parallel, a largely separate literature has documented the sensitivity of climate change damages estimates to the treatment of inequality. Because the climate change problem is global, inequality in consumption can be of first-order importance for the evaluation of climate change damages (Errickson et al. 2021). Past work in this area (e.g. Anthoff and Emmerling 2019) has examined the effects of international inequality using multi-region integrated assessment models such as RICE (Nordhaus and Yang 1996) and FUND (Anthoff et al. 2009). Inequality in consumption *within* regions was introduced by Dennig et al. (2015) with their Nested Inequalities Climate-Economy (NICE) model, which features 12 regions, each divided into 5 income quintiles. This model can be used to evaluate the welfare effects of redistributive policies in the context of climate change. It shows that within-region inequality has a large effect on the social cost of carbon and (Budolfson et al. 2021). Further iterations on the NICE model increased its level of detail, with 176 countries and 10 deciles per country in the latest published version (Young-Brun et al. 2025). This work, however, has focused almost entirely on consumption inequality, ignoring the potentially important role of non-market goods and their interaction with widely varying consumption of market goods.

Our contribution to this literature is twofold. The first one is a theoretical finding: with a standard social welfare function, damages to the environment can either increase or decrease the social cost of inequalities. Likewise, inequalities can either raise or lower the social cost of damages to the environment. The direction of the effect depends on two critical parameters of the social welfare function: inequality aversion and substitutability between manufactured and environmental goods. When both parameters are high, inequalities increase the marginal value of the environment, and environmental losses increase the marginal social cost of inequalities. When both are low, the opposite holds.<sup>1</sup> This result contributes to understanding how standard

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<sup>1</sup>Except if both parameters are *very* low, in which case the sign of the effect depends on other parameters and variables.

social welfare functions behave in models with limited substitutability between market goods and ecosystem services.

Our second contribution is to quantify the effect of inequalities on the social cost of damages to the environment. We introduce ecosystem services in the latest version of the NICE model (Young-Brun et al. 2025), updating the social welfare function to distinguish between manufactured goods and non-market environmental goods. The flow of ecosystem services decreases as global temperatures increase, following a damage function from Bastien-Olvera et al. (2024). We call this model GreenNICE. It is, to our knowledge, the first cost-benefit climate-economy model to integrate both ecosystem services and national inequalities. Our simulations show that the effect of national inequality on the social cost of environmental damages is highly sensitive to inequality aversion and substitutability. In our central calibration, the presence of national inequality alone doubles the social cost of damages to the environment, while other forms of inequality have a smaller effect. If natural goods are less substitutable, the effect of national inequality becomes smaller in relative terms, and is even reversed for low inequality aversion. Our main calibration is based on a narrow subset of ecosystem services from terrestrial vegetation. If we assume a 100-times-larger flow of ecosystem services, the social cost of damages to the environment grows by a factor of 7, and remains approximately twice as large with national inequalities than without. This sensitivity exercise shows that our relative results are robust to the calibration of environmental goods. More comprehensive estimates of ecosystem services would yield a higher social cost of environmental loss.

Taken together, our results highlight the interconnected nature of three defining challenges of the 21st century: global warming, ecological decline and rising inequality. Their welfare effects are highly inter-related. Their interactions can change model results and associated policy recommendations in significant and non-obvious ways.

In the next section, we explain why inequality can either increase *or* decrease the marginal value of nature. We then use simulations to quantify this effect for a range of parameterizations: [section 3](#) explains how we integrate ecosystem services into the NICE model, and [section 4](#) reports simulation results. We discuss the implications and limitations of these results in the [final section](#).

## 2 Theoretical analysis

We first abstract from the particulars of the climate change problem to establish general theoretical results regarding the interaction between inequality in consumption of market goods and the value of environmental goods (i.e. ecosystem services). Our theoretical finding is

the following: within-country inequality can either increase *or* decrease the marginal value of ecosystem services, depending on inequality aversion and substitutability between consumption goods and the environment. We start by introducing our framework (2.1). Then, we state our result formally and explain the intuition behind it (2.2). We finally show how these results impact social cost of carbon estimates (2.3).

## 2.1 Theoretical framework

To study the interaction between within-country consumption inequalities and the environment, we combine these two variables in a two-good social welfare function. In this sub-section, we explain how we model inequality, what we mean by “the environment”, and how these two components fit together in a social welfare function.

### Inequality

We consider a set of  $m$  countries. The population  $L_i$  of each country  $i \in \{1, \dots, m\}$  is divided into  $n$  consumption quantiles. Consumption  $c_{i,j}$  of quantile  $j$  in country  $i$  can be defined as a function of the country’s average consumption  $c_i$ , and some constant  $\delta_{i,j}$ :

$$c_{i,j} = c_i(1 + \delta_{i,j} \gamma).$$

Constant  $\delta_{i,j} = (\hat{c}_{i,j} - c_i)/c_i$  is the relative difference between the observed consumption  $\hat{c}_{i,j}$  of income group  $j$  and national average  $c_i$ . In this paper, we are interested in comparing situations with different levels of economic inequality. We introduce parameter  $\gamma \in [0, 1]$  to arbitrarily vary the level of within-country inequality. When  $\gamma = 0$ , there is no national consumption inequality: the average consumption of an income group is the average consumption of its country. When  $\gamma = 1$ , national inequalities are fully implemented. The  $\gamma$  parameter is the same for all countries. Note that, by construction,  $\gamma$  only changes the spread of the income distribution, without changing the mean. More precisely, for a given country  $i$ , the standard deviation of consumption in the model is equal to the actual observed standard deviation of the country’s income distribution,  $\hat{\sigma}_i$ , scaled by  $\gamma$ :

$$\sigma_i = \gamma \cdot \hat{\sigma}_i.$$

See [Appendix C](#) for a formal derivation.

## Social welfare function

Following Hoel and Sterner (2007), Sterner and Persson (2008), and Drupp and Hänsel (2021), we define utility as a function of market good consumption  $c$  and a non-market environmental good  $E$ :

$$u : (c, E) \mapsto \frac{[(1 - \alpha)c^\theta + \alpha E^\theta]^{(1-\eta)/\theta}}{1 - \eta}, \quad (1)$$

where  $\alpha \in (0, 1)$  is the share of ecosystem services in the utility function, and  $\theta \in (-\infty, 1] \setminus \{0\}$  is the degree of substitutability between consumption and non-market environmental goods.<sup>2</sup> Consumption and ecosystem services are perfect complements for  $\theta \rightarrow -\infty$ , and perfect substitutes for  $\theta = 1$ . Parameter  $\eta$  is a positive number different from one.<sup>3</sup>

Variable  $E$  is the annual, per-capita flow of non-market environmental goods. Ecosystem services that contribute to market production are already valued through consumption  $c$ . But many environmental benefits, including subsistence production, and some regulating environmental services such as pollution prevention, flood control, or recreation are not captured in standard market accounting.  $E$  can be thought of as a composite of these non-market environmental goods. In our setting though,  $E$  excludes potential non-use values of the environment, such as existence or bequest values.<sup>4</sup> Our framework models the environmental good as being equally distributed across income groups within a country (i.e.  $E$  is the same for all levels of  $c$ ). This is a necessary assumption given the absence of systematic data on the within-country distribution of environmental goods.

There are two different ways of seeing the parameter  $\eta$ . It can be interpreted as society's level of aversion to inequality. In that case, it is a normative parameter that only makes sense at the social level. Alternatively,  $\eta$  can be understood at the individual level, as the inverse of the constant intertemporal elasticity, as the constant coefficient of relative risk aversion (CRRA), or as the elasticity of marginal utility of consumption. In these interpretations,  $\eta$  also implies a form of inequality aversion, as a consequence of diminishing marginal utility. Because this paper focuses on inequalities, we will mainly refer to  $\eta$  as inequality aversion, without excluding other interpretations.

Social welfare is the sum of individual utilities over all countries and income groups:

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<sup>2</sup>The  $\theta = 0$  case corresponds to a Cobb-Douglas function (Hoel and Sterner 2007):  $u : (c, E) \mapsto \frac{[c^{1-\alpha} E^\alpha]^{1-\eta}}{1 - \eta}$ .

<sup>3</sup>The utility function can also be extended to the  $\eta = 1$  case:  $u : (c, E) \mapsto \ln \left[ ((1 - \alpha)c^\theta + \alpha E^\theta)^{1/\theta} \right]$ .

<sup>4</sup>This departs from the GreenDICE model (Bastien-Olvera and Moore 2021), where the utility function distinguishes between both use and non-use values.

$$W = \sum_{i=1}^m \sum_{j=1}^n \frac{L_i}{n} \cdot u(c_{i,j}, E_i), \quad (2)$$

with  $n$  the number of quantiles per country and  $L_i$  the population of country  $i$ .

## 2.2 Interaction between inequality and ecosystem services

The extent to which inequalities interact with environmental loss is directly linked to the cross derivative of social welfare with respect to environment  $E$  and inequalities  $\gamma$ . This cross derivative indicates how the social marginal value of  $E$  changes when inequality increases slightly. We let  $\partial_{E,\gamma}^2 W$  denote this cross derivative. If the cross derivative is positive, the marginal value of  $E$  increases with inequality. If on the contrary the cross derivative is negative, then within-country inequalities reduce the marginal value of the environment. In that case, a more equal country would suffer more from climate damages to the environment than a more unequal country.

Due to the symmetry of second derivatives ( $\partial_{E,\gamma}^2 W = \partial_{\gamma,E}^2 W$ ), the sign of the cross derivative also tells us about the effect of the environment on the social value of reducing inequality. If  $\partial_{E,\gamma}^2 W$  is positive, the marginal welfare cost of inequality is lower when environmental quality is high. Then, inequalities are less of a problem in countries with abundant ecosystem services than in countries with lower  $E$ , all else equal. Conversely, if the cross derivative is negative, environmental goods increase the marginal welfare cost of inequality. In that case, reducing national inequalities brings more social welfare when  $E$  is high, all else equal.

In [Proposition 1](#), we show that the sign of cross derivative  $\partial_{E,\gamma}^2 W$  depends on inequality aversion  $\eta$  and substitutability  $\theta$ . It is always positive when inequality aversion  $\eta$  is higher than complementarity  $1 - \theta$ ; always negative when  $\eta$  is between  $-\theta$  and  $1 - \theta$ ; and indeterminate when  $\theta < \eta$  (see [Figure 1](#)).

### PROPOSITION 1

With  $n$  consumption quantiles, each with the same environment  $E$ , and each with different consumption levels, the sign of  $\partial_{E,\gamma}^2 W$  depends on parameters  $\theta$  and  $\eta$  in the following way:

1. if  $\eta > 1 - \theta$ , then  $\partial_{E,\gamma}^2 W > 0$ ,
2. if  $-\theta < \eta < 1 - \theta$ , then  $\partial_{E,\gamma}^2 W < 0$ .

*Proof.* See [Appendix D](#). □

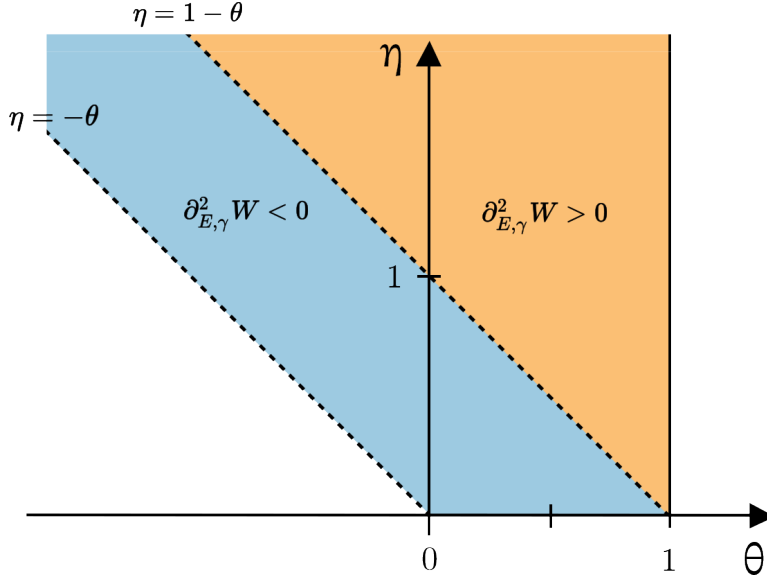


Figure 1: The sign of cross derivative  $\partial_{E,\gamma}^2 W$  depends on substitutability  $\theta$  and inequality aversion  $\eta$  (Proposition 1).

Note: The plot shows how the cross derivative changes as a function of  $\eta$  and  $\theta$ . The orange area indicates the region where the sign is positive. The light blue region indicates the values under which the cross derivative is negative. Within the white area, the sign of the cross derivative is indeterminate.

The division of the  $(\theta, \eta)$  plane in three zones in Figure 1 is due to two competing effects. One effect comes from inequality aversion  $\eta$ , and the other from complementarity  $1 - \theta$ . Inequality aversion  $\eta$  is the curvature of the utility function  $u$ . When utility is more concave, getting richer in one of the two goods makes the other less valuable at the margin. For instance, when there is more environment, market goods become less useful marginally, because many needs are already satisfied by nature. Likewise, being richer makes the wood of an additional tree less useful, because, for example, there might be substitutes for biofuels on the market. Notice that this is only true if ecosystem services and market goods are substitutable enough. When the two goods are highly complementary, an increase in one makes the other *more* valuable at the margin. With a more efficient stove, additional wood from the forest provides more energy. A more diverse fauna increases the willingness to pay for binoculars. So, the cross derivative of welfare with respect to the environment and *consumption* ( $\partial_{E,c}W$ ) is positive when inequality aversion and substitutability are both high, and negative when they are both low.

As inequality  $\gamma$  increases, quantiles above average income get richer, while the others get poorer. When inequality aversion  $\eta$  is higher than complementarity  $1 - \theta$ , the consumption loss of the low-income groups makes the environment more valuable at the margin. At the same time, the environment becomes less marginally useful to the high-income groups, as they get slightly richer — but the effect of the low-income groups is stronger.

When inequality aversion  $\eta$  is *lower* than complementarity  $1 - \theta$ , the consumption loss of the low-income groups makes the environment *less* valuable at the margin. At the same time, the environment becomes *more* marginally useful to the high-income groups. Here, the effect of the low-income groups is not always stronger. The lower-income groups still drive the result when  $\eta > -\theta$  (blue area on the figure). When  $\eta < -\theta$  (white area), which effect prevails depends on the level of inequality, on the balance between  $c$  and  $E$ , and on the other parameters of the social welfare function.

### 2.3 Relevance for the social cost of carbon

Cross derivative  $\partial_{E,\gamma}^2 W$  is also interesting because it is part of the answer to another question: in the presence of ecosystem services, what is the effect of inequalities on the social cost of carbon? The social cost of carbon (SCC) is the marginal social cost of greenhouse emissions. It is usually expressed in dollars per ton of CO<sub>2</sub> equivalent. Van der Ploeg et al. (2023) propose a straightforward analytical formula for the social cost of carbon. The present value of climate damages caused by marginal emissions in the present is a discounted sum of future marginal welfare costs, divided by some marginal utility of consumption, to ensure the result is in a monetary unit (van der Ploeg et al. 2023, equation 11).

Adapting this formula to our discrete-time, two-good setting, we define the social cost of carbon as:

$$\text{SCC} = \frac{1}{\partial_c u(\bar{c}_0, \bar{E}_0)} \sum_t \beta^t \sum_{i,j} [\partial_{c_{i,j,t}} W_t \cdot (-\partial_{e_0} c_{i,j,t}) + \partial_{E_{i,j,t}} W_t \cdot (-\partial_{e_0} E_{i,j,t})]. \quad (3)$$

At time  $t$ , in income group  $j$  of country  $i$ , damages  $(-\partial_{e_0} c_{i,j,t})$  are caused to consumption by additional marginal present emissions  $e_0$ . These damages are multiplied by the marginal social value of consumption,  $\partial_{c_{i,j,t}} W_t$ . The resulting product is the welfare cost of climate damages to consumption. Likewise, damages to the environment  $(-\partial_{e_0} E_{i,j,t})$  are multiplied by marginal value  $\partial_{E_{i,j,t}} W_t$  to obtain their welfare cost. Welfare costs of damages to consumption and to the environment are summed across all income groups and countries. The global welfare cost series is then aggregated across time, with utility discount factor  $\beta = 1/(1 + \rho)$  and rate of pure time preference  $\rho$ . Finally, the present welfare cost is converted to dollars by dividing it by marginal utility of consumption  $\partial_c u$ , evaluated at global average present consumption  $\bar{c}_0$  and average present environment  $\bar{E}_0$ . This conversion factor does not vary with inequality coefficient  $\gamma$ , because  $\gamma$  changes the spread of within-country consumption without changing its average.

When calculated this way, the social cost of carbon is the present social value of climate

damages, expressed in dollars, from the point of view of a theoretical person living in the present at the average level of consumption and environmental services.

In this paper, we are specifically interested in the environmental part of the social cost of carbon. We decompose the SCC as the sum of a consumption part and an environmental part:

$$\text{SCC} = \text{SCC}_c + \text{SCC}_E,$$

with

$$\text{SCC}_c = \frac{1}{\partial_c u(\bar{c}_0, \bar{E}_0)} \sum_t \beta^t \sum_{i,j} \partial_{c_{i,j,t}} W_t \cdot (-\partial_{e_0} c_{i,j,t})$$

and

$$\text{SCC}_E = \frac{1}{\partial_c u(\bar{c}_0, \bar{E}_0)} \sum_t \beta^t \sum_{i,j} \partial_{E_{i,j,t}} W_t \cdot (-\partial_{e_0} E_{i,j,t}).$$

The marginal effect of within-country inequality on the environmental component of the social cost of carbon is given by the derivative of  $\text{SCC}_E$  with respect to inequality coefficient  $\gamma$ :

$$\partial_\gamma \text{SCC}_E = \frac{1}{\partial_c u(\bar{c}_0, \bar{E}_0)} \sum_t \beta^t \sum_{i,j} \partial_{\gamma, E_{i,j,t}}^2 W_t \cdot (-\partial_{e_0} E_{i,j,t}).$$

Marginal utility of consumption  $\partial_c u(\bar{c}_0, \bar{E}_0)$ , discount factor  $\beta^t$  and marginal damages  $-\partial_{e_0} E_{i,j,t}$  all have positive values. Therefore, the sign of  $\partial_\gamma \text{SCC}_E$  depends on the sign of the cross derivative of welfare with respect to  $\gamma$  and  $E$ . If the cross derivative is positive for all  $i$  and all  $j$ , then the environmental component of the social cost of carbon increases with within-country inequality. If the cross derivative is negative for all  $i$  and all  $j$ , then the SCC is lower when inequalities are high. If the cross derivative is sometimes positive and sometimes negative, then the effect of  $\gamma$  on  $\text{SCC}_E$  is indeterminate. Since [Proposition 1](#) tells us the sign of the cross derivative, it also tells us the direction of the effect of inequality  $\gamma$  on  $\text{SCC}_E$ , for all combinations of  $\eta$  and  $\theta$  such that  $\eta > -\theta$ .

In this section, we showed how the sign of the interaction effect between inequality and environmental loss depends on inequality aversion and substitutability. In the following section, we present the climate-economy model that we build to quantify this interaction effect.

### 3 Making NICE green

The prior section provides a general theoretical result and intuition for understanding how inequalities might interact with climate damages on non-market environmental goods. The

magnitude of this effect however depends on specifics such as the nature of climate damages on environmental services and the degree of consumption inequality. To investigate this effect quantitatively, we extend a country-level climate-economy model that captures national consumption inequality to integrate a flow of ecosystem services in the utility function. This model calculates the welfare impacts of global warming on both the economy and the environment, at a high level of resolution (consumption deciles within each country). We call this model GreenNICE.

The GreenNICE model is based on the latest version of the NICE model (Young-Brun et al. 2025). The NICE model includes 176 countries and 10 income deciles in each country. The damage function for country-level economic output is a quadratic function of local temperature anomalies calibrated to estimates from Kalkuhl and Wenz (2020). The climate module of NICE is the FaIR model (Leach et al. 2021). We set the emission abatement rate to obtain a temperature trajectory that is compatible with the 2°C target of the Paris agreement. Temperature starts at +1.17°C in 2020, and stabilizes slightly below +2° at the end of the model horizon in 2300 (see Figure A1).

### 3.1 Ecosystem services

GreenNICE departs from NICE by modifying the utility function to represent two partially-substitutable goods, namely market consumption  $c$  and ecosystem services  $E$  (Equation 2).

$E$  is calibrated to represent non-market goods from terrestrial ecosystems. This limited quantification ignores numerous other important ecosystem services that might be affected by climate change, for instance services from oceans and freshwater systems or air quality. However, the need for global, country-specific estimates of both ecosystem service flows and future climate impacts on those flows limits a more extensive calibration for the purposes of this paper.

Country-level ecosystem service flows are derived from the *Changing Wealth of Nations* database (CWON, World Bank 2024), which estimates the natural capital stock in forests based on three services: water services (freshwater provision, water purification, rainfall pattern regulation, soil erosion control, and flood regulation); non-wood forest products (wild animals, plants, and other non-aquatic biomass provisioning services from uncultivated ecosystems), and recreation, hunting and fishing (Siikamäki et al. 2024, Table 2.3). We recover annual ecosystem flows from the capital stock reported in CWON by reversing their capital valuation procedure, which uses a 100-year time frame and 4% discount rate (World Bank 2024, chapter 7, equation 6, p. 145).

The yearly per-capita flow of forest ecosystem services in country  $i$  with population  $L_{i,t}$  is:<sup>5</sup>

$$E_{i,t} = N_{i,t} \left( \frac{0.04}{1 - (1 + 0.04)^{-100}} \right) \cdot \frac{1}{L_{i,t}}. \quad (4)$$

Monetary units are converted to 2017 USD for consistency with the NICE model. Note that dividing by population effectively treats the ecosystem service flows as rival goods. This may be true for some goods, notably non-wood forest products, but will not hold for others, most significantly recreation. However, the CWON valuation process appears to implicitly account for the non-rival nature of some ecosystem services<sup>6</sup> meaning there is a risk of double counting if values are not normalized by population, as in Equation 4.

Figure A3 shows the initial per-capita flow  $E_{i,2020}$  of ecosystem services for each country. The highest baseline values for environment per capita (in USD per year) are New Zealand (\$690.8), Australia (\$604.27) and Bhutan (\$545.07). There is no clear correlation between the initial level of ecosystem services and the level of inequality in a country.<sup>7</sup>

Some countries are missing in the CWON database. For these countries, we set initial natural capital  $N$  to match the closest country with a similar forest cover in 2020, as reported by the World Bank. Island states with missing data are matched to other island states based on similarity in land area. We provide a detailed list of matched countries in Appendix E. Four small countries have zero initial environment (Kuwait, Macau, the Maldives, and Qatar). We exclude these four countries when calculating the social cost of carbon, because their marginal value of the environment ( $\partial_E W$ ) is infinite.

The natural capital stock is treated as static, except for the damages from climate change (described in the next section), abstracting from any other anthropogenic processes acting on terrestrial vegetation and from any natural dynamics of recovery or regeneration. The flow  $E$  is treated as sustainable in the sense that its consumption does not degrade the stock  $N$ . Ecosystem services are further assumed to flow equally to all income groups within a country.

### 3.2 Environmental damage function

The warming and rainfall changes induced by climate change are expected to drive a host of shifts in terrestrial vegetation and, by extension, the functions and services they provide to people. Most notably, climate change is expected to drive the replacement of tundra by forest

<sup>5</sup>See Appendix G for a detailed derivation.

<sup>6</sup>For instance, the meta-analysis used to generalize from individual measurements of ecosystem value includes local population density and urban area, which are statistically significant and positive predictors of value, likely partly capturing the non-rivalrous nature of some ecosystem benefits (Siikamäki et al. 2024, Section 4.1).

<sup>7</sup>See Figure A2 for a plot of each country's Gini index against its initial value of  $E$ .

at high-latitudes and an expansion of savanna at the expense of tropical forests near the equator (Bastien-Olvera et al. 2024). Here we adopt the country-specific linear damage functions from warming estimated in Bastien-Olvera et al. (2024). These are derived by combining shifts in terrestrial vegetation cover under climate change from three dynamic global vegetation models with a global meta-analysis of standardized ecosystem service valuations.

The damage function for the stock of the non-market environmental good in country  $i$  and year  $t$  is:

$$N_{i,t} = N_{i,2020}(1 + \xi_i \Delta T_t), \quad (5)$$

with  $\xi_i$  being the country-level damage parameter, and  $\Delta T_t$  the change in temperature between 2020 and year  $t$  (Bastien-Olvera et al. 2024, equation 14). The initial natural capital stock  $N_{i,2020}$  is expressed in 2017 USD. It is then converted back to a flow of services using Equation 4.

For countries without an initial damage coefficient, the parameter is assigned according to a hierarchical rule. Priority is given to existing assignments (see Appendix E); if none are available, we use the coefficient from the geographically closest country; for the remaining island states, we assign the damage coefficient of the Dominican Republic. We show how we impute these missing values in Appendix F.

Figure A4 shows the values of damage parameter  $\xi$  by country. Most countries have a negative coefficient, meaning climate change produces a net loss in ecosystem service flows. Countries with the largest relative loss with warming are Kuwait ( $\xi = -0.22$ ), Egypt ( $-0.18$ ), and Libya ( $-0.18$ ). 40 countries have a net gain in ecosystem services with climate change; countries with the largest positive coefficients are Yemen (0.19), Eritrea (0.13), and Oman (0.13).

### 3.3 Inequality and social welfare function parameters

We keep the same consumption-share-by-decile projections as Young-Brun et al. (2025). Young-Brun et al. assume that the income distribution follows a log-normal distribution, and estimate income shares until 2100 using Gini index projections from Rao et al. (2019). We also keep the default NICE value for the income elasticity of damages, which controls how climate damages to consumption are distributed across income groups. This value is set at 0.6 based on empirical estimates from Gilli et al. (2024).

Some parameters in the social welfare function are unobserved and therefore difficult to constrain empirically. Drupp (2018) shows how the substitutability parameter  $\theta$  can be recovered from the income elasticity of willingness-to-pay (WTP) for non-market goods. Drupp and Hänsel (2021) review studies that reported the income elasticity of WTP for environmental goods,

finding an implied average value for the elasticity of substitution  $\theta$  equal to 0.43, with estimates ranging from  $-0.42$  to  $0.9$  (Drupp and Hänsel 2021, table 2). We therefore set  $\theta = 0.43$  in our central calibration. When WTP estimates for health and cultural goods are included, the implied mean value declines to 0.23. To account for uncertainty in the degree of substitutability between consumption and environmental quality, we conduct a sensitivity analysis over values of  $\theta \in [-1, 1]$ . This range allows us to test Proposition 1 while remaining consistent with empirical evidence from the literature.<sup>8</sup>

Values for  $\eta$  in the literature span from 0 to 4, depending on the setting (Del Campo et al. 2024; Drupp et al. 2018). Most studies, however, adopt values between 1 and 2, in line with empirical evidence from progressive taxation studies (Del Campo et al. 2024). We set  $\eta = 1.5$ , which corresponds to the default value in NICE (Dennig et al. 2015) and has been included in previous integrated assessment models (see Del Campo et al. (2024) for a review). This value is also the best estimate reported by Groom and Maddison (2013), based on empirical evidence, and is close to the average expert opinion among economists and philosophers in recent surveys (Nesje et al. 2023; Drupp et al. 2018). In our sensitivity analysis, we consider values for  $\eta \in [0, 2]$ .

Our sensitivity analysis focuses on the joint variation of  $\theta$  and  $\eta$ , reflecting the uncertainty in both parameters. We define the *relevant parameter region* as the subset of this space that is most consistent with existing empirical evidence, given by  $\theta \in [-0.42, 0.9]$  and  $\eta \in [1, 2]$ .

The environmental share in utility,  $\alpha$ , is even more difficult to measure. Drupp and Hänsel (2021) report literature values ranging between 0.1 and 0.29. We set  $\alpha = 0.1$  in our central calibration as a conservative assumption. We set the rate of pure time preference ( $\rho$ ) to 0.1%, following the Stern report (2007). Because our theoretical findings depend on the interaction between  $\eta$  and  $\theta$ , we hold the share of environment and the rate of pure time preference fixed in the sensitivity analysis.

## 4 Quantifying the effect of inequalities on the social cost of climate damages to the environment

We quantify the effect of national income inequality on the environmental component of the SCC (i.e.,  $SCC_E$ ) by running simulations that systematically vary inequality while holding all other elements of the model constant. We introduce the parameter  $\gamma$  into the model,

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<sup>8</sup>When health and non-cultural goods are included, estimated values of  $\theta$  span a wider range, from  $-2.5$  to  $0.9$ . We exclude values below  $-1$  because the range  $\theta \in [-1, 1]$  is sufficient to characterize our theoretical results in Proposition 1.

which scales the income distribution between perfect equality ( $\gamma = 0$ ) and current levels of within-country inequality ( $\gamma = 1$ ), as described in [subsection 2.1](#).

The interaction effect  $I$  is defined as the difference between  $\text{SCC}_E$  with  $\gamma = 1$  and  $\gamma = 0$ :

$$I = \text{SCC}_{E|\gamma=1} - \text{SCC}_{E|\gamma=0}. \quad (6)$$

Interaction effect  $I$  is the social cost of damages to the environment due to the presence of within-country inequalities. We also define the relative interaction effect,  $I_{\%}$ , as the *share* of the social cost of damages to the environment that is due to the presence of within-country inequalities:

$$I_{\%} = \frac{\text{SCC}_{E|\gamma=1} - \text{SCC}_{E|\gamma=0}}{|\text{SCC}_{E|\gamma=1}|}. \quad (7)$$

For example, a relative interaction effect of  $I_{\%} = 50\%$  means that half of  $\text{SCC}_E$  is due to national inequality. We use the absolute value of the  $\text{SCC}_E$  in the denominator to preserve the sign of interaction  $I$ . The interaction effect can be negative for some values of  $\theta$  and  $\eta$  (see [Proposition 1](#)). It can also be negative for some countries, depending on the sign of their damage function parameter  $\xi$  (see [Figure A4](#)).

#### 4.1 The cost of intra-regional inequality in the social cost of damages to the environment

For our first simulations, we assume standard levels of inequality aversion ( $\eta = 1.5$ ) and substitutability ( $\theta = 0.43$ ). Under these parameters, [Proposition 1](#) implies that the cross derivative  $\partial_{E,\gamma}^2 W$  is positive. Hence, an increase in inequality should raise the cost of marginal damages to the environment. [Figure 2](#) shows how the 2025 social cost of carbon changes when within-country inequality increases, decomposed into damages to consumption ( $\text{SCC}_c$ ) and damages to the environment ( $\text{SCC}_E$ ).

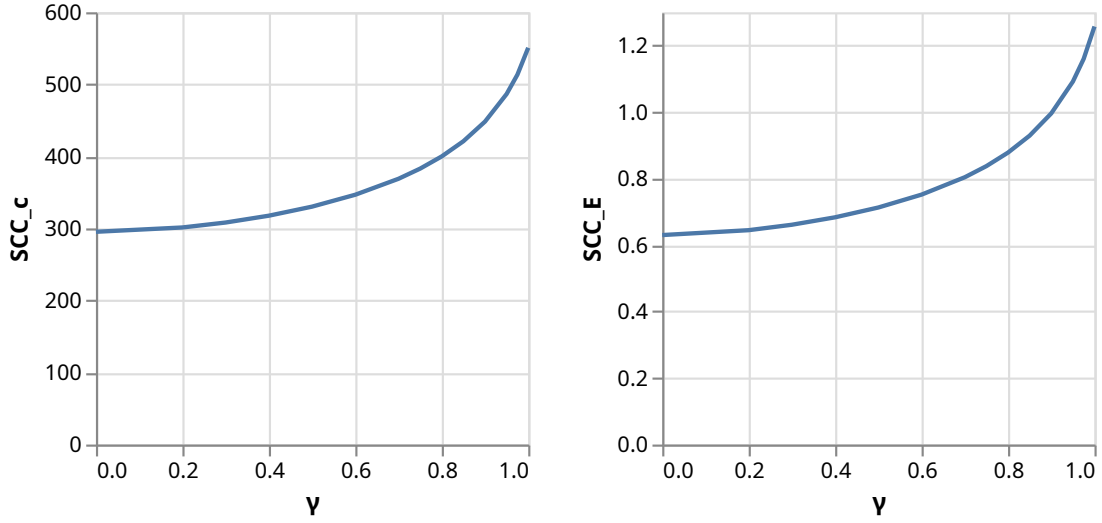


Figure 2: Social cost of carbon as a function of within-country inequality

Note: The left panel shows the social cost of damages to consumption caused by an additional ton of  $CO_2$ , in 2017 USD. The right panel shows the cost of damages to the environment. When  $\gamma = 0$ , there is no within-country inequality. When  $\gamma = 1$ , income inequalities are fully implemented, based on the NICE2020 model.

With full national inequality, the total social cost of carbon is 552.01\$/tCO<sub>2</sub>. This result is comparable to Anthoff and Emmerling (2019), who find a social cost of carbon of \$765.4 in the RICE model after accounting for intra-regional inequality. As predicted,  $SCC_E$  is an increasing function of  $\gamma$  at these parameter values. Damages to the environment amount to 0.63\$/tCO<sub>2</sub> when  $\gamma = 0$ . The presence of national inequality doubles this cost to \$1.26 ( $I = 0.63$ ). In other words, half of  $SCC_E$  is due to national inequality. Overall, under this calibration, damages to the environment represent a modest share of the total social cost of carbon, but double in the presence of national inequality. Appendix B gives a country-level breakdown, showing largest interaction effects in populous countries with high income inequality (notably India, South Africa and Zambia).

## 4.2 Effect of inequality aversion and complementarity

In section 2 we show that the effect of inequality on the marginal value of the environment can be positive or negative, depending on the values of inequality aversion  $\eta$  and substitutability between market and environmental goods  $\theta$ . Figure 3 shows the share of the global  $SCC_E$  due to intra-regional income inequality (i.e.  $I_{\%}$ ) for a wide range of alternate parameter values. The star shows the central parameter estimates ( $\eta = 1.5$  and  $\theta = 0.43$ ), and the dotted box shows the *relevant parameter region* discussed in subsection 3.3.

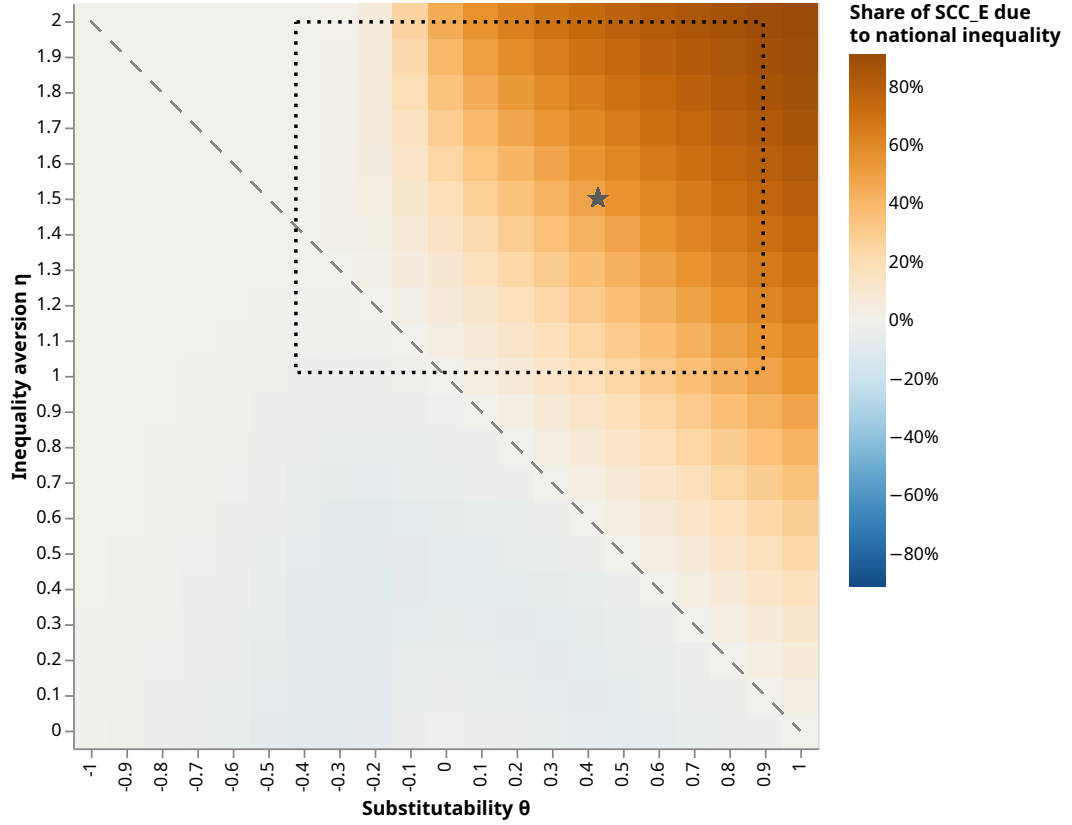


Figure 3: Share of  $SCC_E$  attributable to within-country inequality ( $\Delta SCC_E / SCC_E$ ) across  $\theta$  and  $\eta$ .

Note: The dotted box indicates the empirically relevant parameter region; the dashed diagonal line marks where the effect changes sign.

The relative interaction effect of intra-regional inequality on  $SCC_E$  is highly sensitive to  $\theta$ . While national inequality doubles the social cost of environmental damages in the central scenario, it has little to no effect at lower levels of substitutability ( $\theta = -1$ ). Under high levels of substitutability ( $\theta = 0.9$ ), inequality aversion plays an important role in determining the relative interaction effect. It ranges from zero (when inequality aversion is zero) to 91.15% of the  $SCC_E$ . Under high substitutability, people are relatively indifferent between consuming manufactured and non-market environmental goods; income disparities play a larger role in determining the interaction effect's relative cost.

Under mid-range values of substitutability and low inequality aversion, we find a region with a negative  $I_{\%}$  (coloured blue in Figure 3). In this region, inequality increases the marginal value of the environment, reaching a relative interaction effect of  $-9.86\%$ . This finding is consistent with Proposition 1 and highlights that the interaction between inequality and environmental loss is theoretically ambiguous.

However, for more realistic values of the two key parameters (illustrated by the dotted box in

Figure 3), the relative interaction effect is only negative for extremely low values of  $\eta$  and  $\theta$ . At its minimum, the relative interaction effect in this region is  $-3.27\%$ , a figure close to zero. In the rest of the parameter space, the relative interaction effect is positive and increases sharply with  $\eta$  and  $\theta$ , reaching up to  $89.12\%$ . This pattern shows that the interaction effect between inequality and ecological decline is substantial. It is negligible only in a narrow, low-parameter region. Ignoring the interaction effect would therefore tend to understate  $SCC_E$  by a wide margin and may ultimately lead to a lower overall SCC.

Figure A5 gives the interaction effect in net, rather than relative terms. It shows regions of the parameter space where  $I$  is high, reaching above \$250 per ton of  $CO_2$  for low ( $< 0$ ) values of  $\theta$  and high ( $> 1.8$ ) values of  $\eta$ . The absolute interaction effect increases sharply in the top-left corner of the *relevant parameter region*, as  $\theta$  drops below 0. This is because the total  $SCC_E$  becomes extremely large in this region (\$140,000 per ton for  $\eta = 2$  and  $\theta = -0.4$ ). This is due to the scarceness of the environmental good and its high complementarity with market consumption.

Overall, inequality aversion  $\eta$  and substitutability  $\theta$  are a critical pair of parameters. They substantially alter the relative social cost of environmental damage. Under specific configurations, the interaction between inequality aversion and substitutability reverses the effect of national inequality.

Sensitivity to substitutability  $\theta$  can partly be explained by the fact that the World Bank’s valuation of ecosystem services is small relative to GDP. When environmental goods are rare yet highly substitutable, damages are limited because lost ecosystem services can be readily replaced by human-made alternatives. By contrast, when environmental goods are difficult to replace, even a small loss of ecosystem services translates into large welfare losses. In the following subsection, we show that while the  $SCC_E$  increases with larger values of  $E$ , the relative interaction effect remains relatively constant.

### 4.3 Sensitivity to the level of environment

The CWON data we use in our main simulation scenario only includes non-wood products, water services, and recreation services provided by forests: a fraction of the ecosystem services that should ideally be included. Some wood products are used as biofuels or for construction and fall within the scope of non-market ecosystem services. Medicinal, biochemical, and genetic resources provided by forests are also absent from this data. Moreover, other biomes also provide non-market ecosystem services. By focusing on forests, we only account for a small share of nature’s contribution to people.

The CWON database values the global flow of non-market forest services at 256 billion USD per year. This represents a 13.3% of the total annual flow of renewable natural capital reported in that database (1,923.7 billion USD). By contrast, Costanza et al. (2014) estimate the value of all ecosystem services at approximately 147,500 billion USD per year — 577 times higher than CWON’s value for non-market forest services and 77.68 times larger than the total annual flow of renewable natural capital. The difference between CWON’s numbers and Costanza et al. (2014) estimates is partly explained by differences in scope, as Costanza et al. include all terrestrial and marine ecosystems, most types of ecosystem services, and some market goods provided by ecosystems.<sup>9</sup> Even after restricting Costanza et al. estimates to water, food, and recreation services provided by forests to approximate the scope of the CWON data, the estimate remains at 6,900 billion USD per year. This number is still 27 times higher than the World Bank’s estimate of the value of non-market environmental goods. Taken together, these differences suggest that the empirical magnitude of non-market environmental goods is uncertain. We perform a sensitivity analysis to dimension the impact of this uncertainty on our estimates.

As a sensitivity exercise, we multiply the baseline level of ecosystem services  $E$  by factors ranging from 1 to 577, using Costanza et al. (2014) as an upper-bound benchmark. In Figure 4, we show how sensitive to  $E$  the  $SCC_E$  is. Inequality aversion and substitutability are set to their central values ( $\eta = 1.5$  and  $\theta = 0.43$ ).

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<sup>9</sup>While the authors note that a certain share of their estimates comes from goods that are traded on markets, they argue that “much of it is not captured in GDP because it is embedded in services that are not marketed or not fully captured in marketed products and services”. They do not report the share of market versus non-market ecosystem services precisely.

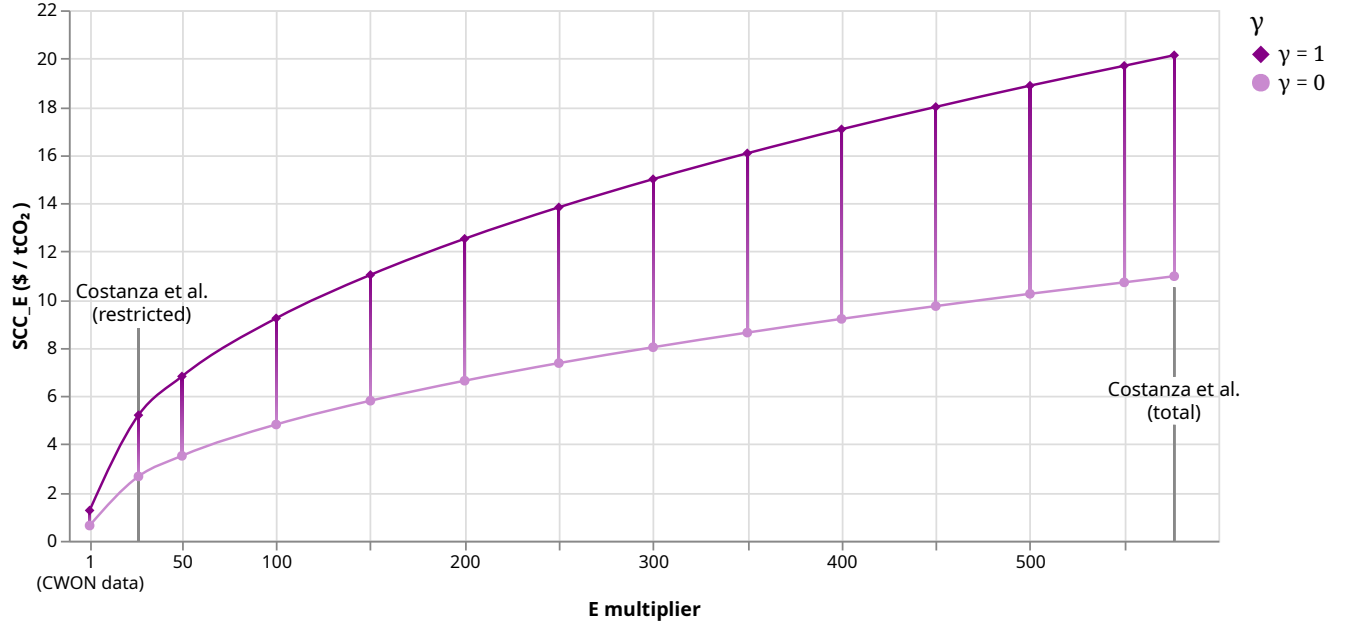


Figure 4: Sensitivity of  $SCC_E$  to baseline environment  $E$

Note: This figure shows the evolution of  $SCC_E$  as the initial global flow of ecosystem services is multiplied by up to 577, in the presence ( $\gamma = 1$ ) or absence ( $\gamma = 0$ ) of intra-regional inequalities, the source of inequality with the largest relative interaction effect. An  $E$  multiplier of 1 corresponds to the baseline CWON data. Multiplying  $E$  by 27 brings it to the estimate of Costanza et al. (2014) restricted to recreation, food, and water services provided by forests. The maximal factor of 577 matches the estimate of Costanza et al. for all services of all ecosystems. The interaction effect  $I$  is represented by the vertical lines between the two curves.

There are two opposing effects at play here. On the one hand, ecosystem services have diminishing marginal utility. On the other hand, more environment also means more environment to lose. As  $E$  increases, damages to  $E$  increase proportionally, but their social cost increases less than proportionally, because of diminishing marginal utility. The result is the concave increasing function shown on Figure 4.

When the level of environment is multiplied by 577 compared to the baseline scenario,  $SCC_E$  grows from \$1.26 to \$20.13 per ton (dark purple line), a factor of just 16. Across all considered calibrations of  $E$ , the presence of national inequalities (the highest relative interaction effect) approximately doubles the social cost of damages to the environment. In the baseline scenario,  $SCC_E$  is 2 times higher when  $\gamma = 1$  (\$1.26) than when  $\gamma = 0$  (\$0.63). With values of  $E$  matching Costanza et al.'s total estimate,  $SCC_E$  is 1.83 times higher when  $\gamma = 1$  (\$20.13) than when  $\gamma = 0$  (\$10.97). In other words, the absolute interaction effect  $I$  for intra-regional inequality goes from \$0.63 to \$9.16, while the relative interaction slightly declines from 49.89% to 45.52%. We provide a plot of the evolution  $I_{\%}$  with respect to  $E$  in Figure A6.

Our main calibration only includes a fraction of ecosystem services. However, the relative effect of intra-regional inequality on  $SCC_E$  stays quite consistent. This relative interaction effect

only decreases slightly for much higher values of  $E$ . Additionally, we can say more confidently that, for  $\eta = 1.5$  and  $\theta = 0.43$ , the presence of national inequalities approximately doubles the social cost of damages to the environment.

#### 4.4 The importance of environmental and cross-country inequalities

Our quantification of the interaction effect described so far is designed to isolate the effect of within-country consumption inequality on the ecological costs of climate change. However, there are other dimensions of inequality relevant to understanding climate damages. Specifically, international consumption inequality and unequal endowments of  $E$  also influence the  $SCC_E$ . To isolate the effects of these forms of inequality, we decompose  $SCC_E$  into four nested counterfactual scenarios that progressively incorporate different sources of inequality. For each counterfactual, we hold the model's baseline parameterization fixed and recompute the implied  $SCC_E$  under the corresponding distributional assumption. This allows us to isolate the interaction effect and attribute differences in  $SCC_E$  solely to distributional changes. We show the result from this analysis in Figure 5.

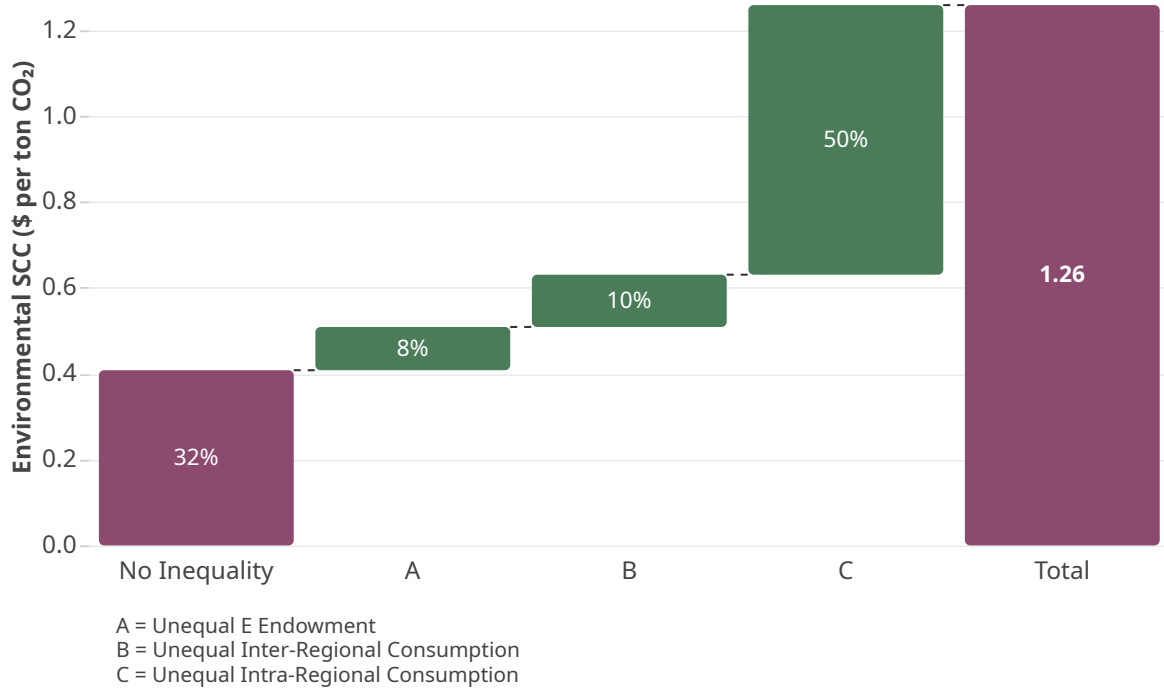


Figure 5: Decomposition of the cost of inequalities in the  $SCC_E$

Note: Each column shows the interaction effect between one source of inequality and ecological decline. *Total* represents the  $SCC_E$  under central calibration ( $\eta = 1.5$  and  $\theta = 0.43$ ).

We first compute  $SCC_E$  under a no-inequality scenario, where everyone in every country gets the same environment  $E$  and consumption  $c$ . In the second counterfactual scenario (column A),

we introduce the observed  $E$  distribution, while maintaining equal consumption both within and between countries. We then introduce international inequalities (column B), while keeping consumption equal to the national average for everyone in each country ( $\gamma = 0$ ). The fourth counterfactual scenario (column C) corresponds to the benchmark  $SCC_E$  that includes national inequalities ( $\gamma = 1$ ).

In the absence of inequalities, the  $SCC_E$  is \$0.41 per ton of  $CO_2$ . This corresponds to 32% of the total. The introduction of the observed unequal distribution of  $E$  endowments raises the  $SCC_E$  by \$0.1 per ton of  $CO_2$  or 8% of the total. The addition of inter-regional inequalities increases the  $SCC_E$  by a similar amount (\$0.12 per ton of  $CO_2$ ). The remaining 50% of the  $SCC_E$  is attributable to within-country consumption inequality, which is \$0.63 per ton of  $CO_2$ .

Despite large average differences in consumption and environmental endowments across countries, within-country inequality is by far the largest driver of a higher  $SCC_E$ . In [Figure A6](#), we show that the relative interaction effect for the three different sources of inequality is quite insensitive to the magnitude of  $E$ . The relative interaction effect of the initial  $E$  endowment exhibits a slight increase, while the relative interaction effect from international inequalities remains virtually constant. The share cost of national inequalities decreases slightly, from 50% to 46%.

## 5 Discussion and conclusion

Climate change, ecological decline and rising inequality are all major drivers of change that will shape the evolution of global welfare over the 21st century. Although often studied independently, they are in fact closely inter-related. Climate change affects natural systems, which in turn have implications for climate change via the carbon cycle. Both are environmental problems driven by similar issues around the governance of common-pool resources and environmental externalities. Both problems also interact with income inequality because of the non-linear relationship between consumption and welfare, and how the environment could either substitute for or complement consumption of market goods.

In this paper we elucidate this three-way interaction, showing both theoretically and in a detailed quantitative model how the marginal costs of climate change damages to the environment depend on income inequality. We show that in theory this interaction effect could be either positive or negative depending on the curvature of the utility function (i.e.  $\eta$ , the inequality aversion parameter) and the substitutability of environmental and market goods (i.e.  $\theta$ ).  $\eta$  is a central parameter in climate economics because of its role in Ramsey discounting where it captures inter-*temporal* inequality in consumption. Past work on climate change's ecological

costs has also emphasized the central importance of substitutability (Tol 1994; Hoel and Sterner 2007; Sterner and Persson 2008; Drupp and Hänsel 2021; Bastien-Olvera and Moore 2021). Here we show how the presence of income inequality together with an imperfectly-substitutable environmental good produces complex interaction effects between these two key parameters in the quantification of climate change costs.

We quantitatively constrain these theoretical findings by integrating country-level ecosystem service flows and marginal climate damages estimates into a recent integrated assessment model that captures both between and within-country income inequality. Though the theoretical effect could go in either direction, we find that reasonable parameter values for  $\eta$  and  $\theta$  almost certainly produce a positive interaction effect, in which the presence of income inequality raises climate change’s ecological cost. In a  $+2^{\circ}\text{C}$  scenario, it accounts for roughly 50% of the social cost of damages to the environment. International inequalities and the initial distribution of non-market environmental goods account for 9.7% and 7.9% of the costs, respectively. In a decomposition exercise, we show that *within country* inequality in consumption, rather than cross-national inequality, is most significant.

Our findings have several limitations that should be kept in mind when interpreting them.

First, there is evidence that consumption inequality might be higher than in our calibration. The projections our model is based on assume that income distribution follows a log-normal distribution across deciles.<sup>10</sup> However, Narayan et al. (2023) show that, under a non-parametric distribution assumption, levels of inequality across different emissions scenarios are consistently higher. Using their projections would yield a higher interaction effect between inequality and ecosystem services.

Furthermore, our model simplifies how people benefit from natural capital. Our main calibration only considers benefits provided by forests, and assumes they are evenly distributed across income groups. Future work can make our central calibration more accurate by considering additional non-market goods supplied by other forms of natural capital, such as oceans and coastal systems (Bastien-Olvera et al. 2026). Moving away from the equal distribution of environmental goods within countries might also better reflect the heterogeneous nature of ecosystem services and how access may co-vary in complex ways with income.

GreenNICE also limits the pathways by which environmental change can affect well-being to the direct consumption of ecosystem goods  $E$ . Some prior work has also considered how ecosystems interact with capital and labor in the production of both market and environmental goods, and the non-use value of the environment (Bastien-Olvera and Moore 2021; Bastien-Olvera et al.

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<sup>10</sup>See subsection 3.3 for a brief explanation

2024). Recent work has estimated the non-use costs of climate-change-induced biodiversity decline and could be used as basis for future expansion (Wingenroth et al. 2024). Unlike DICE, the NICE model does not capture capital dynamics, making integrating the environment into production challenging.

Finally, this paper abstracts away from the dynamics of environmental change other than climate change. Land-use change can decrease forest cover, substituting it for agricultural or urban land uses (Johnson et al. 2021), while afforestation policies can increase the area covered by forests and other forms of natural capital (Mirzabaev and Wuepper 2023). Natural systems also exhibit internal dynamics of reproduction, recovery or decline that are not captured here. Actors may choose to invest resources in restoration or adaptation to mitigate the adverse effects of climate change in ways outside the scope of our modeling.

Our results are very sensitive to inequality aversion and substitutability between manufactured and non-market environmental goods. In our central calibration, the relative interaction effect for national inequality is 50% per additional ton of CO<sub>2</sub>. This result ranges from −9.86% to 91.15% depending on the inequality aversion and substitutability parameters. Altogether, our results show that the interaction effect between inequality and the environment can vary substantially in magnitude and even change direction depending on two critical parameters. This points to the value of further improving empirical constraints on these two parameters critical for the evaluation of climate policy.

## Data availability

All code used for this paper is available on GitHub at [rturquier/GreenNICE](https://github.com/rturquier/GreenNICE).

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## A Supplementary figures

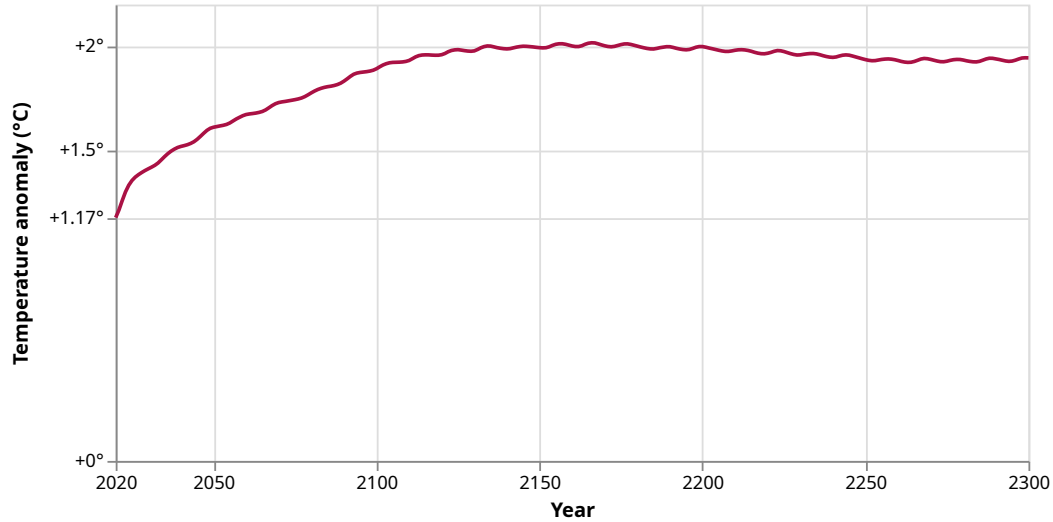


Figure A1: Default temperature trajectory

Note: temperature anomaly is expressed relative to pre-industrial times. The exogenous abatement rate is set such that temperature stabilizes below the 2°C target of the Paris agreement in the long run. There is a slight overshoot in the middle of the twenty-second century. The subsequent cooling is caused by some of the greenhouse gases dissipating from the atmosphere.

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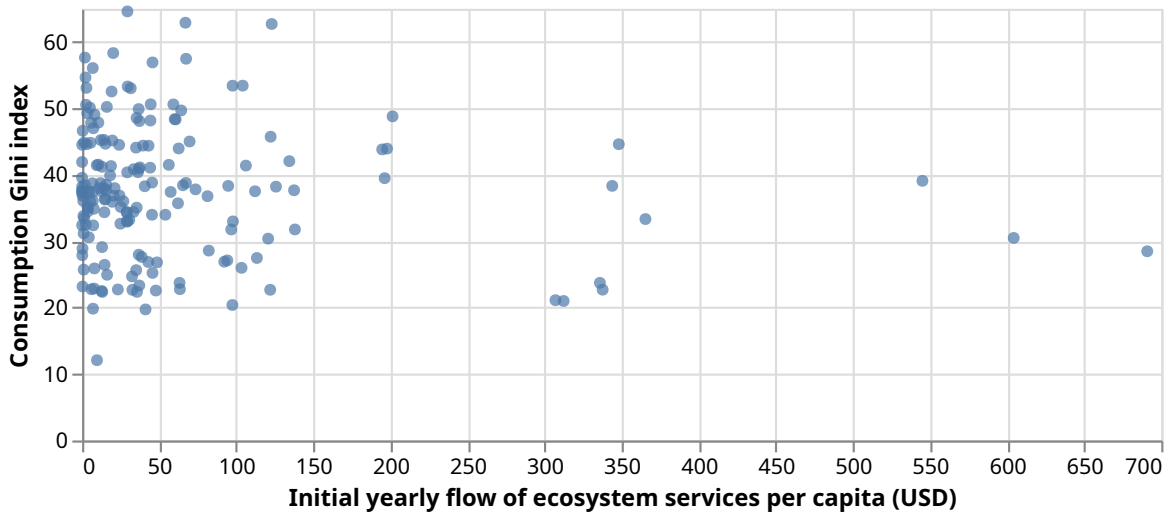


Figure A2: Consumption gini index vs value of ecosystem services per capita in 2020

Note: Each dot represents a country. A larger Gini index indicates higher inequality. The countries with the highest consumption Gini index are South Africa, Namibia, and Botswana. The countries with the lowest consumption Gini index are Azerbaijan, Denmark, and Ukraine.

Finding the lowest consumption inequality in Azerbaijan is unexpected. Ersado (2006) argues that this figure is due to how data are collected in the country, pointing out that inequality should be higher. We keep this country in our sample to be consistent with previous research and because it is an observation that does not bias our aggregate results.

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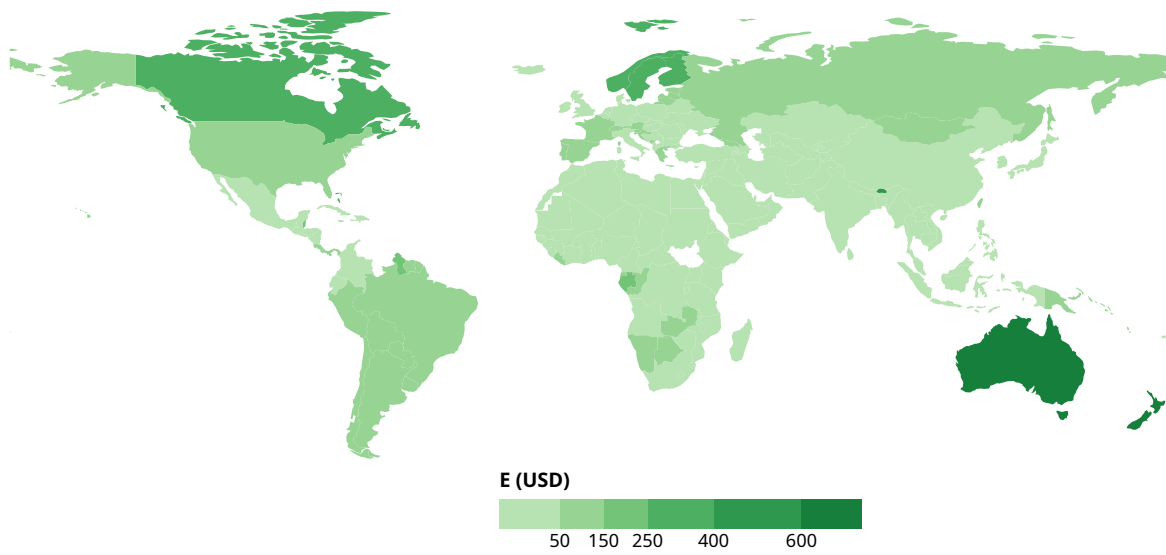


Figure A3: Flow of ecosystem services per capita in 2020 by country (USD)

Note: Darker green represents a higher initial flow of natural capital in dollars. The highest natural capital flow per capita is found in New Zealand.

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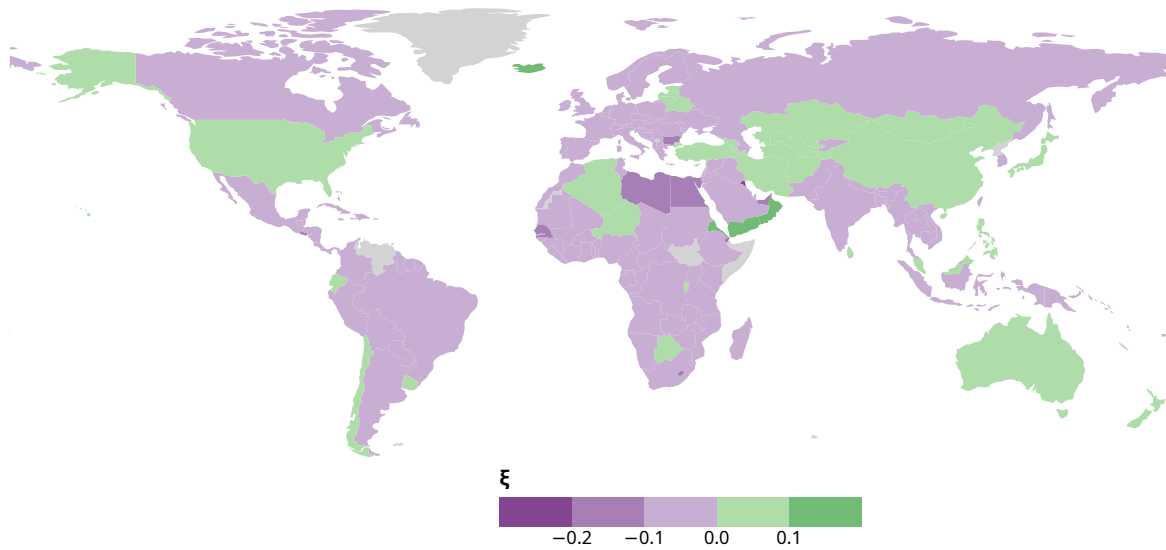


Figure A4: Spatial distribution of environmental damage coefficient  $\xi$

Note: Purple represents a negative coefficient, resulting in natural capital loss due to climate change. Dark purple represents larger damage. The green color indicates a positive value of  $\xi$ . This implies an increment in natural capital. Darker green represents larger increments.

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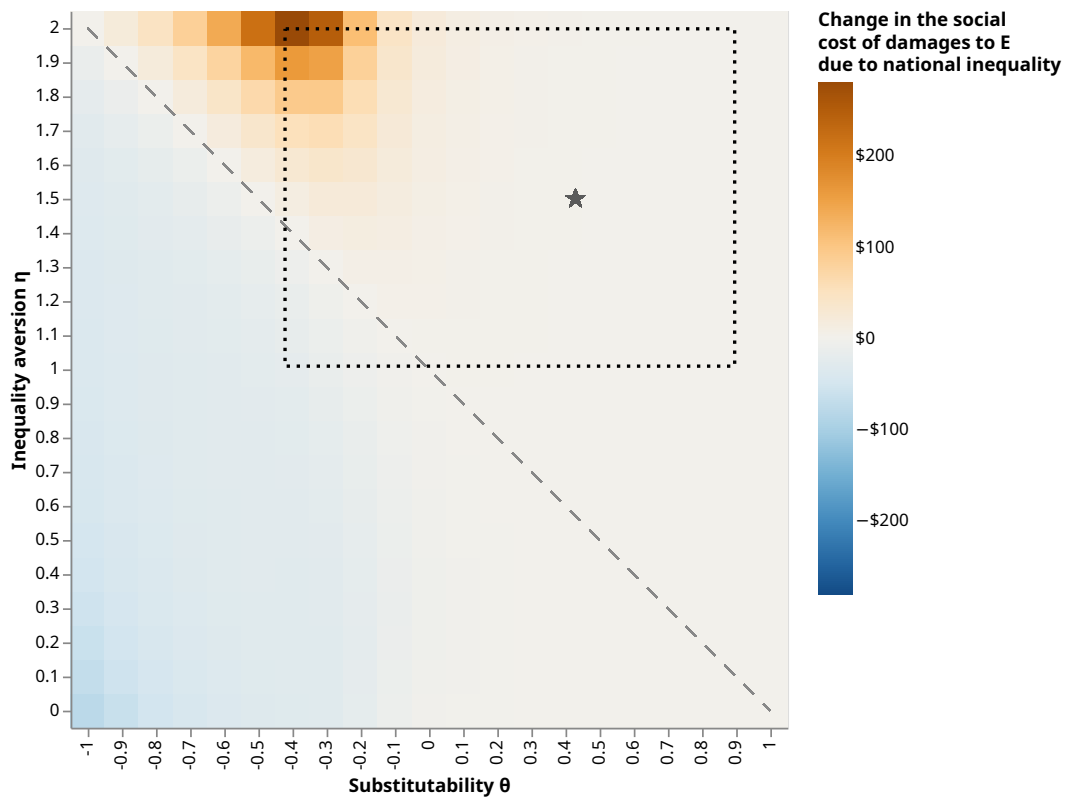


Figure A5: Interaction effect ( $I$ ) between inequality and damages to the environment ( $E$ ) (\$ per ton of  $\text{CO}_2$ )

Note: Star shows central calibration ( $\eta = 1.5$  and  $\theta = 0.43$ ). Values for the interaction effect range from  $-80.51$  to  $280.44$  USD.

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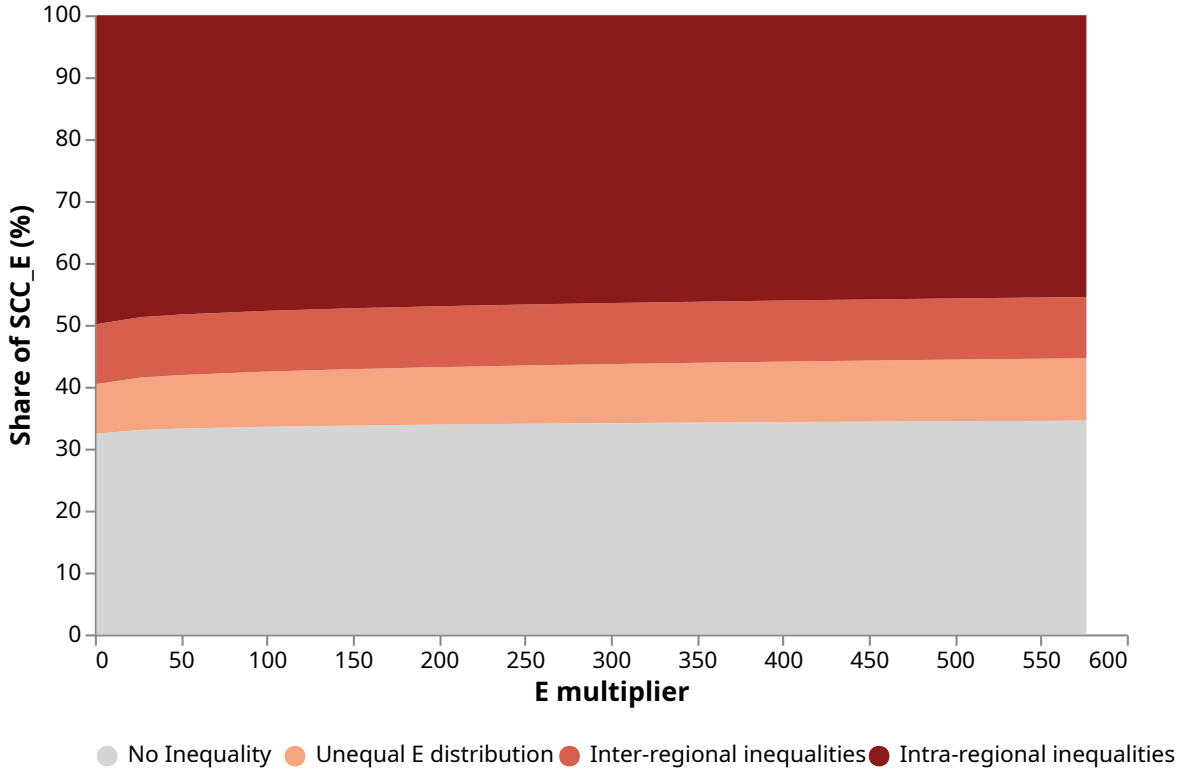


Figure A6: Sensitivity of the relative interaction effect  $I\%$  (in %) to the initial flow non-market environmental good, by source of inequality

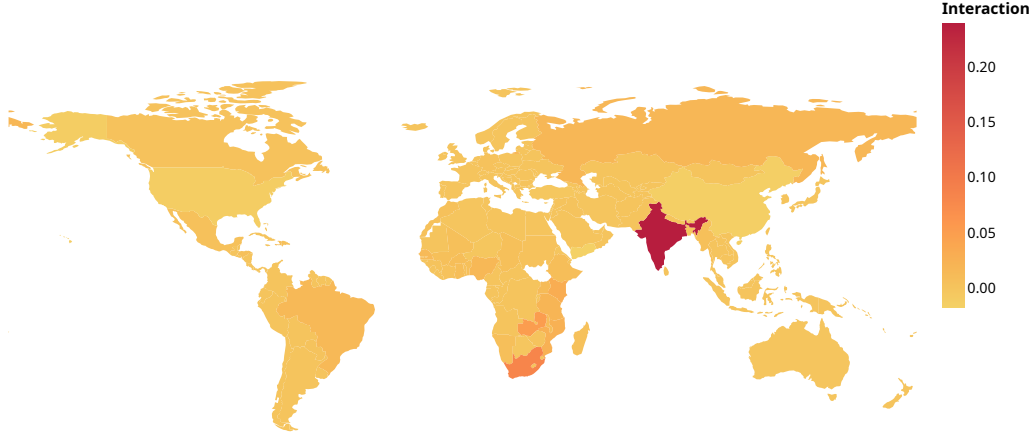
Note: Each color represents how the relative interaction effect varies as the initial global flow of ecosystem services is multiplied by up to 577. Results for central calibration ( $\eta = 1.5$  and  $\theta = 0.43$ ).

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## B Interaction effect between ecological decline and inequality across countries

We show a decomposition of  $I$  and  $I\%$  by country in [Figure A7](#). The interaction effect  $I$  ranges from \$0.24 to  $-\$0.02$ . The maximum cost increase is borne by India (\$0.24), followed by South Africa (\$0.12) and Zambia (\$0.08). These are populous countries with high income inequality and negative climate change impacts on natural capital ([Figure A4](#)). The lowest interaction effect is observed in Yemen ( $-\$0.02$ ), the USA ( $-\$0.01$ ) and China ( $-\$0.01$ ). The relative interaction effect  $I\%$  is highest in South Africa (77.34%), Namibia (74.36%), and the Dominican Republic (68.24%). The countries whose benefits increase most (negative  $SCC_E$ ) in relative terms are: Botswana ( $I\% = -74.27\%$ ), Rwanda ( $I\% = -58.48\%$ ), and Belarus ( $I\% = -57.03\%$ ).

Panel A. Interaction effect ( $I$ )



Panel B. Relative interaction effect ( $I_{\%}$ )

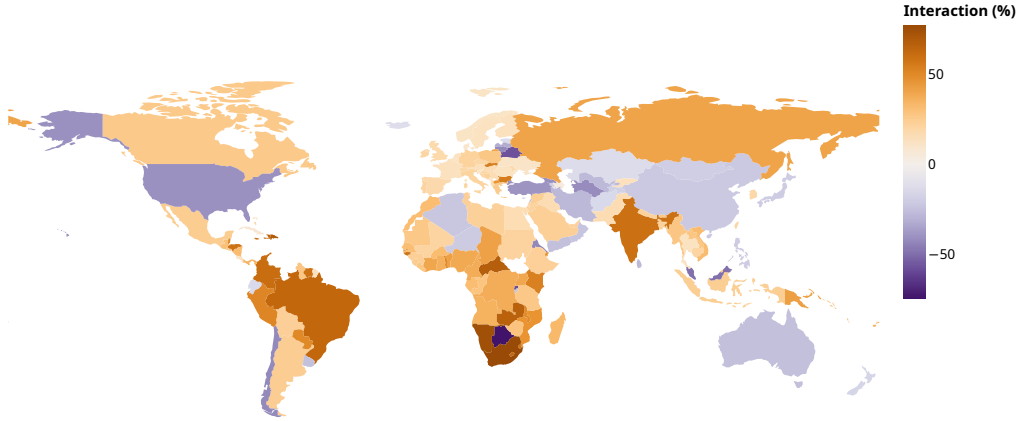


Figure A7: Interaction effects by country

Note: Panel A reports the interaction effect in USD per ton of CO<sub>2</sub> equivalent. Dark red represents a higher interaction effect. Yellow represents welfare gains from the interaction effect. This is the case when  $E$  increases with climate change. Panel B reports the interaction effect as a percentage of total environmental damages. Darker orange indicates a larger share of the interaction effect relative to total environmental damages. Darker purple represents the highest negative value, representing the share of the interaction effect with respect to welfare gains from the environment.

A negative  $I$  and  $I_{\%}$  imply that national inequalities reduce the social cost of damages to the environment. At our central calibration ( $\eta = 1.5$  and  $\theta = 0.43$ ), where inequality increases the marginal value of the environment, this arises from positive marginal effects of climate change on natural capital (compare with Figure A4). Despite cross-country heterogeneity, damages exceed benefits at the global scale. Thus, the global interaction effect is positive: within-country inequality increases the social cost of environmental damage.

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## C Relationship between the inequality coefficient and the standard deviation of national consumption

In country  $i$ , the variance of consumption is:

$$\begin{aligned}
\sigma_i^2 &= \frac{1}{n} \sum_{j=1}^n [c_i - c_{i,j}]^2 \\
&= \frac{1}{n} \sum_{j=1}^n [c_i - (1 + \delta_{i,j}\gamma)c_i]^2 \\
&= \frac{1}{n} \sum_{j=1}^n [c_i - c_i - \delta_{i,j}\gamma c_i]^2 \\
&= \frac{1}{n} \sum_{j=1}^n [\delta_{i,j} \cdot \gamma c_i]^2 \\
&= \frac{1}{n} \sum_{j=1}^n \left[ \frac{\hat{c}_{i,j} - c_i}{c_i} \cdot \gamma c_i \right]^2 \\
&= \frac{1}{n} \sum_{j=1}^n [(\hat{c}_{i,j} - c_i)\gamma]^2 \\
\sigma_i^2 &= \gamma^2 \frac{1}{n} \sum_{j=1}^n (c_i - \hat{c}_{i,j})^2.
\end{aligned}$$

So:

$$\begin{aligned}
\sigma_i &= \gamma \times \sqrt{\frac{1}{n} \sum_{j=1}^n (c_i - \hat{c}_{i,j})^2} \\
&= \gamma \times \hat{\sigma}_i.
\end{aligned}$$

The standard deviation  $\sigma_i$  of country  $i$ 's consumption distribution is the actual observed standard deviation  $\hat{\sigma}_i = \sqrt{\frac{1}{n} \sum_{j=1}^n (c_i - \hat{c}_{i,j})^2}$ , multiplied by  $\gamma$ .

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## D Proof of proposition 1

### Definitions

We consider  $n \geq 2$  consumption quantiles of equal size, with consumption levels  $c_1 < c_2 < \dots < c_n$ . Average consumption is  $\bar{c}$ . The consumption of each group  $j \in \{1, \dots, n\}$  is defined as:

$$c_j = \bar{c}(1 + \delta_j \gamma),$$

with  $\delta_j \in \mathbb{R}$  and  $\gamma > 0$  such that every  $c_j$  is positive. For simplicity, we assume that all quantiles have the same level of environment  $E$ . We define function  $v$  as the constant elasticity of substitution function that goes into the utility function:

$$v : c, E \mapsto \left[ (1 - \alpha)c^\theta + \alpha E^\theta \right]^{1/\theta}.$$

Utility  $u$  and welfare  $W$  are defined as:

$$u : (c, E) \mapsto \frac{v(c, E)^{1-\eta}}{1-\eta},$$

$$W : (\bar{c}, E) \mapsto \sum_{j=1}^n u(c_j, E).$$

### Expression of the cross derivative

Let us start by writing the cross derivative of welfare with respect to  $c$  and  $E$ . For that, we will need the first derivatives of functions  $v$ .

$$\begin{aligned} \forall c, E > 0, \quad \partial_c v(c, E) &= (1 - \alpha)\theta c^{\theta-1} \cdot \frac{1}{\theta} [(1 - \alpha)c^\theta + \alpha E^\theta]^{(1-\theta)/\theta} \\ &= (1 - \alpha)c^{\theta-1} \cdot v(c, E)^{1-\theta}. \end{aligned}$$

Likewise:

$$\begin{aligned} \forall c, E > 0, \quad \partial_E v(c, E) &= \alpha\theta E^{\theta-1} \cdot \frac{1}{\theta} [(1 - \alpha)c^\theta + \alpha E^\theta]^{(1-\theta)/\theta} \\ &= \alpha E^{\theta-1} \cdot v(c, E)^{1-\theta}. \end{aligned}$$

We can now differentiate  $u$ , first with respect to  $c$ :

$$\begin{aligned}\partial_c u(c, E) &= \frac{1}{1-\eta} \cdot (1-\eta)v(c, E)^{1-\eta-1} \cdot \partial_c v(c, E) \\ &= v(c, E)^{-\eta} \cdot (1-\alpha)c^{\theta-1}v(c, E)^{1-\theta} \\ &= (1-\alpha)c^{\theta-1} \cdot v(c, E)^{1-\eta-\theta}.\end{aligned}$$

And then with respect to  $E$ :

$$\begin{aligned}\partial_{c,E}^2 u(c, E) &= (1-\alpha)c^{\theta-1} \cdot (1-\eta-\theta)v(c, E)^{1-\eta-\theta-1} \cdot \partial_E v(c, E) \\ &= (1-\alpha)c^{\theta-1} \cdot (1-\eta-\theta)v(c, E)^{-\eta-\theta} \cdot \alpha E^{\theta-1}v(c, E)^{1-\theta} \\ &= \alpha(1-\alpha)c^{\theta-1}E^{\theta-1} \cdot (1-\eta-\theta)v(c, E)^{1-\eta-2\theta}.\end{aligned}$$

Excluding edge cases, all factors are always positive, except for  $1-\eta-\theta$ . So, the sign of  $\partial_{c,E}^2 u(c, E)$  is the sign of  $1-\eta-\theta$ .

The cross derivative of welfare with respect to  $E$  and inequality coefficient  $\gamma$  can now be expressed as a function of  $\partial_{c,E}^2 u(c, E)$ .

$$\begin{aligned}\partial_E W(\bar{c}, E) &= \sum_{j=1}^n \partial_E u(c_j, E) \\ \partial_{E,\gamma}^2 W(\bar{c}, E) &= \sum_{j=1}^n \partial_\gamma c_j \cdot \partial_{c,E}^2 u(c_j, E).\end{aligned}\tag{8}$$

Now, remember that for any quantile  $j$ , consumption  $c_j$  is defined as a functions  $\gamma$  and average consumption  $\bar{c}$ :

$$\begin{aligned}\forall \bar{c} > 0, \quad c_j &= \bar{c} (1 + \delta_j \gamma) \\ c_j &= \bar{c} + \bar{c} \delta_j \gamma.\end{aligned}$$

Its derivative with respect to  $\gamma$  is therefore:

$$\partial_\gamma c_j = \bar{c} \delta_j.$$

Replacing the expressions for  $\partial_\gamma c_j$  and  $\partial_{c,E}^2 u(c_j, E)$  in Equation 8, we get:

$$\begin{aligned}\partial_{E,\gamma}^2 W(\bar{c}, E) &= \sum_{j=1}^n \bar{c} \delta_j \cdot \alpha(1-\alpha) c_j^{\theta-1} E^{\theta-1} (1-\eta-\theta) v(c_j, E)^{1-\eta-2\theta} \\ &= \bar{c} \alpha(1-\alpha) E^{\theta-1} (1-\eta-\theta) \sum_{j=1}^n \delta_j c_j^{\theta-1} v(c_j, E)^{1-\eta-2\theta}.\end{aligned}\tag{9}$$

### Sign of the cross derivative in different cases

Now that we have an expression for the cross derivative, we can study its sign. We can start by noticing that the first four factors,  $\bar{c} \alpha(1-\alpha) E^{\theta-1}$ , are all positive. And  $1-\theta-\eta$  is positive if, and only if  $\eta < 1-\theta$ .

Now, the sign of the expression in the sum is not obvious. To study it, let us define function  $f$  as:

$$f : c \mapsto c^{\theta-1} v(c, E)^{1-\eta-2\theta}.$$

The sum in Equation 9 can now be written as:

$$\sum_{j=1}^n \delta_j f(c_j).\tag{10}$$

We will now rewrite this sum in a form that shows that its sign depends on whether  $f$  is increasing or decreasing. First, by definition,  $\bar{c}$  is the average consumption. This implies that the sum of coefficients  $\delta_j$  must be equal to zero:

$$\begin{aligned}\bar{c} &= \frac{1}{n} \sum_{j=1}^n c_j \\ \bar{c} &= \frac{1}{n} \sum_{j=1}^n \bar{c} (1 + \delta_j \gamma) \\ 1 &= \frac{1}{n} \sum_{j=1}^n (1 + \delta_j \gamma) \\ 1 &= \frac{1}{n} \cdot n + \frac{1}{n} \sum_{j=1}^n \delta_j \gamma\end{aligned}$$

$$\begin{aligned}
1 &= 1 + \frac{1}{n} \sum_{j=1}^n \delta_j \gamma \\
0 &= \frac{1}{n} \gamma \sum_{j=1}^n \delta_j \\
0 &= \sum_{j=1}^n \delta_j
\end{aligned}$$

We now define  $\Delta_k$  as the sum of all  $\delta_j$  for  $j \leq k$ :

$$\forall k \in \{1, \dots, n\}, \quad \Delta_k = \sum_{j=1}^k \delta_j.$$

Let also  $\Delta_0 = 0$ . Notice that weight  $\delta_j$  is equal to the difference between  $\Delta_j$  and  $\Delta_{j-1}$ . So, sum 10 can be written as a function of  $\Delta_k$ :

$$\begin{aligned}
\sum_{j=1}^n \delta_j f(c_j) &= \sum_{j=1}^n (\Delta_j - \Delta_{j-1}) f(c_j) \\
&= \sum_{j=1}^n \Delta_j f(c_j) - \sum_{j=1}^n \Delta_{j-1} f(c_j) \\
&= \sum_{j=1}^n \Delta_j f(c_j) - \sum_{k=0}^{n-1} \Delta_k f(c_{k+1}) \\
&= \sum_{j=1}^{n-1} \Delta_j f(c_j) - \sum_{k=0}^{n-1} \Delta_k f(c_{k+1}).
\end{aligned}$$

Now, since  $\Delta_0$  and  $\Delta_n$  both equal 0, the sum is equal to:<sup>11</sup>

$$\begin{aligned}
\sum_{j=1}^n \delta_j f(c_j) &= \sum_{j=1}^{n-1} \Delta_j f(c_j) - \sum_{k=1}^{n-1} \Delta_k f(c_{k+1}) \\
&= \sum_{j=1}^{n-1} \Delta_j f(c_j) - \Delta_j f(c_{j+1}) \\
&= \sum_{j=1}^{n-1} \Delta_j [f(c_j) - f(c_{j+1})].
\end{aligned}$$

Since  $c_1 < c_2 < \dots < c_n$ , we also have  $\delta_1 < \delta_2 < \dots < \delta_n$ . And since  $\sum_j \delta_j = 0$ ,  $\delta_1$  has to be negative, and  $\delta_n$  has to be positive. So, for all  $j \in \{1, \dots, n-1\}$ ,  $\Delta_j$  is negative. Indeed, if  $\delta_j$

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<sup>11</sup>The idea of introducing  $\Delta_k$  to rewrite the sum in this way is credited to Anthropic's Claude Sonnet 4.6 model.

is negative, then  $\Delta_j$  is a sum of negative terms, so it must be negative. And if  $\delta_j$  is positive, then  $\Delta_j = \Delta_n - \sum_{k=j+1}^n \delta_k$  is guaranteed to be less than  $\Delta_n = 0$ .

Since  $c_1 < c_2 < \dots < c_n$ , if  $f$  is decreasing, then for all  $j \in \{1, \dots, n-1\}$ :

$$\begin{aligned} c_j &< c_{j+1} \\ f(c_j) &> f(c_{j+1}) \\ f(c_j) - f(c_{j+1}) &> 0 \\ \Delta_j[f(c_j) - f(c_{j+1})] &< 0. \end{aligned}$$

So, if  $f$  is decreasing, then sum 10 is negative. In that case, the sign of  $\partial_{E,\gamma}^2 W$  is opposite to the sign of  $1 - \eta - \theta$ .

We will now show that  $f$  is decreasing for all  $\theta$  and  $\eta$  such that  $\eta > -\theta$ . We will proceed by looking at different pieces of the  $(\theta, \eta)$  plane, which we will put together at the end. But first, let us take a closer look at function  $f$ . For all  $c > 0$ , we have:

$$\begin{aligned} f(c) &= c^{\theta-1} v(c, E)^{1-\eta-2\theta} \\ &= c^{\theta-1} \left[ (1-\alpha)c^\theta + \alpha E^\theta \right]^{(1-\eta-2\theta)/\theta}. \end{aligned}$$

We can distribute  $c^{\theta-1}$  inside the bracket, like so:

$$f(c) = \left[ (1-\alpha)c^{\theta+(\theta-1)\theta/(1-\eta-2\theta)} + \alpha E^\theta c^{(\theta-1)\theta/(1-\eta-2\theta)} \right]^{(1-\eta-2\theta)/\theta}.$$

Simplifying the first inside exponent:

$$\begin{aligned} \theta + \frac{(\theta-1)\theta}{1-\eta-2\theta} &= \theta \left( 1 + \frac{\theta-1}{1-\eta-2\theta} \right) \\ &= \theta \cdot \frac{1-\eta-2\theta+\theta-1}{1-\eta-2\theta} \\ &= \theta \cdot \frac{-\eta-\theta}{1-\eta-2\theta} \\ &= -(\eta+\theta) \cdot \frac{\theta}{1-\eta-2\theta}, \end{aligned}$$

we get:

$$f(c) = \left[ (1-\alpha)c^{-(\eta+\theta)\cdot\theta/(1-\eta-2\theta)} + \alpha E^\theta c^{(\theta-1)\cdot\theta/(1-\eta-2\theta)} \right]^{(1-\eta-2\theta)/\theta}.$$

We will now study the sign of the three exponents in this function, in different cases. If the

two exponents of  $c$  inside the bracket are of the same sign, then  $f$  is monotonous. Otherwise, the variation of  $f$  depends on its parameters, and  $f$  is not guaranteed to be monotonous.

**Case 1:** if  $\frac{1 - \eta - 2\theta}{\theta} > 0$ .

There are two ways for  $\frac{1 - \eta - 2\theta}{\theta}$  to be positive. Either the numerator are both positive, or they are both negative.

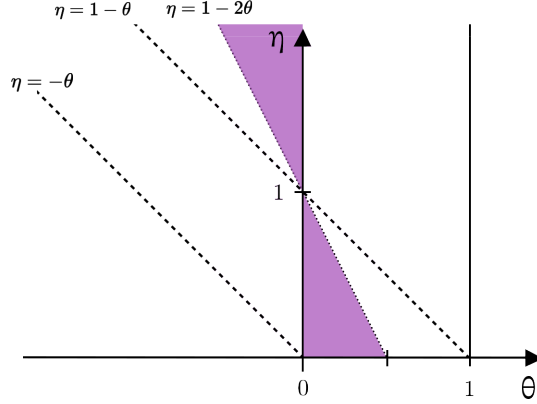


Figure A8: Case 1 :  $\frac{1 - \eta - 2\theta}{\theta} > 0$

In both cases,  $\eta + \theta > 0$ . Indeed:

$$\theta > 0 \Rightarrow \eta + \theta > \eta > 0,$$

and:

$$\begin{aligned} & \theta < 0 \quad \text{and} \quad 1 - \eta - 2\theta < 0 \\ \Rightarrow & \theta < 1 \quad \text{and} \quad 1 - \theta < \eta + \theta \\ \Rightarrow & 0 < 1 - \theta \quad \text{and} \quad 1 - \theta < \eta + \theta \\ \Rightarrow & 0 < \eta + \theta. \end{aligned}$$

Because  $\eta + \theta > 0$  and  $\frac{1 - \eta - 2\theta}{\theta} > 0$ , the first exponent is negative:

$$-(\eta + \theta) \cdot \frac{\theta}{1 - \eta - 2\theta} < 0.$$

Since, for all  $\theta \in (-\infty, 1) \setminus \{0\}$ ,  $\theta - 1$  is negative, the second exponent is also negative:

$$(\theta - 1) \cdot \frac{\theta}{1 - \eta - 2\theta} < 0.$$

So, both terms inside the brackets of function  $f$  are decreasing functions of  $c$ . Since  $\frac{1-\eta-2\theta}{\theta} > 0$ , the outside exponent is positive. So  $f$  is decreasing. We can conclude our first case: if  $\frac{1-\eta-2\theta}{\theta} > 0$ , then:

$$\text{sign}(\partial_{E,\gamma}^2 W) = -\text{sign}(1 - \eta - \theta).$$

We now move to cases where  $\frac{1-\eta-2\theta}{\theta}$  is negative. There are two ways for  $\frac{1-\eta-2\theta}{\theta}$  to be negative. Either the numerator is negative and the denominator is positive, or the reverse. We start with the case where the numerator is negative.

**Case 2: if  $1 - \eta - 2\theta < 0$  and  $\theta > 0$ .**

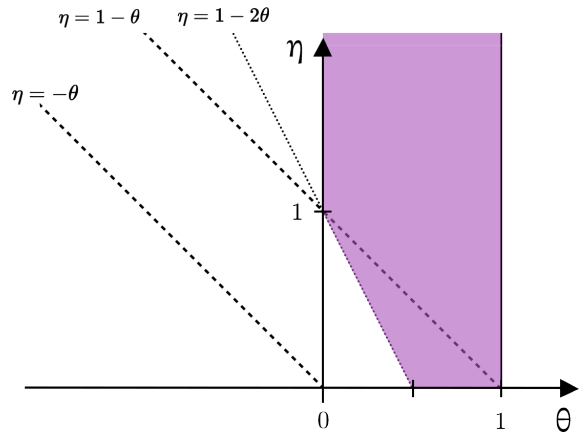
If  $1 - \eta - 2\theta < 0$  and  $\theta > 0$ , then  $\frac{1-\eta-2\theta}{\theta}$  is negative. We also have:

$$1 - \eta - 2\theta < 0$$

$$1 - \theta < \eta + \theta.$$

Now,  $\theta \leq 1$ , so  $0 \leq 1 - \theta$ . Therefore:

$$\eta + \theta > 0.$$



Case 2 :  $1 - \eta - 2\theta < 0$  and  $\theta > 0$

We can now look at the different exponents of function  $f$ . We have:

$$-(\eta + \theta) \frac{1 - \eta - 2\theta}{\theta} > 0$$

and

$$(\theta - 1) \frac{1 - \eta - 2\theta}{\theta} > 0.$$

So, function

$$c \mapsto (1 - \alpha)c^{-(\eta+\theta) \cdot \theta / (1-\eta-2\theta)} + \alpha E^\theta c^{(\theta-1) \cdot \theta / (1-\eta-2\theta)}$$

is increasing. It becomes decreasing when raised to the power  $(1 - \eta - 2\theta)/\theta < 0$ . So function  $f$  is decreasing. We can now conclude case 2: if  $1 - \eta - 2\theta < 0$  and  $\theta > 0$ , then  $\text{sign}(\partial_{E,\gamma}^2 W) = -\text{sign}(1 - \eta - \theta)$ .

**Case 3:** if  $1 - \eta - 2\theta > 0$ ,  $\theta < 0$ , and  $\eta + \theta > 0$ .

If  $1 - \eta - 2\theta > 0$ ,  $\theta < 0$ , and  $\eta + \theta > 0$ , then:

$$-(\eta + \theta) \frac{\theta}{1 - \eta - 2\theta} > 0,$$

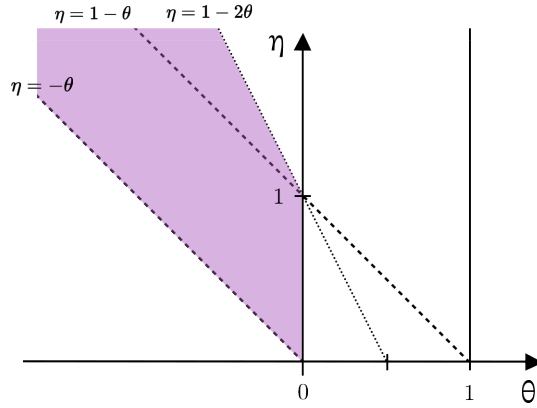
and:

$$(\theta - 1) \frac{\theta}{1 - \eta - 2\theta} > 0.$$

So, function

$$c \mapsto (1 - \alpha)c^{-(\eta + \theta) \cdot \theta / (1 - \eta - 2\theta)} + \alpha E^\theta c^{(\theta - 1) \cdot \theta / (1 - \eta - 2\theta)}$$

is increasing. It becomes decreasing when raised to the power  $(1 - \eta - 2\theta)/\theta < 0$ . So function  $f$  is decreasing. Case 3 concludes just like the two previous cases: if  $1 - \eta - 2\theta < 0$ ,  $\theta > 0$ , and  $\eta + \theta > 0$ , then  $\text{sign}(\partial_{E,\gamma}^2 W) = -\text{sign}(1 - \eta - \theta)$ .



Case 3 :  $1 - \eta - 2\theta > 0$ ,  $\theta < 0$ , and  $\eta + \theta > 0$

**Case 4:** if  $1 - \eta - 2\theta > 0$ ,  $\theta < 0$ , and  $\eta + \theta < 0$ .

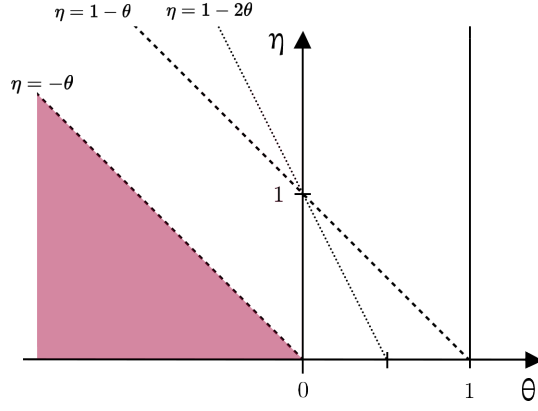
If  $1 - \eta - 2\theta > 0$ ,  $\theta < 0$ , and  $\eta + \theta < 0$ , then:

$$-(\eta + \theta) \frac{\theta}{1 - \eta - 2\theta} < 0,$$

and:

$$(\theta - 1) \frac{\theta}{1 - \eta - 2\theta} > 0.$$

Since the two exponents of  $c$  are of opposite signs, the variation of  $f$  is ambiguous.



Case 4 :  $1 - \eta - 2\theta > 0$ ,  $\theta < 0$ , and  $\eta + \theta < 0$ .

### Conclusion

Taken together, cases 1, 2 and 3 cover the part of the  $(\eta, \theta)$  plane where  $\eta$  is greater than  $-\theta$ . Since the three cases have the same conclusion, we can say that on the domain they cover, the sign of the cross derivative of welfare is opposite to the sign of  $1 - \eta - \theta$ :

$$\forall \theta < 1, \forall \eta > \max \{-\theta, 0\}, \text{sign}(\partial_{E,\gamma}^2 W) = -\text{sign}(1 - \eta - \theta).$$

In other words:

1. if  $\eta > 1 - \theta$ , then  $\partial_{E,\gamma}^2 W > 0$ ,
2. if  $-\theta < \eta < 1 - \theta$ , then  $\partial_{E,\gamma}^2 W < 0$ .

Back to proposition 1.

## E Countries used as input for for natural capital missing values

Table 1: Countries used as input for natural capital missing values

| Country with missing $N$ |                     | Input country |                |
|--------------------------|---------------------|---------------|----------------|
| ISO3                     | Country             | ISO3          | Country        |
| ABW                      | Aruba               | MLT           | Malta          |
| AFG                      | Afghanistan         | TJK           | Tajikistan     |
| BHS                      | Bahamas             | JAM           | Jamaica        |
| BRB                      | Barbados            | SLB           | Solomon Is.    |
| BRN                      | Brunei              | SGP           | Singapore      |
| BTN                      | Bhutan              | NPL           | Nepal          |
| CPV                      | Cabo Verde          | MUS           | Mauritius      |
| CUB                      | Cuba                | DOM           | Dominican Rep. |
| CYP                      | Cyprus              | MLT           | Malta          |
| DZA                      | Algeria             | NER           | Niger          |
| ERI                      | Eritrea             | OMN           | Oman           |
| FJI                      | Fiji                | SLB           | Solomon Is.    |
| GNQ                      | Eq. Guinea          | BEN           | Benin          |
| HKG                      | Hong Kong           | SGP           | Singapore      |
| LBY                      | Libya               | EGY           | Egypt          |
| MMR                      | Myanmar             | THA           | Thailand       |
| PSE                      | Palestine           | JOR           | Jordan         |
| PYF                      | Fr. Polynesia       | SLB           | Solomon Is.    |
| SYR                      | Syria               | IRQ           | Iraq           |
| TKM                      | Turkmenistan        | KAZ           | Kazakhstan     |
| TLS                      | Timor-Leste         | SLB           | Solomon Is.    |
| TON                      | Tonga               | SLB           | Solomon Is.    |
| TWN                      | Taiwan              | KOR           | South Korea    |
| UZB                      | Uzbekistan          | KAZ           | Kazakhstan     |
| VCT                      | St. Vincent & Gren. | SLB           | Solomon Is.    |
| VUT                      | Vanuatu             | SLB           | Solomon Is.    |
| WSM                      | Samoa               | SLB           | Solomon Is.    |
| YEM                      | Yemen               | SAU           | Saudi Arabia   |

Note: Initial natural capital for countries not included in CWON is assigned based on geographic proximity and similarity in forest area. For small island states, the initial natural capital stock is set equal to that of an island of comparable size.

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## F Countries used as input for damage coefficient missing values

Table 2: Countries used as input for missing damage coefficient values

| Country with missing $\xi$ |                     | Input country |                  |
|----------------------------|---------------------|---------------|------------------|
| ISO3                       | Country             | ISO3          | Country          |
| ABW                        | Aruba               | DOM           | Dominican Rep.   |
| AFG                        | Afghanistan         | TJK           | Tajikistan       |
| AGO                        | Angola              | COD           | Congo, Dem. Rep. |
| BHR                        | Bahrain             | QAT           | Qatar            |
| BHS                        | Bahamas             | JAM           | Jamaica          |
| BRB                        | Barbados            | DOM           | Dominican Rep.   |
| BRN                        | Brunei              | IDN           | Indonesia        |
| BTN                        | Bhutan              | NPL           | Nepal            |
| COM                        | Comoros             | MDG           | Madagascar       |
| CPV                        | Cabo Verde          | MDG           | Madagascar       |
| CUB                        | Cuba                | DOM           | Dominican Rep.   |
| CYP                        | Cyprus              | TUR           | Turkey           |
| DZA                        | Algeria             | NER           | Niger            |
| ERI                        | Eritrea             | OMN           | Oman             |
| FJI                        | Fiji                | SLB           | Solomon Is.      |
| GNB                        | Guinea-Bissau       | GIN           | Guinea           |
| GNQ                        | Eq. Guinea          | BEN           | Benin            |
| HKG                        | Hong Kong           | CHN           | China            |
| ISR                        | Israel              | JOR           | Jordan           |
| LBY                        | Libya               | EGY           | Egypt            |
| LCA                        | St. Lucia           | DOM           | Dominican Rep.   |
| MAC                        | Macao               | CHN           | China            |
| MDV                        | Maldives            | LKA           | Sri Lanka        |
| MLT                        | Malta               | ITA           | Italy            |
| MMR                        | Myanmar             | THA           | Thailand         |
| MNE                        | Montenegro          | ALB           | Albania          |
| MUS                        | Mauritius           | MDG           | Madagascar       |
| NZL                        | New Zealand         | AUS           | Australia        |
| PSE                        | Palestine           | JOR           | Jordan           |
| PYF                        | Fr. Polynesia       | SLB           | Solomon Is.      |
| SDN                        | Sudan               | TCD           | Chad             |
| SGP                        | Singapore           | MYS           | Malaysia         |
| SRB                        | Serbia              | HRV           | Croatia          |
| STP                        | São Tomé & Príncipe | GAB           | Gabon            |
| SYR                        | Syria               | IRQ           | Iraq             |
| TKM                        | Turkmenistan        | KAZ           | Kazakhstan       |
| TLS                        | Timor-Leste         | SLB           | Solomon Is.      |
| TON                        | Tonga               | SLB           | Solomon Is.      |
| TWN                        | Taiwan              | KOR           | South Korea      |
| UZB                        | Uzbekistan          | KAZ           | Kazakhstan       |
| VCT                        | St. Vincent & Gren. | SLB           | Solomon Is.      |
| VUT                        | Vanuatu             | SLB           | Solomon Is.      |
| WSM                        | Samoa               | SLB           | Solomon Is.      |

Note: The criteria used are as follows. First, keep input criteria for  $N$ . Second, input the damage coefficient from the closest country. Third, assign the Dominican Republic damage coefficient for the remaining island states.

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## G Converting a stock of natural capital to a flow of ecosystem services

The Common Wealth Of Nations database gives a *stock* of natural capital for each country. This stock is obtained by aggregating a flow of ecosystem services over time, as explained by equation 6 of the CWON report (World Bank 2024, chapter 7, p. 145). Adapting this equation to our notation, the formula is:

$$N = \sum_{t=1}^{100} \frac{E}{(1+r)^t},$$

where  $N$  is the present value of ecosystem services,  $E$  is the yearly flow, and  $r$  is a 4% discount rate. To recover the value of constant  $E$ , we start by factorizing it:

$$N = E \sum_{t=1}^{100} \frac{1}{(1+r)^t}.$$

Using the formula for geometric sums, we can write:

$$N = E \cdot \frac{1}{1+r} \cdot \frac{1 - \left(\frac{1}{1+r}\right)^{100}}{1 - \frac{1}{1+r}}.$$

The second denominator simplifies:

$$\begin{aligned} 1 - \frac{1}{1+r} &= \frac{1+r-1}{1+r} \\ &= \frac{r}{1+r}. \end{aligned}$$

So:

$$\begin{aligned} N &= E \cdot \frac{1}{1+r} \cdot \frac{1 - \left(\frac{1}{1+r}\right)^{100}}{\frac{r}{1+r}} \\ &= E \cdot \frac{1}{1+r} \cdot \frac{1+r}{r} \cdot \left(1 - \left(\frac{1}{1+r}\right)^{100}\right) \\ &= E \cdot \frac{1}{r} \cdot (1 - (1+r)^{-100}). \end{aligned}$$

We can now express  $E$  as a function of  $N$ :

$$E = N \cdot \frac{r}{1 - (1+r)^{-100}}.$$

Replacing  $r$  by its value gives us the stock-to-flow conversion factor:

$$E = N \cdot \frac{0.04}{1 - (1 + 0.04)^{-100}}$$

$$E \approx N \cdot 0.040808.$$

Back to subsection 3.1.