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Publication date
2024

Document Version
Accepted author manuscript

Citation (APA)
Zheng, Y., Emmerling, J., Grottera, C., & Marangoni, G. (2024). *Within-country inequality and climate change - A model for IAMs with an application to multiple countries*. Paper presented at 27th Annual Conference on Global Economic Analysis, United States.
https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=7200

Within-country inequality and climate change - A model for IAMs with an application to Multiple Countries *

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April 12, 2024– DRAFT Do not quote

Abstract

The role of inequality for the evaluation and policy response to climate change has received great attention in recent years. Yet, endogenizing the evolvement of inequality has so far not been addressed with standard IAMs widely used. We address this research gap by developing an inequality module based on household deciles and an optimization routine for each group of households. Capturing skill premia, capital income dynamics, and consumption heterogeneity including energy and food consumption, we are able to endogenously simulate the impact of carbon prices and other macroeconomic drivers on the evolvement of inequality consistent with the IAM socioeconomic and climate scenarios. Moreover, we validate the module by a hind-casting exercise and find broad consistence with observed inequality trends.

*The authors would like to thank Bjoern Soergel and Francis Dennig for very helpful comments. The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821124 (NAVIGATE). The usual caveat applies.

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1 Introduction

Climate change modelling involves representing phenomena and agents that interact in very complex ways. Climate impacts affect livelihoods through different channels, including changes in production output and resource availability, price variation of essential goods and even destruction of assets and hence has important implication on individuals resulting in changes in inequality in poverty (Burke et al., 2015; Rao et al., 2017; Dell et al., 2014, 2012; Schlenker and Roberts, 2009; Hsiang, 2010). These impacts lead to shifts in sectoral employment, income losses, adverse health impacts and higher risk of food and water insecurity.

Climate mitigation policies also generate income and price shocks. Structural shifts are required to limit temperature increase well below 2 degrees relative to pre-industrial levels, as postulated by the Paris Agreement. Such changes range from technological deployment to carbon pricing mechanisms, which affect price signals, unemployment and income generation, consumption choices and overall growth. Moreover, in a world with such different dimensions of inequality and sources of heterogeneity such as income, wealth, health, education, etc., it is difficult to predict how they will interact with pre-existing inequalities (Klinsky and Winkler, 2018; Markkanen and Anger-Kraavi, 2019; Fouquet and Pearson, 2012).

There is consensus that climate change will disproportionately affect the poorest, with lower income strata carrying the burden of climate impacts (Tol et al., 2004; Tol, 2009; Hallegatte and Rozenberg, 2017; Hsiang et al., 2019; Mendelsohn et al., 2006). Many lower income countries are dependent on agricultural activities that are especially vulnerable to climate change (Byers et al., 2018; **?**). They also lack financial resources, leading to lower adaptive capacity. From the mitigation perspective, on the other hand, carefully designed policies are needed, otherwise they risk posing a heavier burden on the poorest who (i) contribute less to GHG emissions, given their lower per-capita emissions, and (ii) have lesser space for coping with eventual adverse effects of climate policies such as energy price increases (Chancel and Piketty, 2015; Oswald et al., 2020; Chakravarty et al., 2009).

While climate change generates shocks on social heterogeneity, there are rising interests in modeling inequality and its dynamics. Wage inequality is studied from the perspective of skilled-based technological change (Acemoglu, 2002, 2003), and education (Aghion, 2002; Lemieux, 2006). For example, Aghion (2002) build a labor market equilibrium model with adaptability constraints to understand inequality within and between educational groups. Another strand of models are build over the framework of stochastic growth models which allow heterogeneity in labor productivity or skill prices (Jones and Kim, 2018; Gabaix et al., 2016), or heterogeneity in wealth return and initial wealth distribution (Jones, 2015). These models well explain the Pareto tail of top income distribution, and have succeed in replicating the historical wealth distribution. Furthermore, with the financial development and increasing wealth accumulation, the source of top income is now being more capital/wealth based instead of labor based (Piketty et al., 2018; Alvaredo et al., 2017; Garbinti et al., 2018). This thus calls for better modelling capital and wealth distribution as well as inter-generational wealth dynamics (Piketty, 2020; Benhabib et al., 2011a). In all, these inequality models shed lights on modeling structurally the channels through which climate change affects inequality.

The scientific community has made several advancements in modelling capacities in the last decades, significantly improving their ability to assess inequality and poverty in its multiple dimensions, providing scientifically robust inputs for policy design. Models of different natures have proven to represent such interaction at varying degrees, hence being suitable for answering different questions. CGE models are often built at the national level and, due to their stylized representation of agents‘ demand and factor supply, have the flexibility to incorporate a more dis-aggregate household using different techniques, such as explicit modeling of multiple households within their framework, micro-simulation of a large number of household types or directly modeling of income distribution by defining a function form of distribution (van Ruijven et al., 2015). Higher resolution allows for incorporating other factors such as education and skills, gender and household assets (Klinsky and Winkler, 2018). They also represent the role of state in a simplified yet straightforward fashion, allowing for simultaneously simulating climate and social policies, such as different recycling schemes for a carbon pricing mechanism.

IAMs are applied to analyze the interaction between climate and the economy Nordhaus (2014). They usually represent the global economy and aggregate countries at the regional level. As much as accounting for inequalities between regions is a major feature of IAMs, regions are represented as an average, and much of the heterogeneity within countries is masked by regional averaging of economic variables. Dennig et al. (2015) introduce heterogeneity in an IAM model by dis-aggregating households into quintiles in twelve different regions and find that, when damages hit the poor more, the optimal mitigation effort is greater than when damages are proportional to income. Results of such kind show that accounting for within-country heterogeneity enables us to differentiate inequality experienced within and across regions and changes aggregate outcomes of optimal pathways (Klinsky and Winkler, 2018).

The Shared Socioeconomic Pathways (SSPs) are largely used by the IAM community to derive plausible future scenarios of societal transformations, accounting for both challenges to mitigation and adaptation to climate change (O'Neill et al., 2014). The main drivers of socioeconomic development have been quantified, such as population (KC and Lutz, 2017), long-term economic development (Dellink et al., 2017; Crespo Cuaresma, 2017), urbanization (Jiang and O'Neill, 2017) and cross-cutting developments on the energy and land-use systems, as well as air pollution (Bauer et al., 2017; Popp et al., 2017; Rao et al., 2017). As much as those are key factors for determining income distribution, inequality within countries has been assessed mostly through a qualitative approach in the SSP story-lines. Recently, they have been used to robustly assess the inequality between countries due to uneven climate damages and differentiated mitigation costs, see Taconet et al. (2020).

A first attempt to quantify income inequality at the country level was made by Rao et al. (2018), who present global scenarios of future national Gini coefficients for the five SSPs. It is based on an econometric model of the evolution of income inequality within countries that considers quantified dimensions of the SSPs, such as total factor productivity (TFP) and different levels of education attainment, in addition to social public spending. TFP presents an ambiguous effect on inequality (a primarily increasing effect, which is however counterbalanced by a positive effect on the quality of education spending), whereas education has an equalizing effect on inequality. Their results are broadly consistent with the SSP narratives, with discrepancies being most salient in emerging economies. Nonetheless, the Gini index is a relative measure of inequality, and provides little information on the situation of the poorest, in absolute terms of consumption, for example. The authors also draw attention to gaps in the SSP narratives related to structural changes in capital and labour income.

We contribute to closing this gap by developing an endogenous inequality module that can be linked to IAM results in terms of the underlying economics, socio-demographics, and energy and food prices and quantities, resulting in inequality projections consistent with the underlying IAM. In doing so, we provide three main contributions to the literature: (1) endogenously the inequality distribution based on deciles linked to macroeconomic boundary conditions, calibrated to household surveys and based on an microeconomic optimization model. (2) Evaluate the climate policy incidence based on carbon prices and implied energy and food prices and potential recycling schemes across the distribution. (3) Take into account the impacts and their incidence along the income distribution based on recent empirical evidence.

2 An inequality module for IAMs

We consider a macroeconomic model representing a set of countries or region $n = 1..N$ over a time horizon $t = 1..T$ which represents the macro-economy for instance through a Ramsey type growth model, a CGE model, or a general IAM. The macro model produces as a result the vector of variables including K_{tn}, the macroeconomic capital stock in the economy, and L_{tn}, the aggregate labor or population. Moreover, on the consumption side, the consumption of goods i are given by the total consumption vector C_{itn}, and a set of net[1] prices associated with each good p_{itn}. Moreover, factor incomes, that is, average wages w_{tn} and interest rates r_{tn} are an output of the model. Finally, given we consider skill/human capital as driver of inequalities, we consider educational attainment of different classes e (no, primary, secondary, tertiary education completed), EDU_{eqn}.

The inequality module thus features Q quantiles $q = 1..Q$ (deciles in most applications), which add another index to the economic variables and distribute the total economic values across consumption/income quantiles, where $q = D1$ represents the poorest share of the population. For each representative household in each quantile, we have its optimization program given by

$$max_{c_{iqt}} \sum_{t=1}^{T} \beta^t \frac{(C_{qt})^{1-\gamma}}{1-\gamma} \tag{1}$$

The bundle of all goods C_{qt} is a CES composite:

$$C_{qt} = \left[\sum_i \alpha_i C_{iqt}{}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where C_{iqt} represents energy goods for transportation, energy goods for buildings, and other consumption goods. σ is the elasticity of substitution between the different goods.

Each household maximizes utility subject to the constraint on wealth accumulation, given by

$$k_{qt+1} = k_{qt}(1 + r_{qt}) + w_{qt} l_{qt} - \sum_i p_{it} c_{iqt} \tag{3}$$

where quantile-specific capital (or wealth), returns on capital, wages, and labour supplies are given by the macroeconomic model and micro-data based estimates described below.

While labour decision we take as exogenous in this version of the model, the savings rate s_{qt} of each decile is endogenously determined and can be computed as $s_{qt} = \frac{k_{qt} r_{qt} + w_{qt} l_{qt} - \sum_i p_{it} c_{iqt}}{k_{qt} r_{qt} + w_{qt} l_{qt}}$.

[1] Typically models will use producer prices without taxes or subsidies to consider the macroeconomic scarcity of goods. Hence in orer to take into account final end use prices one might need to adjust them based on the existing fiscal distortions.

2.1 Consumption

Utility maximization implies the following equilibrium conditions,

$$C_{qt}^{-\gamma} = C_{qt+1}^{-\gamma}(\frac{P_{qt}}{P_{qt+1}})\beta(1 + r_{qt+1}) \tag{4}$$

where saving is implicitly decided from Euler condition (4) and wealth constraint (3), $P_{qt}$is the price of the bundle of all consumption goods given by,

$$P_{qt} = (\sum_i \alpha_i^\sigma P_{iqt}^{1-\sigma})^{1/(1-\sigma)} \tag{5}$$

From equation (2), the demand of the transportation, buildings and other goods is given by,

$$C_{iqt} = C_{qt}\left(\frac{\alpha_i P_{qt}}{P_{iqt}}\right)^\sigma \tag{6}$$

2.2 Labour income and skill premia

Wage inequality is closely linked to education (Aghion (2002); Lemieux (2006)). A growing body of literature investigates the determinants of wage differentials. Among the consistent findings across the various surveys are a remarkable increase in educational attainment in recent decades worldwide. Over the time, returns to schooling tend to decrease modestly, despite rising average levels of schooling attainment. This suggests that the world demand for skills has been increasing as world skill supply has also increased (Patrinos and Montenegro (2014); Crespo and Reis (2009)) Moreover, returns to schooling vary by level, being the highest at the tertiary level. This shows that the demand for higher levels of skills is increasing and that the demand for skills is global. At the same time the returns to schooling are high at the primary level, signaling continued need for basic skills. Returns are lower at the secondary school level. According to Montenegro and Patrinos (2013), this is a result of the increased demand for skills, prompting the best secondary school students to continue their education at the tertiary level. Finally, there is also evidence that private returns to education are higher in low or middle income economies than in industrialized economies. Theory suggests that countries which are further away from the technological frontier profit more than proportionally from investment in human capital, since an educated labour force accelerates the process of catching up with technology advancements (Nelson and Phelps (1966); Crespo Cuaresma (2017)). Average education years determine differences on labour income across quantiles. The model explicitly assumes a (non-constant) premium on wage parameter that responds to the schooling years of the representative agent in each quantile. The model builds upon Mincer‘s human capital wage function, which relates the logarithm of worker earnings (wages) with investment in human capital, through the individual's schooling (measured in years of completed education) and experience after finishing his studies (measured in working years). Our model focuses on schooling years, notably taking into consideration educational attainment categories. This allows for incorporating a threshold effect, that is when the rate of return to schooling becomes relatively higher after a given point/level.

The average wage w_{tn} is given by the macro model. In order to obtain wages by quantiles, we use educational attainment data by quantile to compute education category dependent wage premia $\pi_{qt}$and henceforth wages.

Besides, we allow for a varying rate g_e in wage premia over the years, considering that wage premia across education year will increase for the future education year projection.

$$\pi_{et} = \pi_{et}^{t=0}(1 + g_e)^t \tag{7}$$

The wage of each quantile is computed compared to the wage of bottom quantile ($q = D1$),

$$w_{qt} = w_{D1t}(1 + \pi_{qt})^{(EDU_{qt} - EDU_{D1t})} \tag{8}$$

where the average wage across quantiles equals the average wage w_{tn} given by the macro model.

We explain the calibration of education years across quantiles, wage premia, and wage premia varying rate in the next section.

2.3 Capital income

The concentration of wealth far exceeds the concentration of labour income, and is therefore an underlying source of inequality (Saez and Zucman (2016)). Wealth returns are found to be positively correlated with wealth (Fagereng et al. (2020); Benhabib et al. (2011b); Bach et al. (2020)) therefore substantially amplifying the gap between upper and bottom deciles of social strata and explaining most of the historical increase in top wealth shares (Bach et al. (2020)). We consider a decile specific return on wealth,

$$r_{qt} = \frac{10 r_{tn}(1 + \pi_r)^q}{\sum_q (1 + \pi_r)^q}$$

where $\pi_r$is the capital return premium, with which the higher income group receives higher returns, and lower income group receive lower returns. The average capital return equals the interest rate r_{tn} given by the macro model.

3 Data of Household Surveys and Calibration of Deciles

To be complete

References

Acemoglu, Daron (2002) "Technical change, inequality, and the labor market," *Journal of economic literature*, 40 (1), 7–72. 1

——— (2003) "Patterns of skill premia," *The Review of Economic Studies*, 70 (2), 199–230. 1

Aghion, Philippe (2002) "Schumpeterian growth theory and the dynamics of income inequality," *Econometrica*, 70 (3), 855–882. 1, 2.2

Alvaredo, Facundo, Lucas Chancel, Thomas Piketty, Emmanuel Saez, and Gabriel Zucman (2017) "Global inequality dynamics: New findings from WID. world," *American Economic Review*, 107 (5), 404–09. 1

Bach, Laurent, Laurent E. Calvet, and Paolo Sodini (2020) "Rich Pickings? Risk, Return, and Skill in Household Wealth," *American Economic Review*, (in press). 2.3

Bauer, Nico, Katherine Calvin, Johannes Emmerling et al. (2017) "Shared Socio-Economic Pathways of the Energy Sector – Quantifying the Narratives," *Global Environmental Change*, 42, 316–330, 10.1016/j.gloenvcha.2016.07.006. 1

Benhabib, Jess, Alberto Bisin, and Shenghao Zhu (2011a) "The distribution of wealth and fiscal policy in economies with finitely lived agents," *Econometrica*, 79 (1), 123–157. 1

——— (2011b) "The distribution of wealth and fiscal policy in economies with finitely lived agents," *Econometrica*, 79 (1), 123–157. 2.3

Burke, Marshall, Solomon M Hsiang, and Edward Miguel (2015) "Global non-linear effect of temperature on economic production," *Nature*, 527 (7577), 235–239, 10.1038/nature15725. 1

Byers, Edward, Matthew Gidden, David Leclère et al. (2018) "Global exposure and vulnerability to multi-sector development and climate change hotspots," *Environmental Research Letters*, 13 (5), 055012, 10.1088/1748-9326/aabf45. 1

Chakravarty, Shoibal, Ananth Chikkatur, Heleen de Coninck, Stephen Pacala, Robert Socolow, and Massimo Tavoni (2009) "Sharing global CO2 emission reductions among one billion high emitters," *Proceedings of the National Academy of Sciences*, 106 (29), 11884–11888, 10.1073/pnas.0905232106. 1

Chancel, Lucas and Thomas Piketty (2015) "Carbon and inequality: From Kyoto to Paris Trends in the global inequality of carbon emissions (1998-2013) & prospects for an equitable adaptation fund World Inequality Lab,"Technical report. 1

Crespo, Anna and Maurício Cortez Reis (2009) "Sheepskin effects and the relationship between earnings and education: analyzing their evolution over time in Brazil," *Revista Brasileira de Economia*, 63, 209 – 231, `http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0034-71402009000300002&nrm=iso`. 2.2

Crespo Cuaresma, Jesús (2017) "Income projections for climate change research: A framework based on human capital dynamics," *Global Environmental Change*, 42, 226 – 236, https://doi.org/10.1016/j.gloenvcha.2015.02.012. 1, 2.2

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken (2012) "Temperature Shocks and Economic Growth: Evidence from the Last Half Century," *American Economic Journal: Macroeconomics*, 4 (3), 66–95, 10.1257/mac.4.3.66. 1

——— (2014) "What Do We Learn from the Weather? The New Climate-Economy Literature," *Journal of Economic Literature*, 52 (3), 740–98, 10.1257/jel.52.3.740. 1

Dellink, Rob, Jean Chateau, Elisa Lanzi, and Bertrand Magné (2017) "Long-term economic growth projections in the Shared Socioeconomic Pathways," *Global Environmental Change*, 42, 200–214, 10.1016/j.gloenvcha.2015.06.004. 1

Dennig, Francis, Mark B. Budolfson, Marc Fleurbaey, Asher Siebert, and Robert H. Socolow (2015) "Inequality, climate impacts on the future poor, and carbon prices," *Proceedings of the National Academy of Sciences*, 112 (52), 15827–15832, 10.1073/pnas.1513967112. 1

Fagereng, Andreas, Luigi Guiso, Davide Malacrino, and Luigi Pistaferri (2020) "Heterogeneity and persistence in returns to wealth," *Econometrica*, 88 (1), 115–170. 2.3

Fouquet, Roger and Peter J.G. Pearson (2012) "Past and prospective energy transitions: Insights from history," *Energy Policy*, 50, 1 – 7, https://doi.org/10.1016/j.enpol.2012.08.014, Special Section: Past and Prospective Energy Transitions - Insights from History. 1

Gabaix, Xavier, Jean-Michel Lasry, Pierre-Louis Lions, and Benjamin Moll (2016) "The dynamics of inequality," *Econometrica*, 84 (6), 2071–2111. 1

Garbinti, Bertrand, Jonathan Goupille-Lebret, and Thomas Piketty (2018) "Income inequality in France, 1900–2014: evidence from distributional national accounts (DINA)," *Journal of Public Economics*, 162, 63–77. 1

Hallegatte, Stephane and Julie Rozenberg (2017) "Climate change through a poverty lens," *Nature Climate Change*, 7 (4), 250–256, https://doi.org/10.1016/j.eneco.2014.04.014. 1

Hsiang, Solomon M. (2010) "Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America," *Proceedings of the National Academy of Sciences*, 107 (35), 15367–15372, 10.1073/pnas.1009510107. 1

Hsiang, Solomon, Paulina Oliva, and Reed Walker (2019) "The Distribution of Environmental Damages," *Review of Environmental Economics and Policy*, 13 (1), 83–103, `https://EconPapers.repec.org/RePEc:oup:renvpo:v:13:y:2019:i:1:p:83-103`. 1

Jiang, Leiwen and Brian C. O'Neill (2017) "Global urbanization projections for the Shared Socioeconomic Pathways," *Global Environmental Change*, 42, 193–199, 10.1016/j.gloenvcha.2015.03.008. 1

Jones, Charles I (2015) "Pareto and Piketty: The macroeconomics of top income and wealth inequality," *Journal of Economic Perspectives*, 29 (1), 29–46. 1

Jones, Charles I and Jihee Kim (2018) "A Schumpeterian model of top income inequality," *Journal of Political Economy*, 126 (5), 1785–1826. 1

KC, Samir and Wolfgang Lutz (2017) "The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100," *Global Environmental Change*, 42, 181–192, 10.1016/j.gloenvcha.2014.06.004. 1

Klinsky, Sonja and Harald Winkler (2018) "Building equity in: strategies for integrating equity into modelling for a 1.5°C world," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376 (2119), 20160461, 10.1098/rsta.2016.0461. 1

Lemieux, Thomas (2006) "Increasing residual wage inequality: Composition effects, noisy data, or rising demand for skill?" *American Economic Review*, 96 (3), 461–498. 1, 2.2

Markkanen, Sanna and Annela Anger-Kraavi (2019) "Social impacts of climate change mitigation policies and their implications for inequality," *Climate Policy*, 19 (7), 827–844, 10.1080/14693062.2019.1596873. 1

Mendelsohn, Robert, Ariel Dinar, and Larry Williams (2006) "The distributional impact of climate change on rich and poor countries," *Environment and Development Economics*, 11 (2), 159–178, 10.1017/S1355770X05002755. 1

Nelson, Richard R. and Edmund S. Phelps (1966) "Investment in Humans, Technological Diffusion, and Economic Growth," *The American Economic Review*, 56 (1/2), 69–75, http://www.jstor.org/stable/1821269. 2.2

Nordhaus, William (2014) "Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches," *Journal of the Association of Environmental and Resource Economists*, 1 (1/2), 273–312, http://www.jstor.org/stable/10.1086/676035. 1

Oswald, Yannick, Anne Owen, and Julia K. Steinberger (2020) "Large inequality in international and intra-national energy footprints between income groups and across consumption categories," *Nature Energy*, 5 (3), 231–239, 10.1038/s41560-020-0579-8. 1

O'Neill, Brian C., Elmar Kriegler, Keywan Riahi, Kristie L. Ebi, Stephane Hallegatte, Timothy R. Carter, Ritu Mathur, and Detlef P. van Vuuren (2014) "A new scenario framework for climate change research: the concept of shared socioeconomic pathways," *Climatic Change*, 122 (3), 387–400, 10.1007/s10584-013-0905-2. 1

Patrinos, Harry and Claudio Montenegro (2014) "Returns to Schooling around the World," in Bank, World ed. *Background paper for the World Development Report 2013*: World Bank. 2.2

Piketty, Thomas (2020) *Capital and ideology*: Harvard University Press. 1

Piketty, Thomas, Emmanuel Saez, and Gabriel Zucman (2018) "Distributional national accounts: methods and estimates for the United States," *The Quarterly Journal of Economics*, 133 (2), 553–609. 1

Popp, Alexander, Katherine Calvin, Shinichiro Fujimori et al. (2017) "Land-use futures in the shared socio-economic pathways," *Global Environmental Change*, 42, 331–345, 10.1016/j.gloenvcha.2016.10.002. 1

Rao, Narasimha D., Bas J. van Ruijven, Keywan Riahi, and Valentina Bosetti (2017) "Improving poverty and inequality modelling in climate research," *Nature Climate Change*, 7, 857–862. 1

Rao, Narasimha D., Petra Sauer, Matthew Gidden, and Keywan Riahi (2018) "Income inequality projections for the Shared Socioeconomic Pathways (SSPs)," *Futures*, 10.1016/j.futures.2018.07.001. 1

Rao, Shilpa, Zbigniew Klimont, Steven J. Smith et al. (2017) "Future air pollution in the Shared Socioeconomic Pathways," *Global Environmental Change*, 42, 346–358, 10.1016/j.gloenvcha.2016.05.012. 1

van Ruijven, Bas J., Brian C. O'Neill, and Jean Chateau (2015) "Methods for including income distribution in global CGE models for long-term climate change research," *Energy Economics*, 51, 530–543, 10.1016/j.eneco.2015.08.017. 1

Saez, Emmanuel and Gabriel Zucman (2016) " Wealth Inequality in the United States since 1913: Evidence from Capitalized Income Tax Data *," *The Quarterly Journal of Economics*, 131 (2), 519–578, 10.1093/qje/qjw004. 2.3

Schlenker, Wolfram and Michael J. Roberts (2009) "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change," *Proceedings of the National Academy of Sciences*, 106 (37), 15594–15598, 10.1073/pnas.0906865106. 1

Taconet, Nicolas, Aurélie Méjean, and Céline Guivarch (2020) "Influence of climate change impacts and mitigation costs on inequality between countries," *Climatic Change*, 160 (1), 15–34, 10.1007/s10584-019-02637-. 1

Tol, Richard S. J. (2009) "The Economic Effects of Climate Change," *Journal of Economic Perspectives*, 23 (2), 29–51, 10.1257/jep.23.2.29. 1

Tol, Richard S.J, Thomas E Downing, Onno J Kuik, and Joel B Smith (2004) "Distributional aspects of climate change impacts," *Global Environmental Change*, 14 (3), 259 – 272, https://doi.org/10.1016/j.gloenvcha.2004.04.007, The Benefits of Climate Policy. 1