Climate change mitigation under socioeconomic uncertainty: does accounting for intragenerational inequalities favor more stringent targets?

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Abstract

The intergenerational trade-off of the climate change issue is intuitive: the costs of reducing emissions today, borne by the present generation, represent an investment to avoid climate change damages, which would otherwise affect future generations. The relationship between intragenerational equity and our willingness to pay for mitigation is less straightforward, as it depends on present inequalities, expected future inequalities, as well as the effect of both mitigation and climate damages on those two. In this paper, we analyze the preferred emission reduction targets considering both inter and intragenerational equity for the wide range of socioeconomic projections of the Shared Socioeconomic Pathways. We show that accounting for intragenerational equity favors equally or more stringent emissions reductions targets than stand-alone intergenerational equity, suggesting that the distributional effects of impacts outweigh those of mitigation. We also find that the overall effect of inequality aversion depends on assumptions about economic convergence. We therefore argue that welfare analysis of climate mitigation cannot overlook the critical role of socioeconomic assumptions driving intragenerational inequalities.

Introduction

Optimal climate policy requires balancing the costs of emission reductions with the future benefits of avoided impacts. This evaluation needs to be weighted according

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to the level of income of the individuals affected by these costs. As future generations are generally considered to be richer than present ones, future impacts of climate change tend to be discounted. This result is the essence of the Ramsey formula for the discount rate, in which inequality aversion deacreases the weight of future generations in the evaluation.

Relying on a single-agent model is however misleading, given that inequalities exist not only between but also within generations, between individuals and countries. Besides, mitigation costs affect countries and individuals unevenly in the short run, while economic impacts of a warmer climate fall primarily on poorer countries, so that climate change bears important distributional effects. In such a setting, considering intragenerational equity would favor allocations that do not hurt the poor of both present and future generations, which can induce either higher or lower optimal emission reductions, depending on the distribution of costs and benefits, and preference for the present. Without further analysis, it is therefore unclear whether including considerations of intragenerational equity would favour more or less stringent mitigation targets. If we assume that society is inequality averse, how do the inequalities induced by deploying costly mitigation options today compare with the inequalities induced by future climate change damages?

Theory-oriented works on the discount rate to apply to climate change have initially focused on intergenerational equity and uncertainty. More recently, Gollier (2015), Emmerling (2018) and Fleurbaey and Zuber (2015) lay the foundations for the analysis of intragenerational equity. In particular, they show that the effect of intragenerational inequality on the discount rate depends on socioeconomic assumptions regarding income convergence among countries or individuals, with convergence favoring higher discount rates. However, applied studies using Integrated Assessment Models to determine optimal emission levels are typically carried out at the global level, and thus overlook distributional aspects (Rao et al., 2017). An important step has been recently made by Budolfson et al. (2017), who account for distributional effects of impacts and mitigation in a stylized way. However, this study does not consider the effect of socioeconomic assumptions regarding growth and convergence. These assumptions matter since they drive future income levels, and because they are strongly linked to mitigation costs and impacts. For instance, reaching the same emissions target would be particularly costly in a world with high growth and low technical progress. Likewise, the same physical changes of the climate would not translate into the same economic costs, depending on the state of development of countries (and thus their ability to adapt). To our knowledge, studies analyzing the influence of socioeconomic projections on optimal climate policy have only been carried out at the global scale (Drouet and Emmerling, 2016; Yang et al., 2018).

Our question is related to Schelling's conjecture that properly accounting for intragenerational equity may change the sign of the effect of inequality aversion (Schelling, 1995). While higher inequality aversion tends to lower the weight of future generations in the case of single-agent generations, distribution of both costs and impacts within each generation could make an inequality averse decision maker prefer more stringent targets to protect the future poor from the impacts of climate change. Budolfson et al. (2017) showed that this reversal could occur under regressive damages and progressive mitigation costs. We further investigate this question when accounting for different socioeconomic assumptions.

We study the effect of intragenerational equity on the preferred global emissions targets under different socioeconomic pathways. We provide country by country projections, thus leaving aside within-country inequalities. We compare preferred global targets with and without intragenerational equity, and show that intragenerational equity tends to favor more stringent emissions targets, suggesting that the distributional effects of impacts outweigh those of mitigation, even for high pure rate of time preference. We also find that the overall effect of inequality aversion on the preferred target depends on socioeconomic assumptions: even though higher inequality aversion reduces the weight of future (richer) generations, we show that it favors lower-emission pathways if we expect convergence, while it is the contrary if inequalities persist over the 21st Century. This suggests that assumptions regarding convergence have a greater influence on optimal climate policy than those regarding global growth.

The paper is organized as follows. We detail our methodology to build the projections in section 1. Results are presented in section 2. Section 3 concludes.

1 Methodology

We build scenarios accounting for various possible socioeconomic evolution, and compute different emissions pathways under these conditions. Each emission pathway is associated with mitigation costs to reach the target, and with economic damages gradually occurring as the climate changes. We use a range of estimates for mitigation costs and economic damages. We perform a welfare evaluation of the different climate targets, and identify the preferred target according to its performance in terms of welfare.

1.1 The Shared Socioeconomic Pathways

We draw from the Shared Socioeconomic Pathways (SSP) exercise to build scenarios with different socioeconomic assumptions (Riahi et al., 2017). SSPs consist in five groups of socioeconomic pathways that contain combined and consistent hypothesis on demographics, technological progress, and broader socio-economic evolutions, leading to differentiated national growth projections in the absence of both mitigation and climate impacts.

Different aspects of these growth projections are particularly relevant for welfare analysis:

- Global growth for its evolution determines how much richer future generations will be compared to present ones. The richer they are, the smaller the marginal welfare losses from climate change, leading higher emission pathways to be more acceptable. As showed in figure 1, SSP 1, 4 and 5 depict high global growth.
- Economic catch-up between rich and poor countries affects the welfare evaluation of damages, in particular as poor countries are expected to suffer greater

losses from climate change. Convergence reduces the welfare losses from impacts, and thus favors more emissions. Inequalities at the end of the century remain high in SSP 3 and 4 (see the GINI evolution in figure 1).

The level of global growth and economic convergence assumed in each SSP is summarized in table 1.

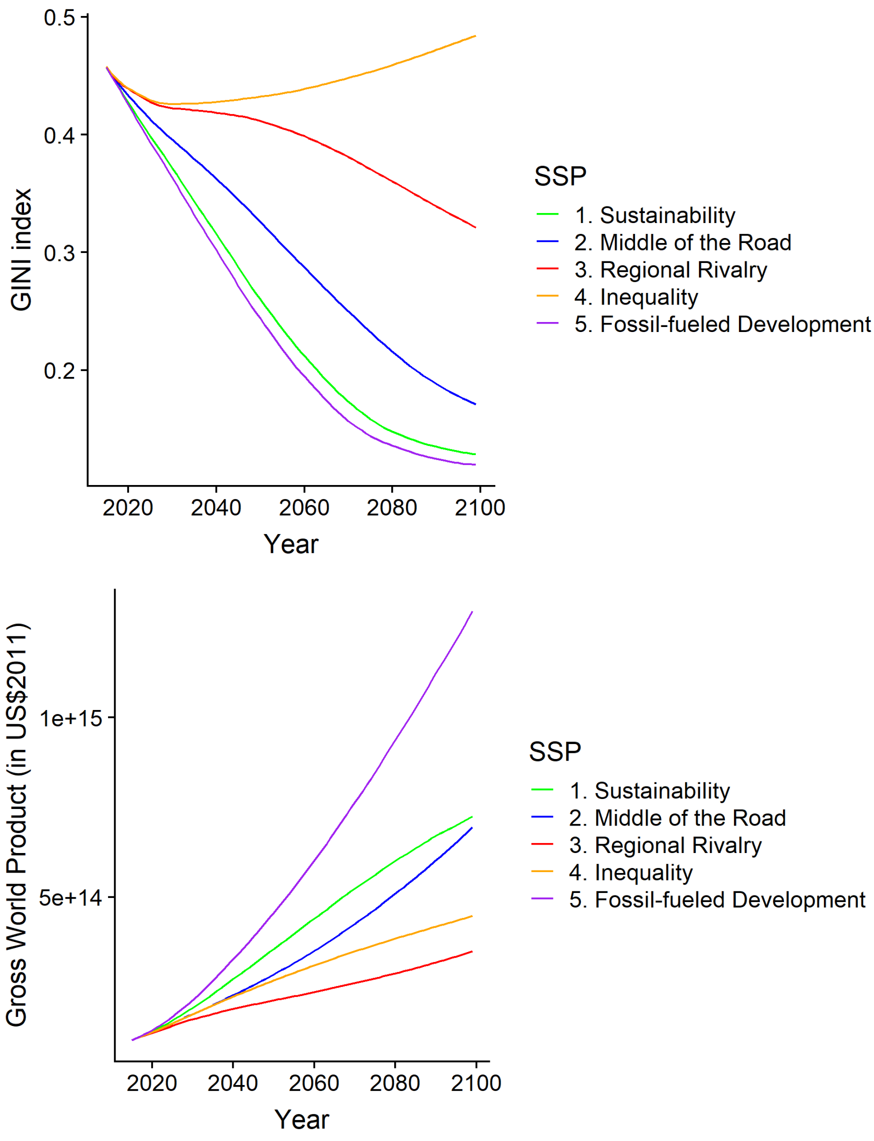

Figure 1: GINI and GWP by SSP

1.2 Mitigation costs

We use mitigation costs from the SSP database, so that the costs are consistent with the socioeconomic assumptions. For each SSP, some models have evaluated

Table 1: Different aspects of SSPs affecting welfare evaluation

	Global Growth	Catch-up	Mitigation costs
SSP 1	medium	high	low
SSP 2	medium	medium	medium
SSP 3	low	low	high
SSP 4	high	low	low
SSP 5	high	high	medium

the cost of reaching different radiative forcing targets. In total, four models with endogenous growth have run the scenarios (namely AIM/CGE, REMIND, MESSAGE and WITCH) for different Representative Concentration Pathways: RCP 6.0, RCP 4.5, RCP 3.4, RCP 2.6 and RCP 1.9. This allows us to estimate the mitigation costs to reach these targets in the five big regions (OECD, Reforming Economies, Asia, Africa and the Middle East, Latin America and the Carribean). RCP 6.0 is missing in some SSPs because baseline emissions are already under the level of RCP 6.0.

However, some models have not completed the exercise for all SSPs and RCPs, which creates a reporting bias. In particular, two models have run no scenarios for some SSPs (MESSAGE has no SSP 4 and 5, REMIND has no SSP 3 and 4). Besides, depending on the SSP, some models were not able to run the lowest RCPs, because it required assumptions deemed unreasonable. To avoid a bias in counting only the optimistic estimates, which have been reported, we fill the missing scenarios using a methodology proposed by Tavoni and Tol (2010). For each year given in the database, we perform a OLS regression to estimate (the natural logarithm of) Regional GDP given a series of factors: SSP, model, and RCP.

Results of this regression are shown in Annex (table 3) for year 2050. This procedures allows us to address the selection bias from the SSP database when using average mitigation costs, and better tackle uncertainty thanks to additional observations.

Once we have completed the database with missing scenarios, we can compute, for each RCP, the loss of regional GDP as a fraction of GDP in the corresponding baseline (i.e. with no climate policy). We translate these regional GDP losses into national GDP losses by assuming proportional mitigation costs within a region. We acknowledge that other downscaling methods could be used (van Vuuren et al., 2007), notably to account more precisely for the regressiveness of mitigation costs, but regional costs already allow us to distinguish five groups of countries that are heterogeneous.

1.3 Economic impacts of climate change

Finally, given the uncertainty around climate damages, we consider different estimates. Damage estimates differ especially between econometric-based regressions on growth and IAM-based damage functions affecting production. We use economic damage functions from RICE (Dennig et al., 2015), and we build on recent econometric studies (Burke et al., 2015; Dell et al., 2012). Each function entails different

Table 2: Uncertainty sources considered

Uncertainty	Models/Scenarios considered
Growth projections	5 Scenarios (SSP) depending on various demographic, technological and social evolution (Source: SSP database)
Mitigation costs	4 models: AIM/CGE, MESSAGE-GLOBIOM, REMIND-MAGPIE, and WITCH; and the average of the 5 (Source: SSP database, costs differ by SSP)
Economic impacts of climate change	4 models: RICE, Dell et al. (2012) (two specifications), Burke et al. (2015)

assumptions on the impacts, both on their levels and their distribution, which allows us to consider a vast array of possible impacts of climate change. As Dell et al. (2012) find that impacts differ between rich and poor countries, we develop two specifications: one "static" where damages affect current poor countries, and one where damages at each timestep depend on the level of income of the country, leaving the possibility for countries to switch from poor to rich status. This specification allows us to account for the role of development on economic damages. Richer countries are less sensitive to the impacts, because a smaller share of their GDP is dependent on activities affected by climate, and because they have a greater ability to adapt to climate change. Additionally, we display the projections with no economic impact of climate change, because some mitigation pathways may be asssociated with long term benefits, such that they can in some instances have higher welfare values than baselines.

1.4 Welfare analysis

For each scenario, we analyze which target (RCP) has the highest intertemporal welfare. Let C_{tr} be the aggregate consumption in country r at time t[1], N_{tr} the associated population, and ρ the pure rate of time preference, welfare W is:

$$W = \sum_t \sum_r N_{tr} u(C_{tr}/N_{tr}) \frac{1}{(1+\rho)^t} \tag{1}$$

Where $u(c) = c^{1-\eta}/(1-\eta)$. η represents aversion to inequality.

To disentangle the effect of pure intergenerational equity, we also compute the

[1]see Appendix on how to compute Consumption based on per capita GDP

welfare based on average consumption at each timestep.

$$W = \sum_t N_t u(\sum_r C_{tr}/N_t) \frac{1}{(1+\rho)^t} \tag{2}$$

Choice of parameters. We cover a large range for the pure rate of time preference ρ, from 0 to 3%, given that the parameter is subject to controversy (Stern, 2007; Nordhaus, 2008). Inequality aversion η ranges from 1 to 3, a common specification in the climate economics literature.

2 Results

For each combination of socioeconomic scenario, damage function and mitigation cost estimates, we plot the preferred emission target (RCP) in terms of total welfare.

2.1 The importance of accounting for intragenerational equity

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First we compare the preferred RCP, between a case with regional heterogeneity and one where regional heterogeneity is disregarded, i.e. case where only intergenerational equity matters (figure 2). As said before, whether the inclusion of intragenerational inequalities leads to higher or lower emissions path is ambiguous, because several issues are at stake. In theory, it depends on the balance between the present welfare losses of mitigation and the future welfare benefits of avoided impacts. This balance is influenced by: the level and distribution of costs from the estimates we use for damage and mitigation, as well as the prospect for growth and convergence. Under regressively shared mitigation costs, society would be less willing to reduce greenhouse gas emissions. Conversely, regressively shared impacts tend to favor lower emissions pathways. Finally, the expected reduction in between-country inequality decreases the welfare benefits of avoided impacts, and thus society's willingness to pay for mitigation. In our projections, we find that if the decision was made based on average consumption at each period, the same or a higher RCP would be systematically chosen for all SSP and all damage functions, and for all values of the parameters defining the social welfare function. In terms of absolute targets, considering intergenerational equity only, high RCPs are generally optimal, meaning that we are willing to pay only for moderate mitigation to limit future impacts. Exceptions where low RCPs are optimal can still occur under high damage levels (Burke's damages). Conversely, when modeling intragenerational heterogeneity, low RCPs can be optimal in many instances.

Unsurprisingly, the difference between the preferred RCP given by both methods is particularly important under socioeconomic evolutions that predict sustained inequality levels (SSP 3 and 4), and for econometrics-based damage functions which assume high heterogeneity in damage distribution. For RICE damages, results are mostly the same for both methods, suggesting that the distributional impacts of these damage estimates are very limited.

This comparison shows first that the intra-generational distribution is a primary driver of optimal abatement, and second that distributional effects of impacts, though they are discounted and apply to richer-on-average individuals, can outweigh distributional effects of mitigation.

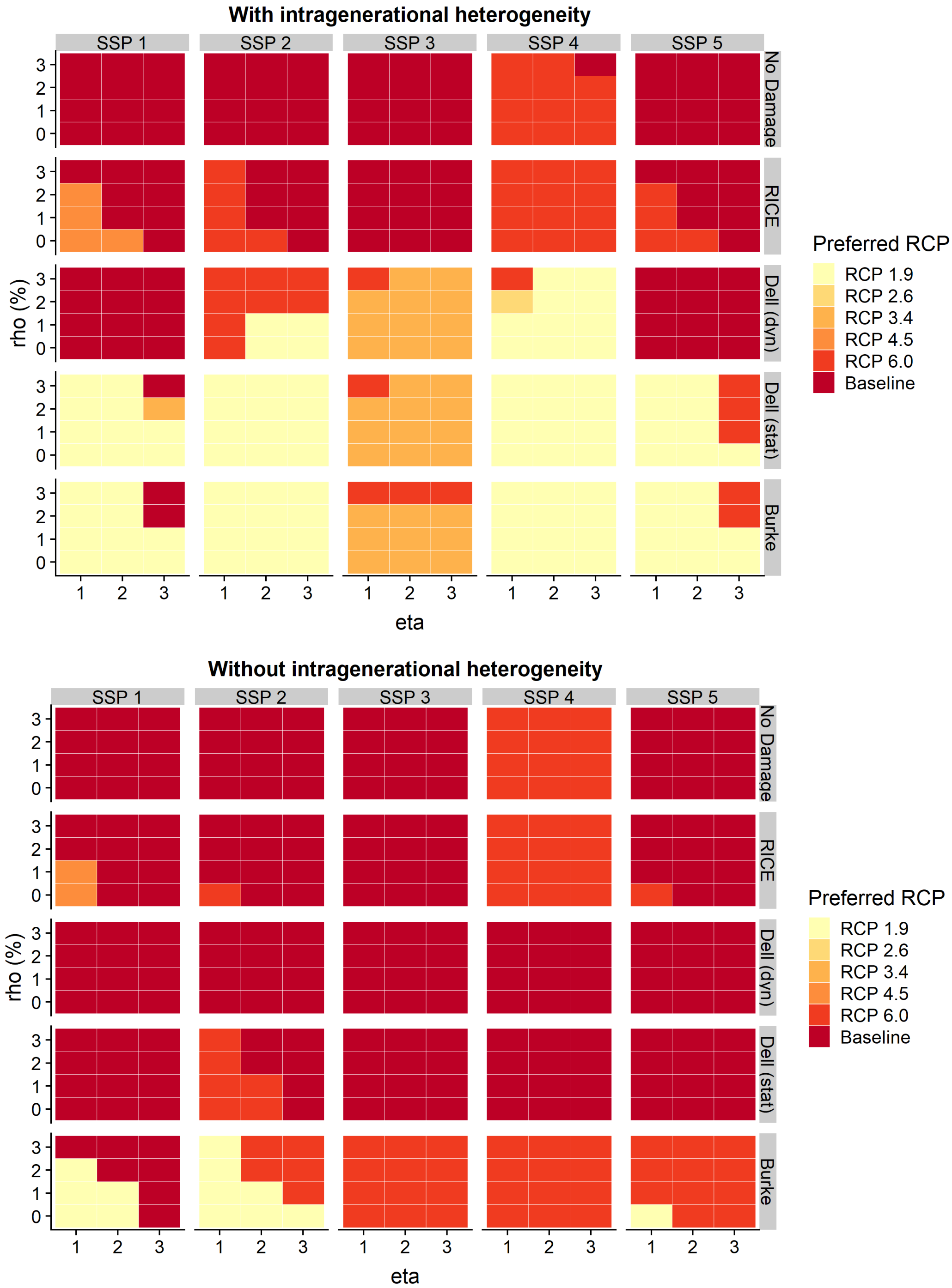

Figure 2: Preferred RCP depending on socioeconomic assumptions, damage estimates and parameters of the social welfare function. Mitigation costs here are based on the average of the four models. Vertical grids represent the damage function. 'N': No Impact, 'R': RICE, 'DD': Dell Dynamic, 'DS': Dell Static, 'B': Burke. Horizontal grid is the SSP.

2.2 The influence of climate damages socioeconomic pathways

We analyze the role of the damage function, mitigation cost estimates and socioeconomic evolution (see figure 3). We find that damage functions and socioeconomic scenario are the main drivers of the preferred RCP. Mitigation cost estimates usually play a more moderate role.

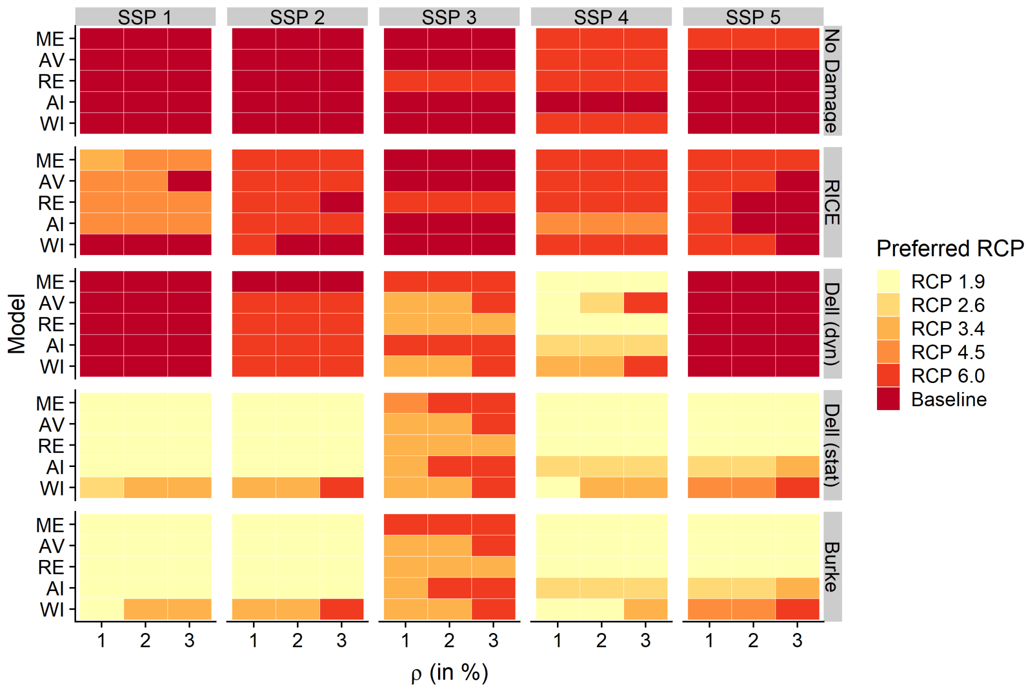

Figure 3: Preferred RCP for $\eta = 1$. The grids along the x-axis represent SSP, while those along the y-axis are the damage functions. Within each box, models are along the vertical axis, 'ME': MESSAGE, 'AV': Average of the four, 'RE': REMIND, 'AI': AIM/CGE, 'WI': WITCH. Along the horizontal axis is the rate of time preference.

Combination of damage functions and SSP. First, we find that the choice of the damage function has a strong influence on the preferred RCP, in combination with the socioeconomic pathway (see figure 3). Under the highest damage estimates (Dell Static and Burke), the lowest RCP is almost always preferred. An exception is SSP 3, where RCP 6.0 is preferred. This is explained by the high mitigation costs in a scenario with low growth rates and substantial inequality. Besides, in some SSPs, the high mitigation costs estimates by the WITCH and AIM/CGE models lead to a preference for RCP 3.4, 4.5 or even 6.0. At the opposite of the damage sprectrum, higher RCPs are preferred under RICE damage estimates, for which the choice of the RCP that has higher total welfare is mostly between baseline and RCP 6.0. Rather lower RCPs are chosen in the case of SSPs that have low mitigation costs (SSP 1 and 4), in particular if convergence is assumed, in line with theory (Emmerling, 2018;

Gollier, 2015). In SSP 1, in particular, RCP 4.5 can be preferred. Finally, under a modeling of damages that includes some form of adaptation (Dell Dynamic), results are contrasted depending on the SSP: the high convergence of SSP 1 and 5 allows most countries to adapt to climate change, so that baselines are optimal. If the world follows the low growth trajectory of SSP 3, mitigation costs are high and RCP 6.0 would be preferred, as in the case of no-adaptation (Dell Static). Finally, if a group of countries stays behind (SSP 4), the preferred RCP depends on the mitigation costs estimates, but the impacts imposed on the low income countries pushes for higher mitigation targets.

Mitigation costs. There is some variability in outcomes depending on mitigation costs estimates, suggesting that it is a relevant parameter. However, we find no clear-cut ranking of the different estimates. Though all models are ranked in terms of global costs (with WITCH being the one showing the highest costs in the set of scenarios considered), the distribution of these costs can be shared differently between regions depending on the model and SSP, which results in differences in preferred RCP.

2.3 Time and inequality preferences

The pure rate of time preference (ρ) drives the intertemporal weighing of welfare, regardless of how welfare is distributed within each generation. The greater the pure rate of time preference, the more we discount future damages, so the less we value emissions reductions – thus the higher the preferred RCP (see figure 2 for average mitigation costs, and figure 3 for the whole range of mitigation costs with inequality aversion $\eta = 1$).

Inequality aversion (η) has ambiguous effect on the outcomes. On the one hand, a higher inequality aversion gives higher weight to the present poor who pay for mitigation costs. The magnitude of this effect depends on the level and regressiveness of mitigation costs. A higher η also reduces the weight given to richer-on-average future generations, more or less so depending on projected global growth. These two effects reduce society's willingness to undertake mitigation. On the other hand, inequality aversion also influences the weight given to the future poor who will be affected by climate change, relative to the future rich. This effect makes society favor more mitigation under a higher η. The overall effect of inequality aversion depends on the balance of these three effects.

Based on our projections, we find that the overall effect is first conditioned by the damage function (see figure 2 for average costs, and 4 for the whole range of mitigation cost estimates and $\rho = 0.01$). If damages are low, the higher the inequality aversion, the more society wishes to prevent the present poor from paying mitigation costs, which results in less mitigation, whatever the socioeconomic assumptions. However, for higher damages (Dell Static and Burke), the overall effect depends on the socioeconomic pathway, and notably the convergence assumptions. In SSP 3 and 4, there are still many poor in the future, so that the welfare impacts of climate change are large, and thus more inequality aversion induces more mitigation, despite the fact that future generations are richer on average. This occurs even for a high pure rate

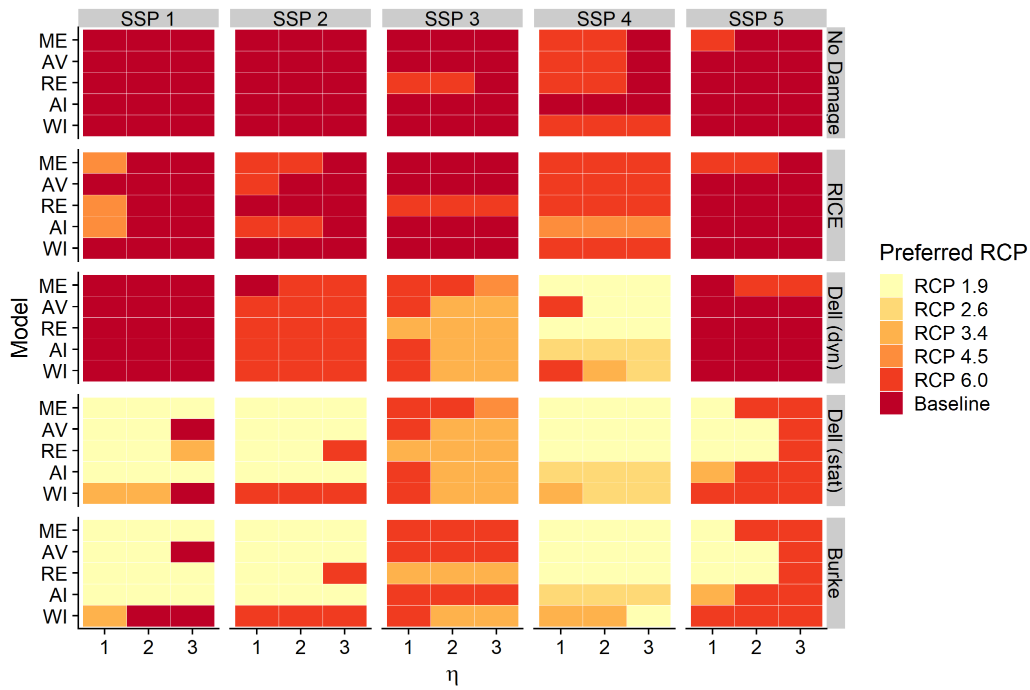

Figure 4: Preferred RCP for $\rho = 0.01$. The grids along the x-axis represent SSP, while those along the y-axis are the damage functions. Within each box, models are along the vertical axis, 'ME': MESSAGE, 'AV': Average of the four, 'RE': REMIND, 'AI': AIM/CGE, 'WI': WITCH. Along the horizontal axis is the inequality aversion.

of time preference. Conversely, in SSP 1 and 5, low-income countries are expected to grow fast, and the situation of the present poor drives the evaluation. A similar remark can be made for Dell Dynamic damages, reinforced by the fact that in case of convergence, future impacts are even more limited.

To conclude, inequality aversion affects both intergenerational equity, via the relative weight given to future generations, and intragenerational equity, because it sets the weight attributed to poor relative to rich. While the intergeneration equity effect favors present generation and thus less mitigation costs, the direction of the intragenerational equity effect can be either positive or negative. We find that the direction of the overall influence of inequality aversion on the preferred emission target depends on assumptions about future convergence. In addition to the distributional effects of climate damages and mitigation (Budolfson et al., 2017), assumptions regarding socioeconomic evolution play an important role on the effect of inequality aversion, and high future inequality levels (in our case, close to present ones) make for a possible condition under which Schelling's conjecture holds.

3 Conclusion

Finding the optimal emission target is an issue of intertemporal allocation of resources, between present generations who will pay for greenhouse gas emission reductions, and future ones who will benefit from avoided climate damages. But beyond this intergenerational comes intragenerational equity issues, as both mitigation costs and impacts are unevenly distributed among and within world regions, and that inequality levels may change in the future.

In this paper, we investigated two related questions: (1) Does accounting for intragenerational equity increase our willingness to undertake mitigation efforts? (2) When accounting for intragenerational equity, does increasing inequality aversion push for higher or lower efforts? In particular we investigate the interplay between inequality aversion and socioeconomic assumptions.

We answer these questions using socioeconomic scenarios from the Shared Socioeconomic Pathways, based on contrasted hypothesis regarding economic growth and convergence, and test for different mitigation costs and damages estimates. Regarding the first question, we find that accounting for intragenerational equity systematically pushes for at least as much mitigation, compared to a case where only intergenerational equity would be considered. This suggests that distributional effects of damages tend to be equally or more important than those of mitigation, although the former concern future, richer generations. Regarding the second question, we find that as soon as high damages estimates are considered, socioeconomic assumptions regarding convergence influence the overall effect of inequality aversion. Under low prospects of convergence among countries, inequality aversion pushes for more stringent mitigation. Economic convergence, rather than economic growth, seems to determine the overall effect of inequality aversion to determine the choice of the preferred RCP. This highlights new conditions under which Schelling's conjecture can be true.

Our results highlight the important role of intragenerational equity when considering global emission targets. As intragenerational equity is strongly tied to the prospect of future inequality, we demonstrate that welfare analysis of mitigation cannot overlook the critical role of socioeconomic assumptions regarding economic convergence.

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A Filling up database with missing observations

For each year in the database, we perform an OLS-regression on the natural logarithm of Regional GDP, given following factors: SSP, model, and RCP. Results for Year 2050 are presented in table 3. Figure 5 compares the database with and without the added dots for SSP 4.

Table 3: OLS regression on Regional GDP in 2050

	Dependent variable:				
			ln(X2050)		
	ASIA	LAM	MAF	OECD	REF
	(1)	(2)	(3)	(4)	(5)
SSP2	-0.292^{***} (0.007)	-0.185^{***} (0.006)	-0.238^{***} (0.015)	-0.121^{***} (0.003)	-0.181^{***} (0.017)
SSP3	-0.618^{***} (0.009)	-0.373^{***} (0.008)	-0.501^{***} (0.018)	-0.353^{***} (0.004)	-0.370^{***} (0.021)
SSP4	-0.368^{***} (0.009)	-0.265^{***} (0.008)	-0.418^{***} (0.019)	-0.062^{***} (0.004)	-0.158^{***} (0.022)
SSP5	0.199^{***} (0.008)	0.167^{***} (0.007)	0.247^{***} (0.017)	0.251^{***} (0.003)	0.227^{***} (0.020)
RCP26	0.041^{***} (0.010)	0.033^{***} (0.009)	0.066^{***} (0.021)	0.020^{***} (0.004)	0.082^{***} (0.024)
RCP34	0.056^{***} (0.010)	0.044^{***} (0.008)	0.100^{***} (0.020)	0.026^{***} (0.004)	0.117^{***} (0.023)
RCP45	0.071^{***} (0.010)	0.055^{***} (0.008)	0.121^{***} (0.020)	0.032^{***} (0.004)	0.154^{***} (0.023)
RCP60	0.083^{***} (0.011)	0.063^{***} (0.009)	0.137^{***} (0.022)	0.037^{***} (0.004)	0.177^{***} (0.026)
RCPBa	0.082^{***} (0.010)	0.062^{***} (0.008)	0.137^{***} (0.020)	0.036^{***} (0.004)	0.181^{***} (0.023)
ModelMESSAGE-GLOBIOM	-0.009 (0.008)	0.078^{***} (0.007)	0.048^{***} (0.016)	0.043^{***} (0.003)	0.123^{***} (0.019)
ModelREMIND-MAGPIE	0.002 (0.007)	0.078^{***} (0.007)	0.035^{**} (0.016)	0.083^{***} (0.003)	-0.342^{***} (0.018)
ModelWITCH-GLOBIOM	-0.123^{***} (0.007)	-0.015^{**} (0.006)	-0.209^{***} (0.014)	0.043^{***} (0.003)	0.312^{***} (0.016)
Constant	11.798^{***} (0.009)	9.912^{***} (0.008)	10.361^{***} (0.020)	11.184^{***} (0.004)	9.020^{***} (0.023)
Observations	80	80	80	80	80
R^2	0.995	0.991	0.978	0.998	0.967
Adjusted R^2	0.994	0.989	0.974	0.998	0.961
Residual Std. Error (df = 67)	0.022	0.020	0.047	0.009	0.054
F Statistic (df = 12; 67)	$1,015.378^{***}$	599.903^{***}	247.844^{***}	$2,884.552^{***}$	163.629^{***}
Note:					$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

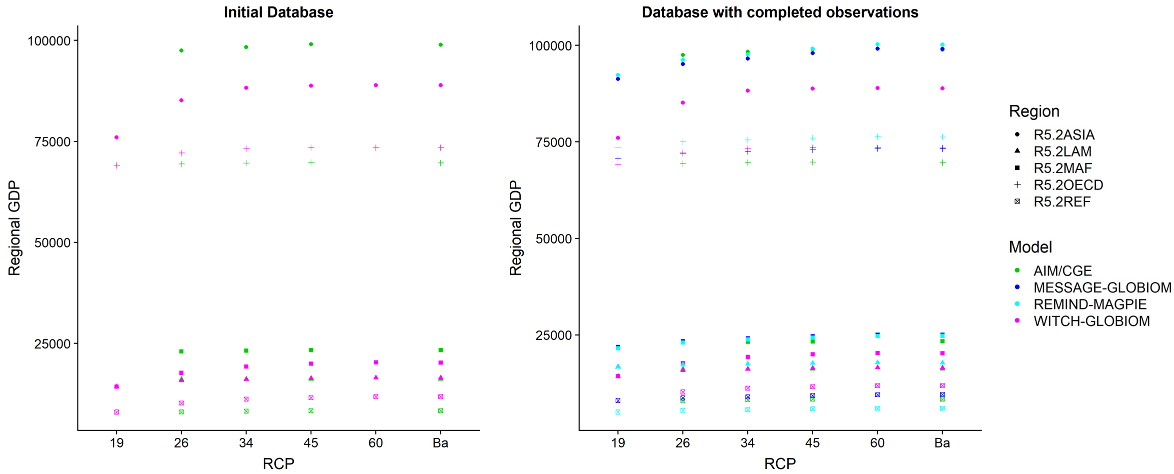

Figure 5: Comparison for SSP4, without and with added scenarios

B Additional elements on methodology

B.1 Savings rate: from GDP to consumption

To translate GDP into consumption, we use, for each country, the median regional savings rate from AR5 scenario database, using the same scenarios as in Drouet et al. (2015).

B.2 Climate system

Projections of temperature changes at the global and national levels are based on the median outcomes from the Fifth Climate Model Intercomparison Project (CMIP5) (Taylor et al., 2011)

B.3 Extending timeframe

Our socioeconomic projections only go until 2100. However, benefits of mitigation start being significant in the second part of the 21st Century, and many benefits occur after this date. Integrated Assessment Models typically consider timeframes of 300 or 400 years. To account for these benefits, we extend the projections by assuming consumption levels stay at their 2100 level through 2200. Though crude, this prevents making ad hoc assumptions about the 22nd Century while accounting for the fact that benefits will occur after 2100.