CHIPS
Climate Change Impacts and Policies
in Heterogeneous Societies

D4.1: New estimates of the social cost of carbon better accounting for inequalities

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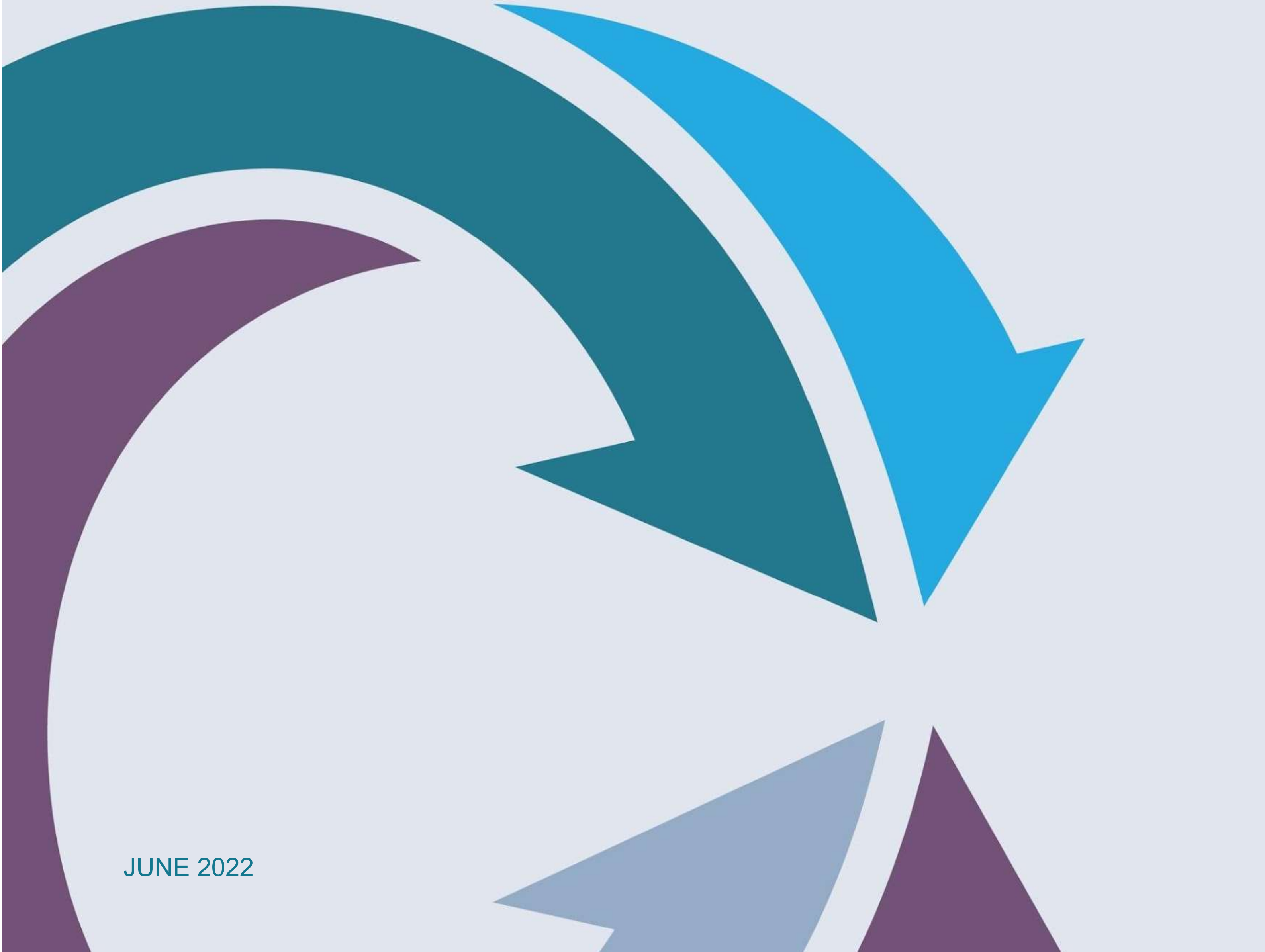
JPI Climate AXIS



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Social Costs of Carbon under Inequality

Abstract

Measuring the social cost of carbon (SCC) beyond the representative-agent fiction is a challenge. Within the CHIPS project, we explored several avenues to account for inequality, where the scales of interest are between-region, between-country, and between-household inequality. In the first line of evidence, the CHIPS project accounts for the effect of tropical cyclones on the SCC. These extreme events are expected to happen more often in the near future for a subset of countries. In a second line, the project disentangled capital- and labor-related climate damages that affect households through their income. Capital- and labor-related damages significantly increase the SCC if they hit the poorest households disproportionately. Finally, the project provided empirically-rooted estimates for inequality aversion, a key parameter that determines the SCC and optimal carbon taxes. A discrepancy is found between national solidarity and international concerns. This report further uses empirically estimated inequality aversion values to derive the optimal carbon tax in an Integrated Assessment Model that incorporates inequality between and within countries.

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1. Introduction

Economists and climate modelers developed a guide for climate policy that summarizes the complexity of climate-change damage costs into the concept of the social cost of carbon (SCC)[1]. This indicator gives, in monetary terms, the total damage resulting from an additional ton of carbon dioxide emissions released into the atmosphere. Interestingly, it constitutes a threshold under which actions resulting in an emission reduction at a lower cost should be undertaken. It is therefore of prime importance in cost-benefit analysis (Interagency Working Group 2021) and used as a guide for carbon pricing levels (Clarkson and Deyes 2002; Astrid and Bünger 2019). If policy levels are optimal, the SCC equals the optimal carbon price level (W. Nordhaus 2014).

The majority of the literature derives estimates of the SCC from Integrated Assessment Models (Greenstone, Kopits, and Wolverton 2013; Metcalf and Stock 2017) that use a representative agent at the global level and thus neglect inequality between and within countries (W. Nordhaus 2014; W. D. Nordhaus 2017; van der Ploeg and Rezai 2019). One of the main findings of this line of research is that the SCC is critically influenced by how damages are valued over time, known as the famous discounting debate in climate change economics. Nordhaus (2014) showed that when putting a high value to future damages (as in N. Stern 2006), the SCC is as high as 90 USD/tCO2, whereas a value of future damages guided by market interest rates results in an SCC of 19 USD/tCO2.

Beyond models with global representative agents, previous literature highlighted the importance of inequality for the SCC (Azar and Sterner 1996; Anthoff, Hepburn, and Tol 2009; Anthoff and Tol 2010; Adler et al. 2017). Here, climate damages are evaluated with a social welfare function to derive the SCC. If society is averse to inequality, damages that fall on people with lower income receive a higher social value compared to damages that fall on people with higher income, thus influencing the SCC. Anthoff and Emmerling (2019) show that the SCC in the United States increases when using a social welfare function that is increasingly averse to inequality between countries. Following this result, inequality would call for a more ambitious climate policy in the US when the costs and benefits of climate change mitigation are evaluated with an inequality aversion.

The SCC is also sensitive to inequality within countries (Anthoff, Hepburn, and Tol 2009; Anthoff and Emmerling 2019). Dennig et al. (2015) developed the NICE Integrated Assessment Model (for Nested Inequalities Climate-Economy) to derive optimal carbon taxes under different assumptions about sub-regional inequality. Inequality is shown to potentially be as important to the SCC and the optimal carbon price as choosing how to value damages over time. Kornek et al. (2021) introduce redistribution between households within countries and derive the SCC as the optimal carbon price. They show that when national redistribution offsets climate damages to the poor, the optimal carbon price is only moderately influenced by inequality. On the contrary, if damages fall disproportionately on the poor and are not compensated, optimal carbon prices increase globally.

The CHIPS project provides new research on the SCC that this report summarizes. First, Krichene et al. (2021 in prep.) is the first study to quantify an SCC for an extreme-event category. These events are expected to occur more often in the coming years and have long-lasting economic consequences. But common assessments of the SCC omit these events and therefore underestimate the benefit of avoided damages. Krichene et al. (2021 in prep.) estimate the impact of one extreme event: tropical

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[1] The word carbon is used here as a synonym of greenhouse gases. An equivalence scale is generally used to convert non-CO2 gases to a CO2 equivalent corresponding to the same global-warming potential. See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent.

cyclones. They compute the SCC from tropical cyclones under different climate and socio-economic scenarios.

Second, Young-Brun and Feindt (2022 in prep.) extended the NICE model of Dennig et al. (2015) through finer modeling of pre-existing inequality. The goal was to take a step toward incorporating the mounting empirical evidence on the distribution of climate impacts. For instance, poorer individuals are found to be more likely to work in occupations with greater exposure to heat stress (Park et al. 2018) and thus bear labor-income losses. In the extended NICE model, households at the sub-regional level receive both labor and capital income. Damages from climate change do not only fall on output, but also on labor or on capital stocks. The disproportionality of damages on output, labor, and capital is captured through channel-specific income elasticities. The calibration of the income elasticities is guided by recent empirical evidence which shows that climate impacts on labor productivity and assets tend to hit the poorest disproportionately. Channel-specific damages and some level of regressivity in damages jointly result in an increase in the SCC by several orders of magnitude.

Third, Del Campo, Anthoff, and Kornek (2021) reviewed reported levels of inequality aversion from the academic literature. Inequality aversion critically influences the level of the SCC and optimal carbon prices (Azar and Sterner 1996; Anthoff Hepburn and Tol 2009; Dennig et al 2015; Anthoff and Emmerling 2019) but choices of inequality aversion for climate policy remain mostly ad-hoc. To guide this choice, Del Campo, Anthoff, and Kornek (2021) provide a systematic review of academic evidence on the level of inequality aversion. They find a wide range of estimates from empirical studies. This line of literature estimates inequality aversion on the basis of revealed ethics: estimates of inequality aversion reflect people's preferences, represented either in real-world data, e.g. progressive income taxation within countries or in survey responses. The axiomatic literature derives levels of inequality aversion that are consistent with some equity principles. Del Campo, Anthoff, and Kornek (2021) find that inequality-aversion estimates found in national contexts, like income taxation, are consistently higher than estimates derived in international contexts, like foreign aid. The report uses these findings and derives new estimates of optimal carbon prices in the NICE model.

The report proceeds as follows. The next section introduces the concept of the SCC and optimal carbon prices. Sections 3, 4, and 5 are devoted to the three contributions from the CHIPS project on inequality and the SCC. Section 6 concludes.

2. Social Cost of Carbon and optimal carbon prices

The SCC aggregates all future climate damages that are caused by an additional unit of CO2 emissions today (Ricke et al. 2018). These damages occur at different times and in different places. To aggregate monetary values along these two dimensions, estimates of the SCC incorporate a decision about how to value a dollar of climate damages that accrues to people at different times and in different places. The SCC can thus be written as:

$$\boldsymbol{SCC} = \sum_t \sum_i \boldsymbol{w}_{it} \frac{\Delta D_{it}}{\Delta E}, \quad (1)$$

where $\frac{\Delta D_{it}}{\Delta E}$ is the additional damage caused by an extra unit of CO2 emissions to individual $\boldsymbol{i}$ at the time $\boldsymbol{t}$ and $\boldsymbol{w}_{it}$ is the weight attached to this damage.

A conventional approach to arrive at today's value of climate damages is to apply a constant discount rate to damages at different times but to apply the same weight to damages in each time-step (Interagency Working Group 2021). Anthoff, Tol, and Yohe (2009) describe the Ramsey rule to discount future damages, where the discount rate follows endogenously from the rate of pure time preference, the consumption growth rate, and the elasticity of marginal utility (also applied in Ricke et al. 2018). Here, inequality over time is important for the value of the discount rate (see also the discussion in Section 3).

Anthoff, Hepburn, and Yohe (2009) describe the use of equity weights to value the additional damage to different people in space and time. Equity weights follow from a social welfare function that is inequality averse. With inequality aversion, damages that affect a person with low income receive a larger weight compared to damages falling on a person with high income.

In cost-benefit analysis, the SCC are the motive for setting carbon prices (W. Nordhaus 2014; Kornek et al. 2021). Here, extra climate damages resulting from an additional unit of emissions are valued against the mitigation costs of avoiding this extra unit of emissions. The optimal carbon price resolves the trade-off. Integrated Assessment Models are used to compute the optimum by implementing a social welfare function to evaluate costs and benefits across space and time (W. Nordhaus 2014; Dennig et al. 2015; Budolfson et al. 2021; Kornek et al. 2021).

3. The Social Cost of Carbon from tropical cyclones

Krichene et al. (2021 in prep.) compute an SCC that is induced by tropical cyclones. The study performs a statistical evaluation of historical growth responses to tropical cyclones. The results of the analysis are preliminary and should not be cited. In a panel regression over the period 1971-2015, they estimate the long-term impact tropical cyclones have had on national economic growth rates in 41 countries (see Figure 1), using the Tropical Cyclone Exposure Database. They find that growth responses to tropical-cyclone events have almost always been negative and that, on average, growth losses increase in the years after a tropical cyclone hit before losses level off. These findings show the importance of accounting for persistent damages from tropical cyclones in SCC estimates.

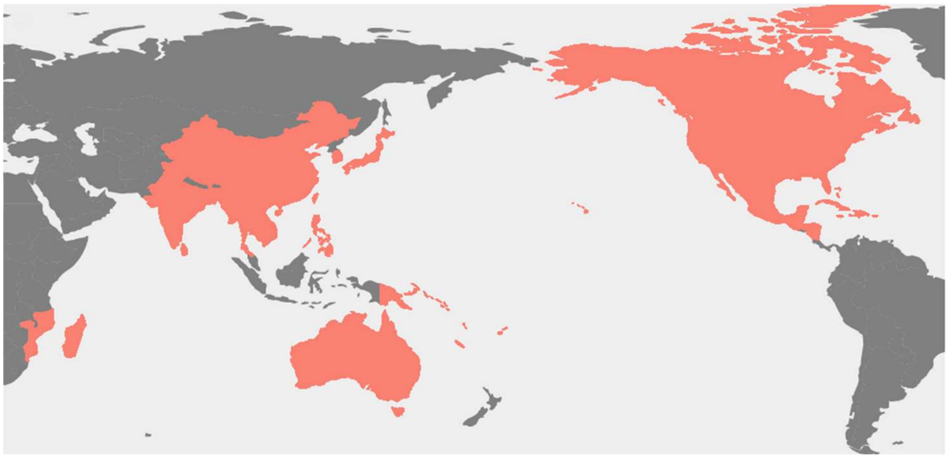

Figure 1 (preliminary, do not cite): The 41 countries impacted by tropical cyclones in the years 1975-2015

Using the panel regression, economic damages from tropical cyclones are projected over the period 2021-2100. Here, the model uses an ensemble of 2,880,000 scenarios that cover 5 uncertainty dimensions to project future impacts. First, the statistical model uses random sampling of the original data (so-called bootstrapping) to account for uncertainty in the growth response to tropical cyclones. Second, different Representative Concentration Pathways (RCP) cover uncertainty about future climate change. Third, an emulator is used to generate probabilistic scenarios of future tropical cyclone landfalls. Fourth, projections of future growth follow different Shared Socioeconomic Pathways (SSP). Lastly, normative assumptions about the welfare weights in (1) are varied. The projected economic damages from tropical cyclones are used to derive how losses in growth depend on increases in global mean temperature in each country.

The relationship between growth losses and temperature increase is used to compute the SCC that is induced by tropical cyclones. Here, Krichene et al. (2021 in prep.) use the same approach as Ricke et al. (2018) to compute additional damages from tropical cyclones that follow from an extra unit of emissions. The additional damage at each point in time is the difference between future GDP per capita under climate change with and without the extra unit of emissions. To arrive at the SCC, additional damages are discounted with an endogenous Ramsey-growth rate. That is, the welfare weights $\boldsymbol{w_{it}}$ in (1) are equal to $\boldsymbol{w_{it} = \frac{1}{(1+r_{it})^{t-t_0}}}$, with $\boldsymbol{r_{it} = \rho + \eta g_{it}}$ where $\boldsymbol{\rho}$ is the rate of pure time preference, $\boldsymbol{\eta}$ the elasticity of marginal utility, and $\boldsymbol{g_{it}}$ the constant-average growth rate of per-capita consumption in the country $\boldsymbol{i}$. The SCC, therefore, accounts for inequality in national growth rates while it abstracts from inequality between countries (Anthoff, Tol, and Yohe 2009).

Discounting damages leads to a higher value given to damages that occur closer to the present, while damages that lie further in the future receive a lower weight in the SCC. Discounting happens for two reasons. First, the rate of pure time preference reflects a lower value given to later periods simply because they are in the future. Second, the elasticity of marginal utility reflects an aversion to unequal consumption over time. If the future is richer than the present (such that $\boldsymbol{g}$ is positive), a positive elasticity of marginal utility leads to a larger discounting of future damages. Because the future is richer, damages receive a lower weight as there is an aversion to inequality over time. It has been argued that the choice of parameters for the discount rate is mainly an ethical one (Nicholas Stern 2008). Krichene et al. (2021 in prep.) reflect normative uncertainty about discounting by varying the rate of pure time preference and the elasticity of marginal utility.

The study finds that the value of the discount rate has the largest influence on the SCC. In Figure 2, the median of the SCC induced by tropical cyclones is reported across different uncertainty dimensions. First, SCC estimates are comparable across different assumptions about future growth when holding the rate of pure time preference ($\boldsymbol{\rho}$) and the elasticity of marginal utility ($\boldsymbol{\eta}$) fixed: SCC estimates are very similar in a future world of moderate growth in GDP (SSP2, left panel) and in a world of fast GDP growth (SSP5, right panel). Second, SCC estimates vary little with the extent of climate change, again holding the normative parameters $\boldsymbol{\rho}$ and $\boldsymbol{\eta}$ fixed. A higher mean temperature increase in RCP8.5 compared to RCP2.6 leads to only small changes in the distribution of the SCC.

However, normative assumptions about discounting future damages critically influence the value of the SCC. When assuming the lowest discount rate for $\boldsymbol{\rho = 0.1\%}$ and $\boldsymbol{\eta = 1.01}$, the SCC induced by tropical cyclones is at 60 USD/tCO2 at the median, which is about five times higher than the level of the SCC for the highest discount rate with $\boldsymbol{\rho = 2\%}$ and $\boldsymbol{\eta = 1.5}$ (Figure 2). This shows the importance of inequality aversion for the SCC. To illustrate this, assume that the future sees constant growth in consumption of 2% per year: if average consumption is USD 20,000 in 2020, it would grow to almost USD 100,000 in 2100. Setting the ethical parameters to $\boldsymbol{\rho = 0.1\%}$ and $\boldsymbol{\eta = 1.01}$, the discount rate is at 2.12%, such that damage of USD 1 in 2100 is worth USD 19 cents in 2020. Setting the ethical parameters to $\boldsymbol{\rho = 2\%}$ and $\boldsymbol{\eta = 1.5}$, the discount rate is at 5%, such that damage of USD 1 in 2100 is only worth USD 2 cents in 2020. Discounting ensures that damages in the nearer future receive a higher weight in the SCC because the nearer future is poorer compared to later periods. However, the choice of ethical parameters drives how much value is given to damages at different times.

Krichene et al. (2021 in prep.) further analyze how much of the total additional damages originates in the 41 countries, i.e. how much each country contributes to the total SCC level. Here, Krichene et al. (2021 in prep.) find that the US has the largest contribution to the SCC with 3.04 USD/tCO2 (or 25.4% of the total SCC), Japan contributes 2.2 USD/tCO2 (or 18.4% of the total SCC) and China 2.19 USD/tCO2 (or 18.3% of the total SCC).Future research should be able to use their results as input to Integrated Assessment Models with endogenous mitigation responses to tropical cyclones.

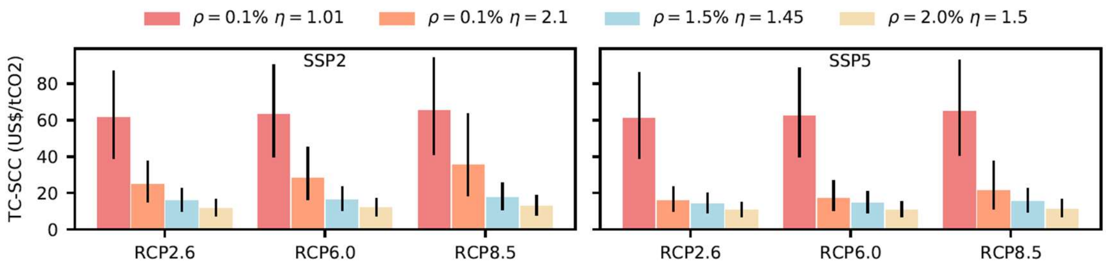

Figure 2 (preliminary, do not cite): Median tropical cyclone-induced social cost of carbon (TC-SCC) for three future climate scenarios (RCP2.6, 6.0, 8.5), two shared socioeconomic pathways (SSPs 2 and 5), and assumption about ethical parameters (ρ, η)

4. The Social Cost of Carbon with channel-specific climate change impacts

Young-Brun and Feindt (2022 in prep.) extend the NICE model (Dennig et al. 2015) to enhance its representation of inequality. The NICE model disaggregates the world economy into 12 regions and each region into five consumption quintiles. Young-Brun and Feindt (2022 in prep.) introduce damages that do not only hit output, but also the capital and productive labor stocks. The split is such that no additional loss of output occurs in the period of impact. Because evidence is still scarce on the relative importance of the three climate impact channels studied (impacts on output, labor productivity, and capital stock), the composition of damages is parametrized. Across all scenarios, the authors assume that up to 50% of damages fall on capital and/or labor productivity.

Within-region inequality is then incorporated through income distributions. Quintile shares in regional income are calibrated, with total income stemming from labor and capital income. The capital income distribution is calibrated to wealth distribution data from *Crédit Suisse Global Wealth* databooks (Davies, Lluberas, and Shorrocks 2017), and labor income distribution is calibrated with data from the ILO (Gomis 2019).

Finally, insights from the literature on the distributional effects of climate change are incorporated through the parametrization of the income-elasticity of damages. For each damage type, this elasticity relates the share of the quintile in the specific income (total, labor, capital income) to the share in the damages (directly on output, labor productivity, capital stock). From the empirical literature, a plausible range for these elasticities is from 0.5 (damages fall disproportionately on the poorest, but the richest still bear the larger share of the damages) to 1 (damages fall proportionally to income). The CHIPS report 4.2 provides the details behind modeling in NICE.

To proceed with welfare evaluation, which is based on per-capita consumption, quintile income shares are finally converted into consumption shares and per-capita amounts. NICE uses a discounted-utilitarian social welfare function, with a common inequality-aversion parameter $\boldsymbol{\eta}$ for inequality between and within generations:

$$\boldsymbol{W} = \sum_t \frac{1}{(1+\rho)^t} \sum_i \boldsymbol{P}_{it} \frac{(C_{it}/P_{it})^{1-\eta} - 1}{1-\eta}, \quad (2)$$

with $\boldsymbol{C}_{it}$ consumption of each quintile over time $\boldsymbol{t}$, $\boldsymbol{P}_{it}$ the population of each quintile over time $\boldsymbol{t}$ and $\boldsymbol{\rho}$ the rate of pure time preference.

Damages ultimately affect the consumption of quintiles, such that the SCC in NICE is today's value of all consumption losses in the future due to the emission of an additional ton of carbon. The consumption losses are aggregated using equity weights that follow from the social welfare function:

$$w_{it} = \frac{\partial W}{\partial C_{it}} / \left(\sum_j \frac{C_{j0}}{C_0} \frac{\partial W}{\partial C_{i0}} \right)$$

where $\boldsymbol{C_o}$is average global consumption in 2025 and $\boldsymbol{W}$ the social welfare function. The numerator in the equity weights transforms the consumption losses in each period, which are due to the additional climate damages, into welfare units. The denominator reflects the normalization that is needed to deal with the comparison of heterogeneous consumption levels, across both regions and quintiles (see also Adler et al. 2017 for an in-depth explanation of the role of normalization). It captures the welfare cost of not emitting an additional ton of carbon in the year for which the SCC is computed, or, in other words, the welfare cost of mitigating. Following Adler et al. (2017), a "World-Fair" normalization is used, meaning that each quintile within each region bears a mitigation cost that is proportional to its consumption level. Finally, because of the inequality aversion in the NICE social welfare function, equity weights are larger, ceteris paribus, for poor quintiles compared to rich quintiles.

Young-Brun and Feindt (2022 in prep.) evaluate the SCC with the extended NICE model along a business-as-usual scenario. The chosen scenario features a persistent fossil fuel dependency, high regional output growth, and emissions that lead to warming levels of around 3.5°C by the end of the century. Normative parameters of the social welfare function are set to the values suggested by Nordhaus (rate of pure time preference $\boldsymbol{\rho}$ = 1.5% and inequality aversion $\boldsymbol{\eta}$ = 2).

In a scenario with damages falling completely on output and damages proportional to income (income elasticity of 1), Young-Brun and Feindt (2022 in prep.) derive a value for the SCC of 42 USD/tC for 2025. This case is displayed in the bottom left corner of figure 3a), i.e. when the share of damages is zero for both the capital and labor channel. Increasing the share of damages that fall on capital from zero to 0.5 (top left corner in figure 3a), leads to a decrease in the SCC by 10 %, down to 38 USD/tC in 2025. The opposite holds true when increasing the share of damages that fall on labor from zero to 0.5, while fixing capital damages to a share of 0 (bottom right corner of Figure 3a): the SCC increases by 140%, amounting to 101 USD/tC in 2025.

The change of the SCC in these two cases reflects two effects. First, damages on capital and labor have a persistent effect on output growth. Persistence of damages arises because both capital and labor accumulate over time, such that a negative shock in one period also reduces the capital and labor stock in the following periods. Second, damages on capital or labor alter the distribution of impacts compared to a case where damages fall only on output. More specifically, poorer households suffer more from labor than capital damages, because they rely more on labor income than capital income.

Young-Brun and Feindt (2022 in prep.) also investigate the role of channel-specific income elasticities of damages. The results show that this parameter is crucial for the analysis of the SCC. If damages fall on labor and disproportionately affect the poor, the SCC increases by several orders of magnitude, reaching hundreds of thousands. This is shown in Figure 3b when the share of labor damages is 0.5 and the share of capital damages is zero (bottom right corner). In the case of disproportionate damages on capital alone, i.e. fixing the share of labor damages to zero, the increase of the SCC is less pronounced, reflecting that the rich still bear the larger share of damages on capital, because the distribution is strongly skewed toward the rich. The SCC increases most when damages on both labor and capital are disproportionately affecting the poor. The SCC in Figure 3b) is over 1.5 million USD/tC when total damages are split fully between the capital and labor channel.

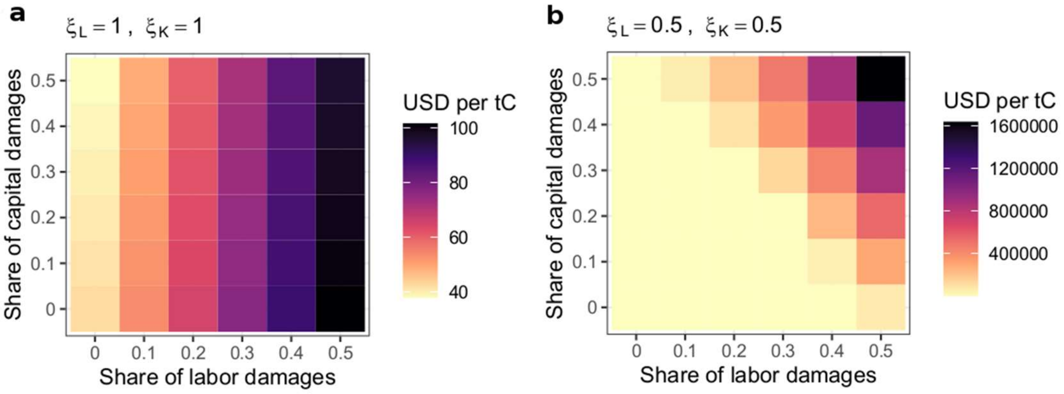

Figure 3: Social cost of carbon for different shares of total damages falling on capital and on labor (rate of pure time preference $\rho = 1.5\%$ and inequality aversion $\eta = 2$).

a) damages are proportional to the income of population quintiles for labor and capital, $\xi_L, \xi_K = 1$;
b) damages fall disproportionately on poor population quintiles for labor and capital, $\xi_L, \xi_K = 0.5$ (Young-Brun and Feindt 2022 in prep.)

Overall, the results of Young-Brun and Feindt (2022 in prep.) imply that the damage distribution across income groups has a stronger impact on the SCC than the capital or labor damage share. If damages more strongly affect the poor, the associated increase in the SCC implies more ambitious mitigation of carbon emissions if the costs of mitigation are proportional to income. More ambitious mitigation would shield the poor from large damages, a policy that increases social welfare in the presence of inequality aversion.

5. Climate policy when inequality aversion is empirically derived

5.1 Revealed ethics: national versus international redistributions

Del Campo, Anthoff, and Kornek (2021) review the literature eliciting the value of the inequality-aversion parameter. This parameter is of prime importance in a world where transfers are not freely implementable since it sets an efficiency-equity trade-off: it gives to what extent a higher mean consumption compensates for a higher inequality. This is naturally important for Integrated Assessment Models where consumption scenarios have different mean-spread pairs, both over time and at each point in time.

The inequality-aversion parameter influences the SCC and optimal carbon prices via the curvature of the social welfare function. Inequality between people living at the same time can increase optimal carbon prices because, with inequality aversion, a higher priority is assigned to the lower end of the income distribution. Kornek et al. (2021) show, using the NICE model, that disproportionate climate damages to low-income groups increase optimal carbon prices compared to the absence of inequality if the costs of reducing emissions are proportional to income.

If inequality between people at different times is evaluated with the same level of inequality aversion, higher aversion to inequality implies a higher (consumption) discount rate (see also Section 3), since the future is expected to be richer (Azar and Sterner 1996; Budolfson et al. 2017; Anthoff and Emmerling 2019). This tends to decrease optimal carbon prices and the SCC (W. D. Nordhaus 2017). However, Budolfson et al. (2017) highlight the role of sub-regional inequality in this finding. Using the NICE model, they show that the optimal global carbon tax increases with a higher level of inequality aversion if damages disproportionately affect low-income groups and costs of reducing emissions are more borne by high-income groups. The relationship is reversed, i.e. higher inequality aversion leads to a lower optimal carbon tax, if climate damages and costs of emission reductions are both proportional to income.

Thus, the choice of inequality aversion critically influences the SCC and optimal carbon prices. To inform this choice, one may align inequality aversion within climate policy with inequality aversion revealed from other policy areas and from normative principles. This is especially important because climate policy simultaneously determines the level of climate action and the level of burden-sharing across unequal populations.

Del Campo, Anthoff, and Kornek (2021) reviewed the existing academic literature systematically and reported estimates of inequality aversion from empirical studies and from estimates based on equity principles. They follow the standard approach of assuming a constant-relative inequality-aversion social welfare function (Atkinson 1970):

$$\boldsymbol{SWF = \sum_i \ (c_i{}^{1-\eta} - 1)/(1-\eta)} \ ,$$

where a person's consumption is $\boldsymbol{c_i}$ and $\boldsymbol{\eta}$ is the inequality aversion parameter. Del Campo, Anthoff, and Kornek (2021) only consider inequality between people at the same point in time. However, the inequality-aversion parameter $\boldsymbol{\eta}$ above is equal to the $\boldsymbol{\eta}$-parameter used in Sections 3 and 4 if inequality across time and space is evaluated with the same inequality aversion. The social welfare function above has widely been used to derive equity weights for estimating the SCC and for estimating optimal carbon prices (see for example Anthoff, Hepburn, and Tol 2009; Anthoff, Tol, and Yohe 2009; Adler et al. 2017).

Del Campo, Anthoff, and Kornek (2021) found 24 publications that estimate inequality aversion based on empirical data. In total, the publications include 435 estimates of η. Figure 3 shows all estimates,[2] which span a wide range between 0 and roughly 3. In addition, three papers provide values for inequality aversion based on equity principles.

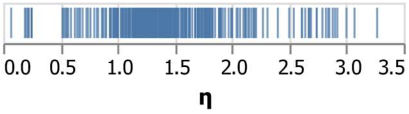

Figure 4: Collection of inequality-aversion estimates

Pooling the findings along the type of data that empirical studies used to estimate inequality aversion, Del Campo, Anthoff, and Kornek (2021) find that national income-tax schedules in developed countries reveal relatively high inequality-aversion values, in the range of 1 to 3. On the contrary, analyzing international transfers in the context of foreign aid reveals relatively low values, in the range of 0 to 1. All equity principles point to positive values for inequality aversion, without a strong case for a specific value.

The findings highlight a discrepancy between national solidarity and international considerations. On the one hand, if climate policy is thought of as an extension of the national income-tax policies, one would favor high inequality-aversion values (η higher than 1). On the other hand, if climate policy is thought of as charity toward the rest of the world, especially toward developing countries, one would favor low inequality-aversion values (η lower than 1). Advocating a precise value for inequality aversion is beyond the scope of the project.

We thus next evaluate optimal carbon-tax levels under different inequality-aversion values using the NICE model.

5.2 From preference to policy: implications for carbon-tax levels

In this report, we draw on the findings of Del Campo, Anthoff, and Kornek (2021) to compute optimal carbon taxes over time. The SCC drives optimal carbon taxes in the following sense: they represent the motive to avoid emissions along the optimal emission pathway against the costs that arise from mitigating emissions. The optimal carbon tax resolves the trade-off. Budolfson et al. (2021) provide a NICE model version, where the distribution of costs from reducing emissions across income groups is based on a meta-analysis of previous results from the literature. The NICE model version is available at https://github.com/Environment-Research/revenue_recycling/tree/master/src.

The social welfare function in NICE aggregates the consumption quintiles in each of the twelve regions. At each point in time, quintile consumption is aggregated with the social welfare function introduced in Section 5a. Over time, instantaneous welfare is discounted with a rate of pure time preference ρ. Social welfare is equal to equation (2) in Section 4. In the model, inequality between people at different points in time and in space is thus evaluated with the same inequality-aversion level. Quintile consumption is a function of climate policy through damages from climate change and costs of climate change mitigation. The income elasticity of damages ξ determines the share of climate

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[2] Data available as a range is not reported here. For all estimates, see Del Campo, Anthoff, and Kornek (2021).

damages that income quintiles experience. The distribution of mitigation costs is based on a meta-analysis of the academic literature (see the CHIPS report 4.2 for details).

We modify inequality aversion $\boldsymbol{\eta}$ and income elasticity of damage $\boldsymbol{\xi}$. The parameter $\boldsymbol{\eta}$ varies from 0 to 3, which captures an increasing inequality aversion. The parameter $\boldsymbol{\xi}$ takes the values 0.5 and 1. When the value is 1, climate damages are proportional to income across quintiles. When the value is 0.5, climate impacts are disproportionately borne by poorer quintiles.

Figure 3 exemplarily plots the optimal carbon-tax levels over time according to a combination of values for the two parameters of interest. Before the backstop price is reached, a higher inequality aversion corresponds to a lower carbon-price path. In particular, the carbon tax increases at a lower rate with a higher inequality aversion and reaches the backstop price later. As previously stated, the inequality-aversion parameter, in general, has an ambiguous effect on optimal carbon tax levels in NICE. With higher $\boldsymbol{\eta}$, damages to the poor at each point in time receive a higher weight, which tends to increase optimal carbon tax levels. However, mitigation costs that are borne by the poor also receive a higher weight, which tends to decrease optimal carbon tax levels. Lastly, a higher $\boldsymbol{\eta}$ also tends to increase the discount rate such that damages in the future receive a lower weight, which tends to decrease optimal carbon-tax levels. Figure 5 reveals how the different effects are resolved in the NICE model. We may here suspect that the intertemporal effect of higher discounting and the distribution of mitigation costs outweigh the intratemporal effect of a stronger weight given to the lower-income households both when damages are proportional to income $\boldsymbol{\xi = 1}$ and when they are more borne by the poorer population $\boldsymbol{\xi = 0.5}$. Comparing the two damage distributions in Figure 5, if damages more strongly affect poorer people, i.e. decreasing $\boldsymbol{\xi}$ from 1 to 0.5, the optimal carbon tax increases at each date. Higher carbon taxes increase mitigation, which shields the poor from disproportionate damages. Table 1 further illustrates the two findings from Figure 5: the optimal carbon tax is higher the lower the inequality aversion and the lower income elasticity of damage.

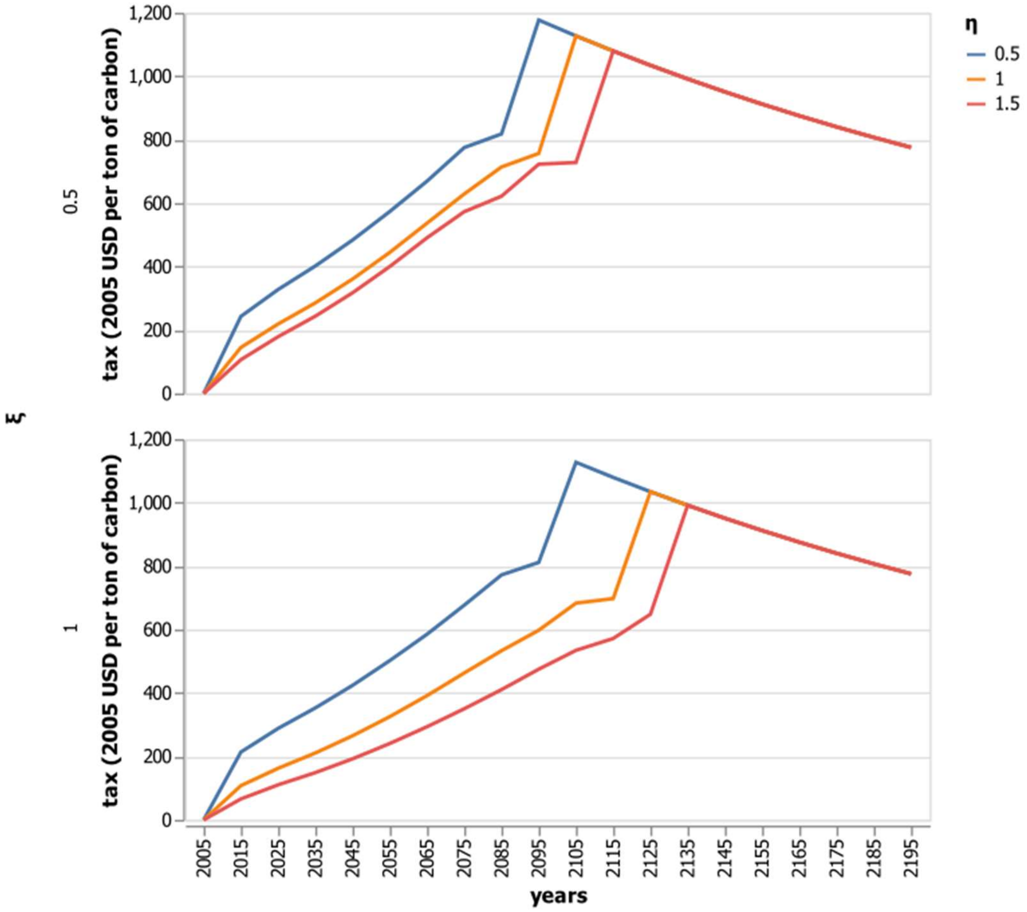

Figure 5: Optimal carbon tax over time according to different values for inequality aversion and income elasticity of damage

years \ η, $\xi = \mathbf{0.5}$	0.5	1	1.5
2025	328	219	179
2045	484	361	317

years \ η, $\xi = \mathbf{1}$	0.5	1	1.5
2025	228	163	111
2045	424	265	192

Table: Optimal carbon tax in 2005 USD per ton of carbon, for 2025 and 2045, and for different values of $\boldsymbol{\eta}$ and $\boldsymbol{\xi}$

We next evaluate the full range of inequality aversion suggested by Del Campo et al. (2021). Figure 6 plots carbon tax levels in the years 2025 and 2045 for η ranging between 0 and 3, and for the two damage distribution parameter values ξ. There is a clear negative relationship between inequality aversion and the carbon-tax level. The red line marks the threshold of η equals one (usually represented through the logarithm), which means that individuals should make a carbon tax payment proportional to their income. The figure on the left is compatible with values found in the international context (η below 1), while the figure on the right is compatible with a national context in developed countries (η above 1) (Del Campo, Anthoff, and Kornek 2021).

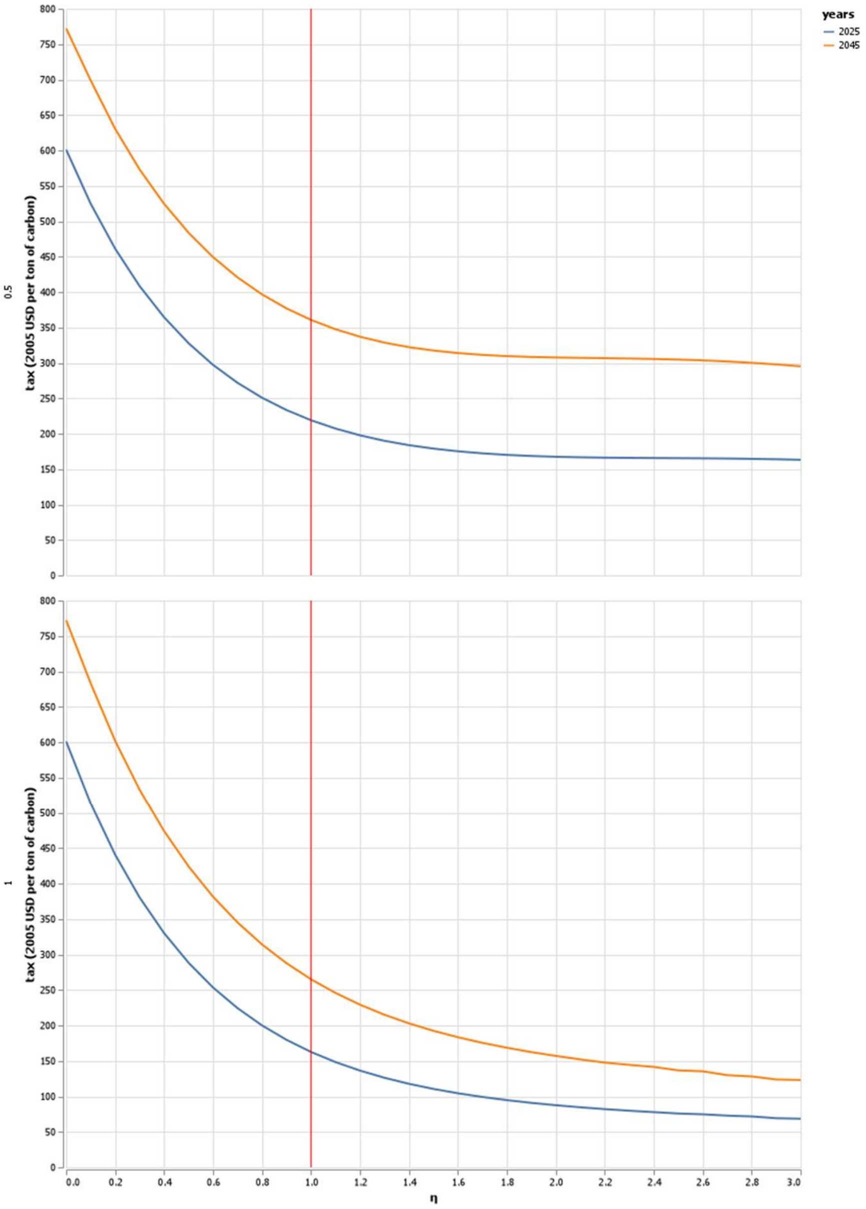

Figure 6: Optimal carbon tax as a function of inequality aversion, for the years 2025 and 2045, and two income elasticities of damage. The red line is a threshold: the left side is compatible with international redistribution; the right side is compatible with national redistribution.

6. Conclusions for climate policy

Climate policy is indeed an integrated assessment: human interaction with the environment is reciprocal, such that reducing emissions induces both environmental benefits in the form of avoided climate change impacts as well as mitigation costs. Social welfare analysis weighs the costs and benefits against each other to evaluate climate policy. Here, recent academic research has shown the significance of inequality to determine climate policy design (Adler et al. 2017; Anthoff and Emmerling 2019; Kornek et al. 2021; Fleurbaey and Kornek 2021; Drupp et al. 2021).

In an ideal world, inequality results only from social preferences and constraints on redistribution. Using a welfare metric with inequality aversion allows setting the trade-off between a higher total income and higher inequality. This is particularly true for climate change since carbon taxation may lead to an uneven share of income losses across individuals (Feindt et al. 2021; Labeaga, Labandeira, and López-Otero 2021) and damages are expected to fall disproportionately on the least well-off people (Ahmed, Diffenbaugh, and Hertel 2009; Leichenko and Silva 2014; Letta, Montalbano, and Tol 2018). The debate on the precise value of inequality aversion is beyond the scope of the CHIPS project and is mainly a normative one. But climate modelers and economists do need a value to compute optimal carbon-tax trajectories and the Social Cost of Carbon. It is common practice to present policymakers with a set of values for ethical parameters, namely the rate of pure time preference and inequality aversion. We showed that higher inequality aversion does not always translate into a higher carbon tax. The intertemporal trade-off comes into play: we do not want the current generation to sacrifice too much for the sake of future generations when we expect them to be richer.

Accounting for damages raises the SCC when they fall disproportionately on the poorest households (Dennig et al. 2015; Budolfson et al. 2021; Kornek et al. 2021). We showed that including impacts from tropical cyclones substantially raises the SCC (Krichene et al. 2021 in prep.). Another avenue is to explore more specifically the impacts on the production factors. We showed that accounting for these specific channels also raises the SCC. The distribution of damages becomes even more important if income is disentangled into capital and labor income (Young-Brun and Feindt 2022 in prep.).

Revealed ethics highlights a discrepancy between national and international concerns in evaluating inequality (Del Campo, Anthoff, and Kornek 2021). Following preferences and policies in national contexts should guide us toward high inequality-aversion values while following observed foreign aid from developed countries should guide us toward low inequality-aversion values. This divide leads to very different carbon-tax levels. In 2045, the difference could be to the tune of 200 USD/tC (national) against 400 USD/tC (international).

International transfers between countries play an essential role in the efficiency and equity part of the Social Cost of Carbon and optimal carbon tax levels (Chichilnisky and Heal 1994). When considering inequality within countries, the distribution of international transfers to households further influences climate policy (Kornek et al. 2021). This report did not study the role of international transfers. Further research should inform us on the role of real-world constraints faced by such transfers. This is especially important since Del Campo, Anthoff, and Kornek (2021) found that, on average, 80% of foreign aid is lost in the transfer, which may have important implications for optimal carbon-tax levels (Del Campo 2022 in prep.).

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