The Geography of Climate Migration*

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Revised version – October, 2020

Abstract

This paper investigates the long-term effects of climate change on the size, skill composition and type of labor migration. Our world economy model covers almost all countries in the world, distinguishes between rural and urban regions, and endogenizes the dyadic structure of migration. The model is calibrated to match international and internal mobility data by education level for the last 30 years, and is then simulated under climate change variants. Considering moderate climate scenarios, we predict mobility responses in the range of 70 to 108 million workers over the course of the 21st century. Most of these movements are local or inter-regional. South-South international migration responses are smaller, while the South-North migration response is of the "brain drain" type and induces a permanent increase in the stock of foreigners in the OECD countries in the range of 6 to 9% only. Changes in the sea level mainly translate into local movements. On the contrary, inter-regional and international movements are sensitive to temperature-related changes in productivity. We finally show that relaxing international migration restrictions may exacerbate the poverty effect of climate change at origin if policymakers are unable to select/screen individuals in extreme poverty.

Keywords: Climate change, Migration, Urbanization, Brain Dain.

JEL codes: E24, F22, J24, J61, 015, Q54

*We thank an anonymous referee for helpful comments and suggestions. This paper benefitted from the financial support of the *Agence Française de Développement* (convention IRS/ECO/437-2017) and of the ARC convention on "New approaches to understanding and modelling global migration trends" (convention 18/23-091). Hendrik Scheewel acknowledges financial support from FNRS (convention FRESH 33847523). Correspondence: Michał Burzyński (michal.burzynski@liser.lu), Frédéric Docquier (frederic.docquier@liser.lu), Hendrik Scheewel (hendrik.scheewel@uliege.be).

1 Introduction

Global warming and sea level rise are two major ingredients of long-term climate change, which are more than likely to affect many economic outcomes in the coming decades (see Dell, Jones, & Olken, 2014). Yet, the magnitude of these long-term economic consequences is highly uncertain as the predicted effects of climate change have barely started to materialize. It is indisputable that the global mean surface temperature of the world and sea level have already increased since the beginning of the 19th century (by 0.9° Celsius and by 0.2m, respectively), and that the process has accelerated since 1980. However, climatologists predict larger changes for the decades ahead. Leaving aside extreme scenarios, temperatures are expected to increase by 1 to 4° over the 21st century, and the sea level is expected to rise by 0.5 to 2 meters by 2050 (e.g., Rigaud et al., 2018). Hence, researchers are in uncharted territory and long-run extrapolation of existing empirical estimates is questionable.

In this context, this paper proposes a structural approach to investigate the long-term effects of climate change on the size, skill composition and dyadic structure of human mobility. The literature has mostly looked at the short-term impact of fast-onset variables (e.g., weather anomalies, storms, hurricanes, torrential rains, floods, landslides, etc.), as opposed to slow-onset variables (e.g., temperature trends, desertification, rising sea level, coastal erosion, etc.).[1] On the contrary, we focus on long-run climate change, subsumed in temperature and sea level scenarios. Damages from long-term climate change are expected to vary across and within countries according to proximity of seas and oceans, land topography, industry structure and initial levels of temperature. Empirical estimates show consistently that the impact of climate change on productivity will be greater in agriculture than in manufacturing (e.g., Dell et al., 2014; Desmet & Rossi-Hansberg, 2015). In particular, climate change is expected to negatively impact crop production in low-latitude countries, while inducing much smaller or even positive effects in northern latitudes. Poor countries that have contributed the least to climate change will be the most adversely affected, and migratory pressures, both internal and international, will presumably be strongest in poor countries.

[1]While CLC has consistently emerged as a potent driver of internal migration (Barrios, Bertinelli, & Strobl, 2006; Dallmann & Millock, 2017; Henderson, Storeygard, & Deichmann, 2017; Kubik & Maurel, 2016; Piguet, Pécoud, & De Guchteneire, 2011), its effect on international migration is not consensual. Some studies find important international migration outflows that are directly associated with weather shocks (Backhaus, Martinez-Zarzoso, & Muris, 2015; Cai, Feng, Oppenheimer, & Pytlikova, 2016; Coniglio & Pesce, 2015) or indirectly induced by CLC-driven pressures on living standards in urban areas (Beine & Parsons, 2015; Marchiori, Maystadt, & Schumacher, 2012, 2017). Others attempt to explain why migration responses to climate shocks have been small, non-existent, or even negative (Black, Arnell, Adger, Thomas, & Geddes, 2013; Black, Bennett, Thomas, & Beddington, 2011; Cattaneo et al., 2019). Recent reviews of the literature are provided in Perch-Nielsen, Bättig, and Imboden (2008), Piguet et al. (2011), Berlemann and Steinhardt (2017), or Cattaneo et al. (2019).

To provide a quantitative economic evaluation of the size and structure of climate migration, we use a micro-founded overlapping generations model of the world economy. The model distinguishes between 180 countries, with two regions – agriculture and nonagriculture – and two areas per region – flooded and non flooded. The regional dimension allows us to model sector-specific responses to climate change and voluntary migration decisions (i.e., decisions driven by economic incentives); the identification of flooded areas allows us to model forced displacements. Each area is initially populated by two types of natives – college graduates and the less educated – who exhibit heterogeneous migratory behaviors. Their mobility decisions determine the geographic distribution and skill structures of the labor force, productivity and wage rates.

The very spirit of our approach is in line with Desmet and Rossi-Hansberg (2015) or Shayegh (2017) although our level of spatial aggregation is different and climate change is exogenously subsumed in the simulation scenario rather than being a result of explicitly modelled mitigation decisions. We also differ in the way we formalize migration decisions. We assume a random utility structure which allows to account for the interplay between alternative forms of migration, namely local (i.e., within a region), inter-regional (i.e., rural-to-urban), and international. We thus explicitly model the choice of the destination country in a dyadic structure with both OECD destinations and developing countries. We parameterize our model so as to match socio-demographic and economic moments for the year 2010 or for the period 1980-2010. We use this calibrated model to simulate the trajectory of the world economy under alternative climate change variants and under constant migration laws and policies.[2]

We find that climate change reinforces divergence in TFP between rich and poor countries, and between urban and rural regions. It thus creates conditions that are conducive to increasing urbanization and international migration. Our baseline scenario corresponds to the mean emission scenario (called *RCP-4.5*) and its mean temperature variant available from the CCKP portal (Taylor, Stouffer, & Meehl, 2012).[3] This scenario can be considered as moderate as it involves mean increases in temperature and sea level of 1.8 degrees Celsius and 0.47 meters, respectively (Stocker et al., 2014). For *RCP-4.5*, our model predicts 29.5, 20.9 and 19.1 million climate migrants in 2040, 2070 and 2100, respectively. This corresponds to a total of about 70 million individuals aged 25 to 64 over the course of the 21st century (adding dependent children, this roughly means a total of

[2]The calibrated moving costs (reflecting all legal barriers as well as the private monetary and psychic costs of moving) are such that the model perfectly matches international mobility and urbanization data from the last 30 years. The backcast exercises conducted in Dao, Docquier, Maurel, and Schaus (2018) and Burzyński, Deuster, and Docquier (2020) demonstrate that such a model accurately fits the past migration trends and generates sensible projections.

[3]CCKP stands for World Bank's Climate Change Knowledge Portal, which provides global data on future climate vulnerabilities and impacts (https://climateknowledgeportal.worldbank.org/).

130 million climate migrants). More than half of these climate-related moves are local (forced displacements) or inter-regional (from rural to urban). Consistently, long-term climate change has little effect on South-South migration (i.e., migration across countries sharing similar climate patterns) and limited effect on South-North migration. This is particularly true in the first half of the 21st century. On average, under constant migration laws and policies, climate change induces a 4.6% permanent increase in the stock of immigrants living in the OECD countries by 2040, and a 7.2% increase by 2100. Climate-driven pressures on South-North migration are small compared with those induced by expected socio-demographic changes in developing countries. Importantly, South-North climate migrants are positively selected along the skill dimension, implying that international climate migration is of the brain drain type and reinforces the inequality effects of climate change (Biavaschi, Burzyński, Elsner, & Machado, 2020). The greatest income loss are obtained for the poorest workers trapped in the poorest regions (i.e., rural regions in low-latitude countries); climate change increases extreme poverty on the extensive and intensive margins. Given positive selection, relaxing international migration restrictions may exacerbate the poverty effect of climate change if policymakers are unable to select/screen the extreme poor.

When doubling predicted changes in temperature, the number of climate migrants reaches 108 million over the course of the 21st century (i.e. +38 million compared with *RCP-4.5*). These involve 41.1 million people moving from developing to rich countries, inducing a permanent increase by 9% in the total stock of immigrants to OECD countries. This is relatively small given the huge impact of climate change on productivity. When doubling predicted sea level rise, local movements increase by 21 million compared with *RCP-4.5*, while additional inter-regional and international migration flows are small. Overall, our results suggest that forced displacements due to sea level rise are mostly local (i.e., from flooded to non-flooded areas within the same region), while inter-regional and international mobility responses are limited and overwhelmingly governed by the TFP responses to temperature changes.

The rest of the paper is organized as follows. Section 2 describes the two-sector, two-skill-group model used to predict the behavioral and market responses to climate change (henceforth CLC). We summarize our parameterization strategy in Section 3. Section 4 presents the results obtained under various climate scenarios. Section 5 concludes.

2 Model

To estimate the mobility responses to climate change, we set up an overlapping generations model of the world economy that endogenizes the dyadic and skill structures of migration. We model migration decisions as an outcome of a micro-founded, random utility maximization (RUM) model, which jointly accounts for the main migration mechanisms through which climate change impacts long-term migration. The RUM structure allows us to model the long-term mobility responses to climate change at various spatial scales, taking into account the interplay between alternative forms of migration, namely local (i.e., very-short-distance), rural-to-urban (i.e., short-distance), and international (i.e., long-distance). Endogenous migration decisions are embedded into a general equilibrium framework with endogenous income distribution. Therefore, the effects of climate change on human mobility, global income inequality, and extreme poverty are jointly determined. Our framework assumes exogenous socio-demographic trends in line with the United Nations median scenario, and does not account for capital and trade. We discuss these assumptions in Section 2.4. The model relies on a production technology and a migration technology only.

More specifically, our model depicts a large set of countries and regions. Countries are denoted by $j = 1, ..., J$, and are made of two regions – a region is equivalent to a production sector in our context – with heterogeneous productivity levels, with $r \in \{a, n\}$ denoting agriculture (a) and non-agriculture (n). The double index jr is used to identify a country-region location. Each region consists of two areas of time-varying size, with the subscript $b \in \{f, d\}$ denoting the flooded area (f) and the non-flooded/dry area (d). Floods are permanent and caused by rising sea level; they arise at the beginning of the period. There is no economic activity and no one can live in the flooded area. Hence, we distinguish between individuals who grew up in a flooded region and are forced to leave their area of birth when becoming adults, and those who grew up in a non-flooded region and choose between staying or leaving. This allows to distinguish between forced displacements (driven by the sea level rise) and voluntary migration (driven by economic incentives).

Individuals live for two periods (childhood and adulthood). One period stands for the active life of one generation (30 years); we ignore the retirement period for simplicity. Adults are the only decision makers. In each location jr and each period, we distinguish between two types of adults, with $s \in \{h, l\}$ denoting college-educated workers (h) and the less educated (l). This allows us to account for the high degree of heterogeneity in migratory behavior between people of different places of origin and levels of education. We denote by $N^{jr}_{b,s,t}$ the number of new adults of type s born in the area b of location jr at time $t-1$ (i.e., becoming adult at time t). The total native population in location jr is defined as $N^{jr}_{s,t} = N^{jr}_{d,s,t} + N^{jr}_{f,s,t}$. Adults maximize their utility by deciding where to live – i.e., whether to stay in the region where they grew up (if the area of birth does not get flooded), to move locally within the same region (if the area of birth gets flooded), to emigrate to the other region within the same country, or to emigrate abroad. This choice depends on the livability of their area of birth, on economic disparities across regions and countries, and on moving costs. It determines the number of residents in each (non-flooded) location, denoted by $L_{s,t}^{jr}$.

In this section, we describe our production and migration technologies (Sections 2.1 and 2.2), and derive the profit and utility maximization conditions. We then define the world-economy intertemporal equilibrium in Section 2.3. We discuss our simplifying assumptions in Section 2.4.

2.1 Production Technology

The production technology determines the wage rates in each location. Production is feasible only in the non-flooded area of each location jr. Output is proportional to labor in efficiency units. And for simplicity, we assume that firms in both sectors produce the same good. Each location is characterized by a constant elasticity of substitution (CES) production function with two types of workers (as in Burzyński et al., 2020; Gollin, Lagakos, & Waugh, 2014; Vollrath, 2009). The output level in location jr at time t is given by:

$$Y_t^{jr} = A_t^{jr} \left(\frac{\eta_t^{jr}}{1+\eta_t^{jr}} L_{h,t}^{jr\ \frac{\sigma^r-1}{\sigma^r}} + \frac{1}{1+\eta_t^{jr}} L_{l,t}^{jr\ \frac{\sigma^r-1}{\sigma^r}} \right)^{\frac{\sigma^r}{\sigma^r-1}} \qquad \forall t, r, \tag{1}$$

where A_t^{jr} denotes the productivity scale factor in location jr at time t (referred to as TFP henceforth), η_t^{jr} is a sector-specific variable governing the relative productivity of college-educated workers at time t (i.e., a skill bias in productivity), and σ^r is the sector-specific elasticity of substitution between the two types of worker. Remember the number of adult workers of type s employed in location jr at time t is denoted by $L_{s,t}^{jr}$.

The labor market is competitive. Wage rates are determined by the marginal productivity of labor:

$$\begin{cases} w_{h,t}^{jr} = A_t^{jr\ \frac{1}{\sigma^r-1}} \left(\frac{\eta_t^{jr}}{1+\eta_t^{jr}} L_{h,t}^{jr\ \frac{\sigma^r-1}{\sigma^r}} + \frac{1}{1+\eta_t^{jr}} L_{l,t}^{jr\ \frac{\sigma^r-1}{\sigma^r}} \right)^{\frac{1}{\sigma^r-1}} \frac{\eta_t^{jr}}{1+\eta_t^{jr}} L_{h,t}^{jr\ \frac{-1}{\sigma^r}} \\ w_{l,t}^{jr} = A_t^{jr\ \frac{1}{\sigma^r-1}} \left(\frac{\eta_t^{jr}}{1+\eta_t^{jr}} L_{h,t}^{jr\ \frac{\sigma^r-1}{\sigma^r}} + \frac{1}{1+\eta_t^{jr}} L_{l,t}^{jr\ \frac{\sigma^r-1}{\sigma^r}} \right)^{\frac{1}{\sigma^r-1}} \frac{1}{1+\eta_t^{jr}} L_{l,t}^{jr\ \frac{-1}{\sigma^r}} \end{cases} \qquad \forall t, r. \tag{2}$$

It follows that the wage ratio between high-skilled and low-skilled workers in location jr at time t is given by:

$$\varpi_t^{jr} \equiv \frac{w_{h,t}^{jr}}{w_{l,t}^{jr}} = \eta_t^{jr} \left(z_t^{jr} \right)^{\frac{-1}{\sigma^r}} \qquad \forall t, r, \tag{3}$$

where $z_t^{jr} \equiv L_{h,t}^{jr}/L_{l,t}^{jr}$ is the skill ratio in employment in location jr at time t.

In our setting, climate change affects production and income differentials through two channels. Firstly, variations in temperature influence TFP in agriculture and in the non-agriculture sector. Secondly, climate change affects mobility decisions, which in turn impact the skill ratio in the labor force. To account for these effects, damage functions and technological externalities are factored in. For TFP, we assume that the aggregate TFP level in each sector depends on the temperature level and the average level of workers' education. We have:

$$A_t^{jr} = \gamma^t \overline{A}^{jr} G(T_t^{jr}) F(z_t^{jr}) \qquad \forall t, r, \tag{4}$$

where γ^t is a time trend in productivity which is common to all countries ($\gamma > 1$), $\overline{A}^{jr}$ is the exogenous component of TFP in location jr (reflecting specific local factors such as the proportion of arable land, soil fertility, land ruggedness, etc.), $G(T_t^{jr})$ links TFP to temperature (T_t^{jr}), while $F(z_t^{jr})$ is a simple Lucas-type aggregate externality (see Lucas, 1988) capturing the fact that college-educated workers facilitate innovation and/or the adoption of advanced technologies. We assume $F(z_t^{jr}) = \left(z_t^{jr}\right)^{\epsilon_r}$ is a concave function of the skill ratio in employment, where $\epsilon_r \in (0,1)$ is the sector-specific elasticity of TFP to the skill ratio in region/sector r of all countries. As for the effect of temperature, the literature suggested that TFP levels in agriculture and non-agriculture can be represented by sector-specific, inverted-U-shaped functions of (T_t^{jr}), as discussed in Section 3 (Desmet, Nagy, & Rossi-Hansberg, 2018; Shayegh, 2017).

As far as the skill bias is concerned, we assume directed technical change that affects different types of workers non-uniformly. As technology improves, the relative productivity of college-educated workers increases, particularly in the non-agricultural sector (Acemoglu, 2002; Restuccia & Vandenbroucke, 2013). The observed relative demand shift favors college-educated versus non-college-educated labor. We write:

$$\eta_t^{jr} = \overline{\eta}^{jr} \left(z_t^{jr}\right)^{\kappa_r} \qquad \forall t, r, \tag{5}$$

where $\overline{\eta}_{jr}$ is an exogenous term and $\kappa_r \in (0,1)$ is the sector-specific elasticity of the skill bias to the skill ratio in sector/region r of all countries.

2.2 Migration Technology

To model migration decisions, our RUM model assumes that the utility of moving to a given location is the sum of deterministic and random components. The deterministic part has a logarithmic functional form and depends on the local wage rate at destination and moving costs. The random part captures heterogeneity in preferences or in moving costs. Hence, the utility of an adult of type s, born in the area b of a location of origin

jr, moving to the (non-flooded) area of a location $j'r'$ is given by:

$$U_{b,s,t}^{jr,j'r'} = \ln w_{s,t}^{j'r'} + \ln(1 - x_{b,s,t}^{jr,j'r'}) + \xi_{b,s,t}^{jr,j'r'} \quad \forall s, t, jr, j'r' \tag{6}$$

where $\ln w_{s,t}^{j'r'} \in \mathbb{R}$ is the deterministic level of utility that can be reached in the location $j'r'$ at period t and $x_{b,s,t}^{jr,j'r'} \leq 1$ captures the effort required to migrate from location jr to location $j'r'$. Migration costs are exogenous; they vary across location pairs and education levels. The individual-specific random taste shock for moving from location jr to $j'r'$ is denoted by $\xi_{b,s,t}^{jr,j'r'} \in \mathbb{R}$ and follows an iid Type I Extreme Value distribution with a common scale parameter $\mu > 0$. This scale parameter governs the responsiveness of migration decisions to changes in $w_{s,t}^{j'r'}$ and to $x_{b,s,t}^{jr,j'r'}$. Although $\xi_{b,s,t}^{jr,j'r'}$ is individual-specific, we omit individual subscripts for notational convenience.

Remember the number of new native adults of type s at time t is denoted by $N_{s,t}^{jr}$. Depending on the elevation structure of the location and on the sea level rise, part of the location of birth may be flooded at the beginning of the period. If so, a fraction Θ_t^{jr} of the native population is forced to leave. We label the number of forcibly displaced people as $N_{f,s,t}^{jr} = \Theta_t^{jr} N_{s,t}^{jr}$, and the rest of the native population as $N_{d,s,t}^{jr} = (1 - \Theta_t^{jr}) N_{s,t}^{jr}$. Only the latter may decide to stay in the area of birth. Hence, those who grew up in the non-flooded area of the location jr have the choice between emigrating to another region jr' within the same country (at a cost $x_{d,s,t}^{jr,jr'}$), emigrating to a foreign country (at a cost $x_{d,s,t}^{jr,j'r'}$), or staying. In the latter case, they incur no moving cost. This means that $x_{d,s,t}^{jr,jr} = 0$.

On the contrary, individuals who grew up in the flooded area have the possibility of relocating within the same region (from flooded to non-flooded area). They incur a welfare loss that corresponds to a fraction $x_{f,s,t}^{jr,jr} > 0$ of their lifetime utility (which is equivalent to an income loss of $x_{f,s,t}^{jr,jr}$ percent in our context). They can also emigrate to another region or to another country at the same cost as those who grew up in the non-flooded area (i.e., $x_{f,s,t}^{jr,j'r'} = x_{d,s,t}^{jr,j'r'}$).

We first focus on *people who grew up in the non-flooded area (d)* of their location of birth. Given their taste characteristics (captured by ξ), each individual chooses the location that maximizes her utility, defined in Equation (6). Under the Type I Extreme Value distribution of ξ with a scale parameter μ, McFadden (1974) shows that the probability of choosing region $j'r'$ for individuals originating from region jr is governed by a logit expression. Therefore, the emigration rate is given by:

$$\frac{M_{d,s,t}^{jr,j'r'}}{N_{d,s,t}^{jr}} = \frac{\exp\left(\ln\left(w_{s,t}^{j'r'}(1 - x_{d,s,t}^{jr,j'r'})\right)^{1/\mu}\right)}{\sum_{kp} \exp\left(\ln\left(w_{s,t}^{kp}(1 - x_{d,s,t}^{jr,kp})\right)^{1/\mu}\right)} = \frac{(w_{s,t}^{j'r'})^{1/\mu}(1 - x_{d,s,t}^{jr,j'r'})^{1/\mu}}{\sum_{kp}(w_{s,t}^{kp})^{1/\mu}(1 - x_{d,s,t}^{jr,kp})^{1/\mu}}. \tag{7}$$

Hence, emigration rates are endogenous, destination- and skill-specific, and fall between 0 and 1. The choices of emigrating internally or internationally are interdependent. Staying rates ($M^{jr,jr}_{d,s,t}/N^{jr}_{d,s,t}$) are expressed by a similar logit expression. It follows that the emigrant-to-stayer ratio ($m^{jr,j'r'}_{d,s,t}$) is governed by:

$$m^{jr,j'r'}_{d,s,t} \equiv \frac{M^{jr,j'r'}_{d,s,t}}{M^{jr,jr}_{d,s,t}} = \left(\frac{w^{j'r'}_{s,t}}{w^{jr}_{s,t}}\right)^{1/\mu} (1 - x^{jr,j'r'}_{d,s,t})^{1/\mu}, \tag{8}$$

such that $m^{jr,jr}_{d,s,t} = 1$.

Equation (8) is a gravity-like migration equation, which states that the ratio of emigrants from location jr to location $j'r'$ to stayers in region jr (i.e., individuals born in jr who remain in jr) is an increasing function of the wage rate in the destination location $j'r'$ and a decreasing function of the utility in jr. The proportion of migrants from jr to $j'r'$ also decreases with the bilateral migration cost $x^{jr,j'r'}_{d,s,t}$. Labor is not perfectly mobile across sectors/regions; internal migration costs capture all private costs that migrants must incur to move between regions.[4] Similarly, international migration costs capture private costs and the legal/visa costs imposed by the destination countries. They are also assumed to be exogenous. Heterogeneity in migration tastes implies that emigrants select all destinations for which $x^{jr,j'r'}_{d,s,t} < 1$ (if $x^{jr,j'r'}_{d,s,t} = 1$, the corridor is empty).

As for *individuals raised in the flooded area* of location jr (denoted by the superscript f), they are forced to move. If they relocate into the non-flooded area of their region of birth jr, they face a local relocation cost equivalent to $x^{jr,jr}_{f,s,t} > 0$. If they move to another country or region, they face the same moving costs as individuals born in the non-flooded area (i.e., $x^{jr,j'r'}_{f,s,t} = x^{jr,j'r'}_{d,s,t}$ $\forall jr \neq j'r'$). The local relocation cost influences decisions to emigrate to another region or country. The emigrant-to-stayer ratio ($m^{f}_{r^*r,s,t}$) for forcibly displaced people is governed by:

$$m^{jr,j'r'}_{f,s,t} \equiv \frac{M^{jr,j'r'}_{f,s,t}}{M^{jr,jr}_{f,s,t}} = \left(\frac{w^{j'r'}_{s,t}}{w^{jr}_{s,t}}\right)^{1/\mu} \left(\frac{1 - x^{jr,j'r'}_{d,s,t}}{1 - x^{jr,jr}_{f,s,t}}\right)^{1/\mu}, \tag{9}$$

such that $m^{jr,jr}_{f,s,t} = 1$. In addition, since $x^{jr,jr}_{f,s,t} > 0$, $m^{jr,j'r'}_{f,s,t} > m^{jr,j'r'}_{d,s,t}$, forcibly displaced people tend to migrate more than those who grew up in non-flooded regions.

For simplicity, we assume that international migrants settle in the urban region of their destination countries. This choice is guided by the fact that the data used to calibrate the migration technology do not document the region of destination of international migrants. This means that $m^{jr,j'a}_{b,s,t} = 0$ or, equivalently, $x^{jr,j'a}_{b,s,t} = 1$ $\forall j \neq j'$. We can define the ratio

[4] In line with Young (2013), internal mobility is driven by self-selection (i.e., skill-specific disparities in utility across regions as well as heterogeneity in individual unobserved characteristics).

of international emigrants to stayers as:

$$m_{b,s,t}^{jr,F} \equiv \sum_{j' \neq j} m_{b,s,t}^{jr,j'n}, \tag{10}$$

Once emigrant-to-stayer ratios are determined, we can characterize the equilibrium structure of the resident labor force in (the non-flooded area of) all regions and by education level. We have:

$$L_{s,t}^{jr} = \sum_{b,j',r'} \frac{m_{b,s,t}^{j'r',jr} N_{b,s,t}^{j'r'}}{1 + m_{b,s,t}^{j'r',j'r} + m_{b,s,t}^{j'r',jr}}. \tag{11}$$

2.3 Dynamics and Intertemporal Equilibrium

The dynamics of the native population is governed by fertility and education decisions. Contrary to Burzyński et al. (2020); Burzyński, Deuster, Docquier, and de Melo (2019), we assume that these decisions are exogenous. We denote by $n_{s,t}^{jr}$ the number of children of parent of type s living in (the non-flooded area of) location jr at time t. We denote by $p_{s,t}^{jr}$ the proportion of children acquiring college education. It follows that the dynamic structure of the model is totally recursive. We have:

$$\begin{cases} N_{h,t+1}^{jr} = \sum_{s,b} L_{s,t}^{jr} n_{s,t}^{jr} p_{s,t}^{jr} \\ N_{l,t+1}^{jr} = \sum_{s,b} L_{s,t}^{jr} n_{s,t}^{jr} (1 - p_{s,t}^{jr}) \end{cases} \tag{12}$$

An inter-temporal equilibrium for the world economy can be defined as following:

Definition 1 *For a set* $\{\mu, \gamma, \sigma_r, \epsilon_r, \kappa_r\}$ *of common parameters, a set of location-specific exogenous characteristics* $\left\{\overline{A}_t^{jr}, \overline{\eta}_t^{jr}, \Theta_t^{jr}, n_{s,t}^{jr}, p_{s,t}^{jr}, x_{b,s,t}^{jr,j'r'}\right\}$*, and a set* $\left\{N_{s,0}^{jt}\right\}$ *of predetermined variables, an intertemporal competitive equilibrium is a set of endogenous variables* $\left\{w_{s,t}^{jr}, A_{r,t}, \eta_t^{jr}, m_{d,s,t}^{jr,j'r'}, m_{f,s,t}^{jr,j'r'}, L_{s,t}^{jr}, N_{s,t+1}^{jr}\right\}$*, which simultaneously satisfies profit maximization conditions and technological constraints (2), (4) and (5), utility maximization conditions (8), (9) in all countries and regions of the world, and such that the equilibrium structure and dynamics of population satisfy (11) and (12).*

2.4 Caveats and Value Added

Our model inevitably leaves out a number of features. Firstly, it abstracts from *physical capital* accumulation. Assuming production is proportional to labor in efficiency unit is equivalent to assuming a constant capital-to-labor ratio (i.e., Burzyński et al., 2020; Delogu, Docquier, & Machado, 2018; Kennan, 2013; Klein & Ventura, 2009). Such a condition holds in a small open economy context with perfect mobility of capital between countries and regions, or on the long-run balanced growth path of a closed economy model. We find this assumption in line with the time structure of our model (one period represents about 30 years), acknowledging that we disregard the effects induced by potential variations in the worldwide level of the capital-to-labor ratio.

Secondly, the model abstracts from *trade*. Assuming that firms in both sectors produce the same good, the model disregards variations in the relative price of the agricultural good. In a context with heterogeneous goods, variations in the relative price of the agricultural good would mitigate or reinforce the urbanization process. In their benchmark scenario, Desmet and Rossi-Hansberg (2015) show that changes in relative prices are small. In addition, Burzyński et al. (2020) show that migration and inequality responses to various types of shock are quantitatively similar when considering that agricultural and non-agricultural goods are identical or imperfect substitutes as in Boppart (2014).

Thirdly, we assume that *fertility and education* decisions are exogenous, which basically means that the dynamics of the size and structure of before-migration populations is assumed to be independent of climate change. Richer results with endogenous population movements can be found in a companion working paper (Burzyński et al., 2019), where the deterministic part of the RUM is itself an outcome of a (second-stage) utility-maximization problem over consumption, fertility, and education. These simulations reveal that the socio-demographic responses to climate changes are small.

3 Parameterization

Our model is calibrated for 180 countries accounting for more than 99% of the world population. Our parameterization strategy involves three steps. Firstly, we calibrate common and location-specific parameters in order to (perfectly) match socio-demographic and economic moments for the year 2010 (referred to as the year 0 below) or for the period 1980-2010. The set of socio-demographic moments includes internal and international migration flows. Secondly, we define a socio-demographic trajectory for the 21st century which is in line with official projections of population, urbanization and human capital. Thirdly, we describe our climate damage functions under three climate scenarios.

Matching the current state of the world. We collect data on socio-demographic and economic characteristics of 180 countries in 1980 and 2010. We use data on Gross Domestic Product (GDP) from the United States Department of Agriculture (USDA) and the agriculture share in value added from the Food and Agriculture Organization of the UN (FAOSTAT). This determines Y_0^{jr}. As for the structure of the resident labor force by education level and by sector ($L_{s,0}^{jr}$), we use the estimates described in Burzyński et al. (2020). Data on wages by education level ($w_{s,0}^{jr}$) are obtained from Biavaschi et al.

(2020) for the non-agricultural sector and from the Gallup World Polls for the agricultural sector. From the Database on Immigrants in OECD and non-OECD countries (DIOC), we extract the dyadic number of international migrants by education level for 2010. Within each country, we split the number of emigrants by region of origin and education level, assuming that the structure of migration aspirations (obtained from the Gallup World Polls) is identical to the structure of actual emigration stocks. This gives $M_{s,0}^{jr,j'r'}$.

As far as technological parameters are concerned, we calibrate the elasticity of substitution between college graduates and less educated workers (σ^r), relying on existing studies. For the non-agricultural sector we follow Ottaviano and Peri (2012), who suggest setting the elasticity close to 2, whereas for the agricultural sector, it is usually assumed that the substitution is perfect (e.g., Lucas, 2009; Vollrath, 2009). Using Eq. (3), we then calibrate the skill-bias term, η_t^{jr}, so as to match the observed income ratio between skill groups. Using Eq. (1), we calibrate the TFP level, A_0^{jr}, so as to match the observed level of GDP. Regressing the logs of η_0^{jr} and A_0^{jr} on the log of the skill ratio, we identify the size technological externalities (ϵ^r and κ^r). Finally, $\overline{A}^{jr}$ and, $\overline{\eta}^{jr}$ are identified as residuals from Eqs. (4) and (5).

As for the migration technology, Bertoli and Fernández-Huertas Moraga (2013) find a value between 0.6 and 0.7 for the migration elasticity to income disparities, captured by $1/\mu$ in our model. Hence, we use $\mu = 1.4$. We obtain international and internal migration costs ($x_{s,0}^{jr,j'r'}$) as residuals from Eq. (8). As climate change is expressed in deviation from the current state of the world, there is no climate-related flooded area in the year 2010. For internal migration costs, we assume positive migration from rural to urban regions (i.e., $x_{s,0}^{ja,jn} < 1$) but no migration from urban to rural region ($x_{s,0}^{jn,ja} = 1$). As for local migration costs in flooded areas, we pessimistically assume $x_{f,s,t}^{jr,jr} = 0.5$ (i.e., relocating within the location of birth induces an income loss equal to 50% of the lifetime utility), in line with the literature on conflict-related displacements (e.g., Fiala, 2015; Ibáñez & Moya, 2006; Kellenberg & Mobarak, 2011). Using a similar parameterization strategy, Burzyński et al. (2020) predict variations in the dyadic stocks of migrants between 1950 and 1980 and obtain a close fit to the observed values.

Socio-demographic environment. Unless otherwise stated, we assume constant migration costs over the 21st century (i.e., $x_{s,t}^{jr,j'r'} = x_{s,0}^{jr,j'r'} \forall t$). As for $n_{s,t}^{jr}$ and $p_{s,t}^{jr}$, we use the projections of Burzyński et al. (2020), who endogenize the trajectory of socio-demographic variables in a similar overlapping generations framework without climate change. They constrain their baseline trajectory to be compatible with medium-term official demographic projections, as reflected by the UN projections of the national adult population and proportion of college graduates for 2040. This can be done by assuming a process of quadratic convergence in access to education. This quadratic convergence process implies that middle-income countries converge towards high-income countries, while low-income diverge or converge less rapidly. For subsequent years and in all climate variants, we assume a continuation of this quadratic convergence process. Resulting changes in the size and structure of the population partly determine the skill ratio and the level of the technology in all locations.

Climate scenarios. Our climate scenarios involve temperature changes and sea level rises. Several temperature and sea level projections are available from the CCKP portal (Taylor et al., 2012), which distinguishes between several emission scenarios labeled as Representative Concentration Pathways (RCP) (Moss et al., 2010). They are organized in 20-year climatological windows. The median-emission scenario is called *RCP-4.5*, which predicts that emissions will peak around 2040 before declining. For each RCP, the CCKP provides data for 16 models obtained from different research institutes. When these 16 models are ranked in ascending order according to the secular temperature variation, the medium resolution model of the Institute Pierre Simon Laplace (the *ipsl_cm5a_mr* variant) takes the 8th (median) position in *RCP-4.5*. We select this "median of the medians" variant as our baseline scenario and consider three alternative scenarios:

- No climate change (**No CLC**): No change in temperature and in the sea level. Most likely unattainable, this scenario serves as the no climate change reference.
- Baseline (**RCP-4.5**): Median temperature scenario corresponding to the median emission scenario (*RCP-4.5*). This baseline involves mean increases in temperature and sea level of 1.8 degrees Celsius and 0.47 meters, respectively.
- Higher temperature (**Higher T**): Starting from the baseline, we double the predicted changes in temperature in all regions, keeping sea level rise identical to those used in the baseline.
- Higher sea level (**Higher SL**): Starting from the baseline, we double the predicted rise in the sea level in all parts of the world, keeping temperature changes identical to those used in the baseline.

Projections of temperature and sea level changes by pixel of 1km by 1km can be obtained from Giorgetta et al. (2012). As far as temperature is concerned and for the baseline, Figure 1(a) illustrates the predicted variations in temperature between 2010 and 2100 by latitude and longitude. The largest variations are observed in the extreme North as well as some regions located close to the Equator and in the East. Similarly, global sea level changes will not be uniform but exhibit substantial regional deviations

(Oppenheimer et al., 2019). Thermal expansion, ocean dynamics and land ice loss contributions will generate regional departures from the global mean sea level rise of about ±30%. Figure 1(b) show that the rise in the sea level will be more pronounced in the extreme North, in the Northern part of the Atlantic Ocean and in the South-East of the Cape of Good Hope. This influences the surface of flooded areas. In order to account for such heterogeneities, we combine sea level projection data by pixel with high-resolution geo-referenced information on topography (Tadono et al., 2014) and distance to coastlines (Stumpf, 2012).

Climate damage functions. To predict the long-term implications of climate change, we consider two mechanisms of transmission. Firstly, we allow changes in the mean level of temperature to affect productivity, expected income and incentives to migrate (as in Dallmann & Millock, 2017; Desmet & Rossi-Hansberg, 2015; Shayegh, 2017). Secondly, we model forced displacements linked to the sea level rise (as in Desmet et al., 2018; Rigaud et al., 2018).[5]

To model the effect of temperature, we follow Desmet and Rossi-Hansberg (2015), who estimate the relationship between temperature and total factor productivity in agricultural and manufacturing sectors. This function corresponds to $G(T_t^{jr})$ in Eq. (4). The curve is inverted-U-shaped in both sectors but flatter in manufacturing. Desmet and Rossi-Hansberg (2015) find an optimal temperature of 21.1 degree Celsius in agriculture, and 17.4 degree Celsius in nonagriculture. The level of TFP increases with temperature in regions with average temperature below these optimal levels; it decreases with temperature in warmer regions.

It is important to notice that our two-sector model does not distinguish between pixels and only establishes a difference between rural/agricultural and urban/nonagricultural regions within each country. The climate literature suggests that levels of temperature observed at the centroid of each country may not reflect accurately the impact of climate change. This can be due to the fact that aggregate measures poorly capture population concentration and individuals' average exposure to temperature change in large countries with regions of heterogeneous population densities. Hence, we use population-weighted changes in temperature from Dell, Jones, and Olken (2012). Figures 1(c) and 1(e) show

[5] The slow-onset mechanisms considered in this paper are foreseeable and likely to induce adaptation strategies such as crop switching – implicitly taken into account in the $G(T_t^{jr})$ damage functions – and migration. The companion working paper (Burzyński et al., 2019) supplements these damage functions with additional mechanisms related to fast-onset climate shocks. This allows connecting the distribution of daily temperature with the frequency of natural disasters as well as with productivity and health costs. These fast-onset mechanisms affect all countries with similar intensities, and hardly impact inter-regional and international migration responses. The working paper version also accounts for conflicts over resources and conclude that climate-related conflicts could become a key component of future climate migration pressures. However, predicting the occurrence of conflicts and the number of countries involved is a complex task. Hence, we focus here on slow-onset mechanisms only.

the direct effect of temperature on agricultural and nonagricultural TFP levels for each country and for the year 2100. On average, in the *RCP-4.5* scenario, agricultural productivity decreases by 20 to 25% in countries close to the equator and increases by the same amount at high latitudes. Similarly, non-agricultural productivity decreases by 10 to 15% in countries close to the equator, and increases slightly at high latitude levels.

This implies that climate change will impact income convergence over the 21st century. From Eq. (4), it appears that TFP levels are also impacted by changes in the skill ratio (z_t^{jr}), which result from our (exogenous) socio-demographic hypotheses and (endogenous) migration outcomes. For each climate scenario and sector, we can run a cross-country regression of the mean annual growth rate of TFP over the 21st century on its initial level (in logs). Results of these beta-convergence regressions are illustrated in Figure 2. The left panel gives the results obtained for agriculture (each country is represented by a red bubble), while the right panel shows the results for nonagriculture (each country is represented by a blue bubble).

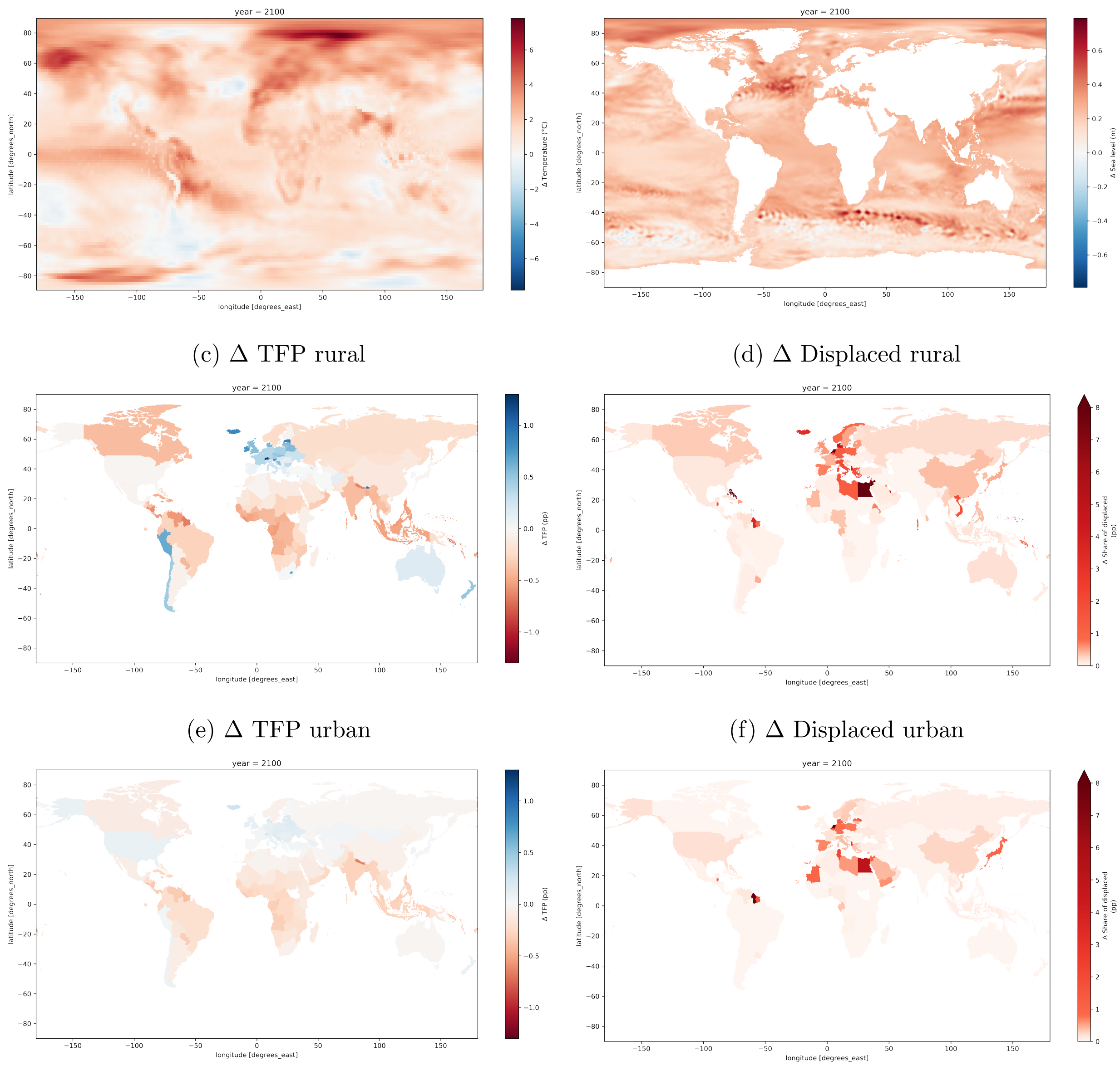
In the *No CLC* scenario (top panel), we abstract from climate change. The beta-convergence regression results are governed by the assumed quadratic convergence process in human capital formation (i.e., in domestic investment in education). In line with the median socio-demographic scenario of the United Nations, our socio-demographic environment assumes that progress in education is larger in middle-income countries than in rich/poor countries. The resulting effect on the skill ratio and TFP are reinforced by internal and international mobility responses – people moving from low- to high-productivity regions and countries. Hence, this scenario implies quadratic convergence in TFP levels. Roughly speaking, in both sectors, TFP levels are converging among countries and regions belonging to the top quartile of the initial TFP distribution. Countries and regions below the top quartile are diverging.

The convergence implications of climate change are illustrated in the bottom panels in Figure 2. Under the *RCP-4.5* scenario, the divergence forces are reinforced. Variation in temperature will induce dramatically different effects on productivity in countries above and below the 35th parallel. Over the 21st century, agricultural productivity decreases by 20-25% in countries close to the equator, and increases by 10-15% at high latitudes. Nonagricultural productivity decreases by 10-15% in countries close to the equator, and slightly increases at high latitude levels. Over the 21st century, the annual growth rate of TFP is 2 percentage points larger in the richest regions compared to the poorest regions. Hence, low-latitude countries in general, and their rural regions in particular, will be the most adversely affected by climate change. The magnitude of these effects larger when temperature variations are doubled (see *Higher T*), whereas higher sea level rise has almost no impact on TFP convergence (see *Higher SL*).

We now turn our attention to forced displacement, which are predicted by combining sea level projection data from Giorgetta et al. (2013) with high-resolution geo-data population density (CIESIN-Columbia University, 2018) and data on the rural/urban divide from Balk et al. (2006). Our approach by pixel enables us to proxy the number of individuals at risk from coastal flooding on a 1km by 1km grid and by region. Coupling this information with data on geographical extent of urban/rural areas (Balk et al., 2006) allows us to compute the fraction of population affected by sea level rise (Θ_t^{jr}) by country.

Figures 1(d) and 1(f) gives the total number of displaced persons over the 21st century in rural and urban regions, respectively. Sea level rise mostly affects countries with a large share of population located along the coasts of all seas and oceans or in the major river deltas and estuaries. The share of displaced persons is large in South Asian and East Asian countries. Some Pacific islands situated a few centimeters above sea level (e.g., Tuvalu, Kiribati) are in a position of extreme vulnerability. Rich and poor countries will be adversely affected by the sea level rise.

Figure 1: *RCP-4.5*



(a) Δ Temperature

(b) Δ Sea level

(c) Δ TFP rural

(d) Δ Displaced rural

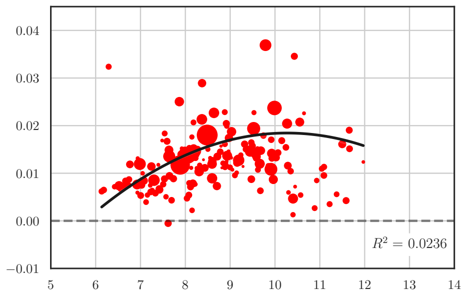
(e) Δ TFP urban

(f) Δ Displaced urban

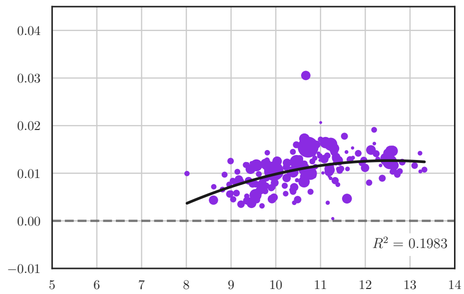
Notes: Own calculations based on climate data by Giorgetta et al. (2012). Subfigures represent deviations from the baseline situation in 2010. Annual mean temperature (a) and sea level deviations (b) are visualized on the pixel level. The effects on TFP (c,e) and forced dispacement (d,f) are aggregated at the region level.

Figure 2: Convergence vs. Divergence in TFP under Alternative Climate Scenarios

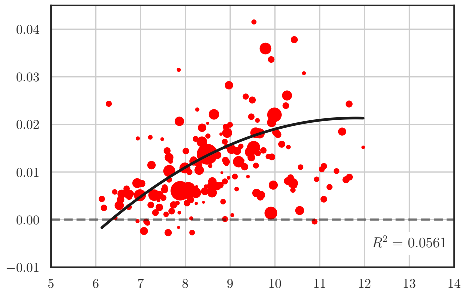
(a) *No CLC* – Agrigulture



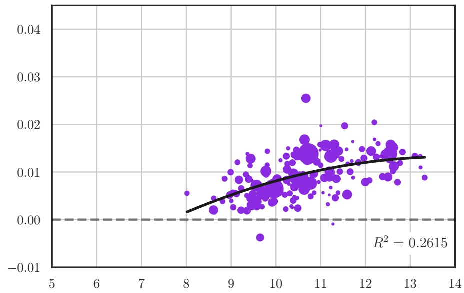
(b) *No CLC* – Nonagriculture



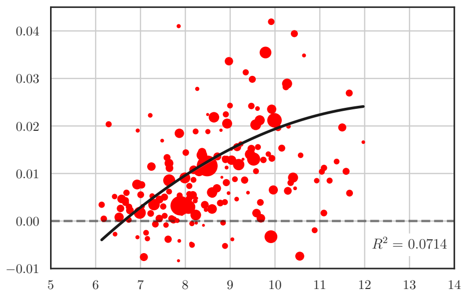
(c) *RCP-4.5* – Agrigulture



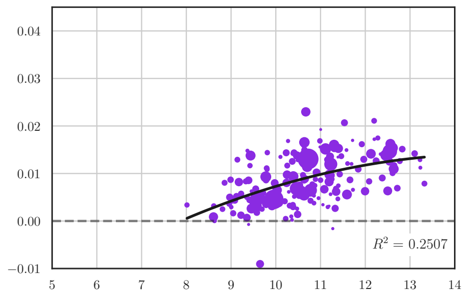
(d) *RCP-4.5* – Nonagriculture



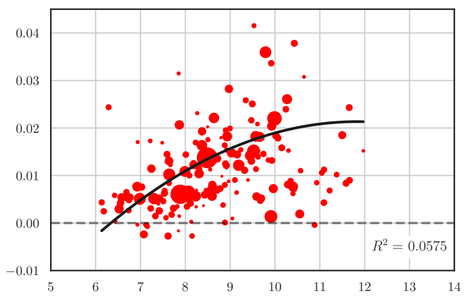
(e) *Higher T* – Agrigulture



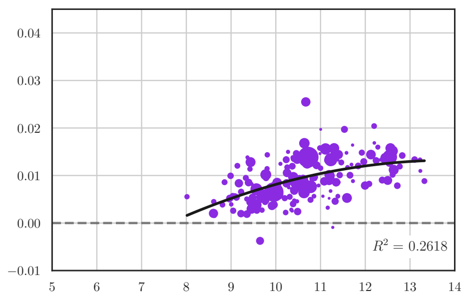
(f) *Higher T* – Nonagriculture



(g) *Higher SL* – Agrigulture



(h) *Higher SL* – Nonagriculture



Notes: Mean annual growth rates of TFP levels over the period 2010-2100 are represented on the vertical axis. The 2010 levels of TFP (in logs) are represented on the horizontal axis. The trends correspond to the quadratic relationship between the two variables. A negative slope indicates a convergence process; a positive slope indicates divergence.

4 Results

As the relationship between temperature and productivity is nonlinear and sector-specific, climate change increases income disparities between and within countries. Table 1 summarizes the macroeconomic implications of climate change for the world and by region. The bottom lines of this table give the worldwide responses, computed as the weighted averages of the positive and negative effects observed in high-income and developing countries. The values in bold characters are the projections obtained in the *No CLC* scenario. The values below are the variations induced by the *RCP-4.5*, *Higher T* and *Higher SL* scenarios, expressed as deviations from the *No CLC* scenario.

In a nutshell, we find that climate change hardly affects the worldwide average level of GDP per worker, but makes its distribution more unequal. Under the *RCP-4.5* scenario, the worldwide level of GDP per worker decreases by 0.2%, 0.2% and 0.1% in 2040, 2070 and 2100, respectively. Similar changes are obtained under *High SL*. Under the *Higher T* scenario, the worldwide loss is even smaller in 2040 (-0.1%) and becomes a small gain in 2070 (+0.1%) and in 2100 (+0.3%). There are two reasons explaining why aggregate GDP effects are small and potentially positive. Firstly, higher temperature levels induce positive changes in TFP at high levels of latitude (where income per worker is initially higher) and negative changes in TFP close to the equator (where income per worker is initially lower). Secondly, climate change reallocates people from poorer to richer countries and regions. These movements explain why climate change increases the worldwide average share of college graduates and reduces the size of the world working age population. It is worth noticing that the utility costs of these movements are not accounted for in our GDP responses to climate change, nor the uncertain income losses due to extreme weather events. This implies that we can expect a (larger) decrease in global welfare.

When looking at the region-specific effects, climate change increases GDP per worker in OECD countries only; the effects amount to 1.5, 2.3 and 2.7% in 2040, 2070 and 2100 under the *RCP-4.5* scenario, and to 2.5, 3.8 and 4.3% under the *Higher T* scenario. On the contrary, climate change decreases GDP per worker in developing regions despite the fact that it reallocates some people from lower-productivity rural regions to higher-productivity urban regions. The losses are important. In sub-Saharan Africa, the poorest region of the world, the effects amount to -2.7, -6.4 and -8.6% in 2040, 2070 and 2100 under the *RCP-4.5* scenario, and by -4.1, -9.4 and -12.8% under the *Higher T* scenario. In relative terms, similar losses are obtained in East Asian and Pacific countries as well as in the Middle East and Northern Africa. Larger long-term effects are obtained in Central Asia (-21.5%) and in Latin America (-14.7%) in the *Higher T* scenario.

Table 1: Aggregate Effects of Climate Change by World Region

Regions	Scenario	GDP in 10e9 $US			GDP per Worker			HS Share in %			Population in 10e6			Urban Share in %		
		2040	**2070**	**2100**	**2040**	**2070**	**2100**	**2040**	**2070**	**2100**	**2040**	**2070**	**2100**	**2040**	**2070**	**2100**
CARE	**No CLC**	**836.52**	**952.07**	**990.09**	**7662.72**	**8743.64**	**10508.80**	**17.84**	**20.92**	**25.13**	**109.17**	**108.89**	**94.22**	**38.67**	**39.90**	**42.75**
	Δ*RCP-4.5*	*-74.70*	*-125.21*	*-157.88*	*-664.52*	*-1085.33*	*-1535.13*	*-0.08*	*-0.09*	*-0.09*	*-0.31*	*-0.92*	*-1.48*	*0.40*	*0.71*	*0.95*
	Δ*Higher T*	*-110.48*	*-184.78*	*-233.67*	*-980.04*	*-1593.53*	*-2258.36*	*-0.13*	*-0.15*	*-0.13*	*-0.52*	*-1.58*	*-2.54*	*0.69*	*1.24*	*1.67*
	Δ*Higher SL*	*-73.85*	*-127.46*	*-157.72*	*-654.77*	*-1098.64*	*-1521.88*	*-0.09*	*-0.19*	*-0.07*	*-0.34*	*-1.03*	*-1.60*	*0.59*	*0.85*	*1.08*
EAP	**No CLC**	**1942.72**	**2177.94**	**2155.79**	**20035.55**	**26532.65**	**33785.23**	**15.93**	**21.29**	**27.02**	**96.96**	**82.09**	**63.81**	**60.68**	**68.00**	**72.97**
	Δ*RCP-4.5*	*-106.62*	*-164.26*	*-192.35*	*-1054.30*	*-1781.73*	*-2471.52*	*-0.09*	*0.00*	*0.13*	*-0.23*	*-0.73*	*-1.11*	*0.84*	*1.31*	*1.53*
	Δ*Higher T*	*-158.84*	*-243.90*	*-286.27*	*-1569.33*	*-2633.58*	*-3649.22*	*-0.14*	*0.02*	*0.23*	*-0.36*	*-1.16*	*-1.77*	*1.34*	*2.15*	*2.54*
	Δ*Higher SL*	*-106.66*	*-163.39*	*-192.28*	*-1055.66*	*-1773.07*	*-2474.02*	*-0.09*	*0.02*	*0.13*	*-0.22*	*-0.73*	*-1.10*	*0.82*	*1.30*	*1.52*
LAC	**No CLC**	**1042.78**	**1144.39**	**1116.01**	**43390.24**	**53409.78**	**65117.75**	**32.31**	**37.90**	**43.59**	**24.03**	**21.43**	**17.14**	**84.93**	**88.17**	**90.43**
	Δ*RCP-4.5*	*-75.32*	*-116.12*	*-132.17*	*-2887.53*	*-4743.00*	*-6423.89*	*-0.01*	*0.07*	*0.20*	*-0.14*	*-0.30*	*-0.38*	*0.15*	*0.27*	*0.37*
	Δ*Higher T*	*-112.64*	*-173.28*	*-196.92*	*-4311.65*	*-7071.77*	*-9576.80*	*-0.02*	*0.11*	*0.32*	*-0.23*	*-0.47*	*-0.59*	*0.26*	*0.47*	*0.63*
	Δ*Higher SL*	*-75.37*	*-116.82*	*-132.12*	*-2871.56*	*-4757.16*	*-6408.24*	*-0.01*	*0.03*	*0.21*	*-0.15*	*-0.31*	*-0.38*	*0.17*	*0.28*	*0.38*
MENA	**No CLC**	**856.98**	**1063.70**	**1146.50**	**30320.61**	**34118.02**	**40103.99**	**28.98**	**31.41**	**35.03**	**28.26**	**31.18**	**28.59**	**67.97**	**66.24**	**66.43**
	Δ*RCP-4.5*	*-29.06*	*-51.15*	*-66.67*	*-1154.46*	*-1660.93*	*-2181.15*	*0.00*	*0.03*	*0.24*	*0.13*	*0.02*	*-0.12*	*0.61*	*0.87*	*1.13*
	Δ*Higher T*	*-42.48*	*-73.61*	*-97.66*	*-1721.14*	*-2441.56*	*-3246.45*	*-0.01*	*0.09*	*0.37*	*0.22*	*0.08*	*-0.13*	*0.92*	*1.36*	*1.76*
	Δ*Higher SL*	*-28.85*	*-50.90*	*-66.47*	*-1159.63*	*-1678.56*	*-2199.53*	*0.00*	*0.04*	*0.23*	*0.14*	*0.04*	*-0.10*	*0.56*	*0.83*	*1.08*
OECD	**No CLC**	**10217.85**	**9862.12**	**9436.58**	**177786.86**	**208568.07**	**244574.22**	**56.17**	**60.87**	**64.94**	**57.47**	**47.28**	**38.58**	**85.79**	**89.73**	**92.75**
	Δ*RCP-4.5*	*266.35*	*417.75*	*518.11*	*2749.90*	*4819.73*	*6519.89*	*-0.07*	*-0.18*	*-0.21*	*0.60*	*0.89*	*1.07*	*0.16*	*0.18*	*0.17*
	Δ*Higher T*	*426.47*	*682.37*	*831.63*	*4385.09*	*7898.26*	*10417.02*	*-0.12*	*-0.25*	*-0.34*	*0.96*	*1.43*	*1.69*	*0.29*	*0.33*	*0.29*
	Δ*Higher SL*	*271.39*	*416.34*	*518.08*	*2761.12*	*4840.04*	*6554.72*	*-0.08*	*-0.19*	*-0.21*	*0.63*	*0.88*	*1.06*	*0.18*	*0.19*	*0.18*
SSA	**No CLC**	**403.55**	**781.45**	**1311.88**	**6950.25**	**7587.66**	**7879.56**	**4.97**	**5.47**	**5.52**	**58.06**	**102.99**	**166.49**	**38.98**	**39.34**	**38.75**
	Δ*RCP-4.5*	*-11.27*	*-52.06*	*-122.62*	*-189.83*	*-482.73*	*-678.33*	*-0.02*	*-0.05*	*-0.05*	*-0.03*	*-0.33*	*-1.34*	*0.12*	*0.41*	*0.63*
	Δ*Higher T*	*-16.79*	*-77.50*	*-182.50*	*-282.42*	*-716.77*	*-1005.49*	*-0.03*	*-0.07*	*-0.07*	*-0.06*	*-0.54*	*-2.19*	*0.20*	*0.68*	*1.06*
	Δ*Higher SL*	*-11.28*	*-52.07*	*-122.63*	*-189.81*	*-482.57*	*-678.01*	*-0.02*	*-0.05*	*-0.05*	*-0.04*	*-0.33*	*-1.35*	*0.13*	*0.41*	*0.63*
World	**No CLC**	**15300.40**	**15981.68**	**16156.84**	**40914.18**	**40577.94**	**39520.13**	**23.01**	**23.51**	**22.66**	**373.96**	**393.85**	**408.83**	**56.85**	**56.30**	**54.21**
	Δ*RCP-4.5*	*-30.61*	*-91.05*	*-153.56*	*-81.83*	*-90.92*	*-51.69*	*0.00*	*0.04*	*0.11*	*0.00*	*-1.36*	*-3.36*	*0.49*	*0.77*	*0.93*
	Δ*Higher T*	*-14.76*	*-70.71*	*-165.39*	*-39.42*	*51.04*	*132.66*	*0.00*	*0.09*	*0.18*	*0.00*	*-2.23*	*-5.54*	*0.80*	*1.28*	*1.56*
	Δ*Higher SL*	*-24.61*	*-94.31*	*-153.12*	*-65.76*	*-89.14*	*-39.82*	*0.00*	*0.02*	*0.11*	*0.00*	*-1.46*	*-3.47*	*0.54*	*0.81*	*0.96*

Notes: This table depicts our aggregated projections of income and population indicators for the *No CLC* scenario and contrasts them with the *RCP-4.5*, *Higher T* and *Higher SL* scenarios. E.g. Δ *RCP-4.5* $\widehat{=}$ *RCP-4.5* − *No CLC*. Regions: Central Asia and the Rest of Europe (CARE), East Asia and Pacific (EAP), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), OECD, Sub-Saharan Africa and the World.

Climate change thus creates conditions that are conducive to increasing urbanization and international migration from developing to rich countries and regions. In Section 4.1, we quantify the number of climate migrants per period and characterize the geography of these movements. Then, Section 4.2 investigates the skill structure of climate migration. The rest of the section focuses on the poverty implications of climate change and on the role of migration policies (Section 4.3).

4.1 Climate Migrants Worldwide

The migration implications of climate changes are represented in Figure 3 and summarized in Table 2. The top panel of Table 2 gives the benchmark numbers of movers obtained in the absence of climate change, distinguishing between local movements (nil under a constant sea level), inter-regional and international movements. For the latter, we classify them as North-North (N-N), North-South (N-S), South-North (S-N) and South-South (S-S). Countries from the North are meant to represent high-income OECD countries. The next two panels give the number of additional climate migrants predicted under the two climate scenarios. In the *RCP-4.5* scenario, we identify 29.5, 20.9 and 19.1 million climate migrants in 2040, 2070 and 2100, respectively. This corresponds to a total of 69.5 million migrants aged 25 and more over the course of the 21st century. Adding dependent children gives a stock of about 130 million movers. These estimates are close to those obtained by Rigaud et al. (2018), though we use a radically different approach.

Table 2: Climate Migration Worldwide (in millions)

		Local	Int-reg	N-N	N-S	S-N	S-S	Total
No CLC	**2040**	0.00	461.5	47.0	3.1	127.0	112.2	–
	2070	0.0	437.3	31.7	2.1	142.4	131.6	–
	2100	0.0	433.9	20.4	1.4	149.3	145.1	–
Δ *RCP-4.5*	***2040***	*7.9*	*12.9*	*0.2*	*-0.1*	*5.9*	*2.8*	*29.5*
	2070	*0.5*	*8.7*	*0.0*	*-0.1*	*9.0*	*2.8*	*20.9*
	2100	*0.6*	*5.5*	*0.0*	*-0.1*	*10.7*	*2.4*	*19.1*
	Total	*9.0*	*27.1*	*0.2*	*-0.3*	*25.6*	*7.9*	*69.5*
Δ *Higher T*	***2040***	*7.9*	*20.6*	*0.3*	*-0.1*	*9.5*	*4.8*	*43.0*
	2070	*0.5*	*14.5*	*0.1*	*-0.2*	*14.5*	*5.2*	*34.6*
	2100	*0.6*	*9.3*	*-0.0*	*-0.1*	*17.2*	*4.2*	*31.0*
	Total	*9.0*	*44.4*	*0.3*	*-0.4*	*41.1*	*14.2*	*108.5*
Δ *Higher SL*	***2040***	*25.4*	*14.5*	*0.1*	*-0.1*	*6.2*	*2.9*	*49.1*
	2070	*2.8*	*8.4*	*0.1*	*-0.1*	*8.9*	*2.9*	*22.9*
	2100	*1.9*	*5.3*	*0.0*	*-0.1*	*10.7*	*2.4*	*20.2*
	Total	*30.1*	*28.2*	*0.2*	*-0.3*	*25.8*	*8.2*	*92.2*

Our model allows endogenizing the preferred destinations of these climate migrants, assuming constant migration costs and policies. Summing up over the three periods, climate changes has negligible impacts on N-N and N-S migration, and a small impact on S-S international movements (the black area in Figure 3). Under the *RCP-4.5* scenario (Panel (a) in Figure 3), 13% of climate-related moves are local (forced displacements) and 39% are inter-regional (rural to urban); these internal movements are depicted by the light and dark grey areas in Figure 3. In addition, long-haul movements from developing to OECD countries (roughly corresponding to the yellow area in Figure 3 as N-N movements are negligible) account for 37% of climate migration. S-N climate migration involves 25.7 million people over the 21st century (i.e., about 8.5 million per period). On average, this represents an increase by 5 to 7% in the total stock of immigrants to OECD countries depending on the period. The sea level rise will have its most significant effects between 2010 and the middle of the century. By the 2040, the stock of climate migrants reached 29.5 million people, including 27% of local movements, 44% of inter-regional movements, and 20% of South-North migrants only. South-South migration involves 2.8 million movers (9% of the total).

In the *Higher T* scenario, we predict 43.0, 34.6 and 31.0 million adult migrants in 2040, 2070 and 2100, which corresponds to a total of 108.5 million individuals over the course of the 21st century (i.e., 39.0 million more than under the *RCP-4.5* scenario). Adding dependent children gives a stock of about 200 million movers. Over the century, we now find that 8% of climate-related moves are local, 41% are inter-regional, and 38% are S-N. In total, S-N climate migration involves 41.1 million people over the 21st century, which represents about 13 million per period. On average, this induces a 7 to 11% increase in the total stock of immigrants to OECD countries depending on the period. By the 2040, the stock of climate migrants reached 43.0 million people, including 18% of local movements, 48% of inter-regional movements, and 22% of South-North migrants only. South-South migration involves 4.8 million movers (11% of the total).

Uncertainty about sea level rise is large because the dynamics of ocean heat uptake as well as the creation and decay of ice sheets and glaciers are poorly understood. It is thus important to check whether our results are robust to the magnitude of sea level rise. In the *Higher SL* scenarios, we double the sea level rise compared to *RCP-4.5*. This scenario is represented in the Panel (c) of Figure 3 and in Table 2. This scenario induces movements of 49.1, 22.9 and 20.2 million climate migrants in 2040, 2070 and 2100, respectively. This corresponds to a total of 92.2 million migrants over the course of the 21st century (i.e., 22.2 million more than under the *RCP-4.5* scenario). Over the century, 33% of climate-related moves are local and 31% are inter-regional. Compared to the *RCP-4.5* scenario, doubling the magnitude of the sea level rise increases local movements by 21.1 million people, while it increases rural-to-urban migration by 1.2 million people only. Sea level rise has negligible impacts on N-N and N-S migration, and a small impact on S-S international movements. Long-haul movements from developing to OECD countries account for 28% of climate migration. Hence, S-N climate migration now involves 25.8 million people over the 21st century, only 0.2 million more than under the *RCP-4.5* scenario.

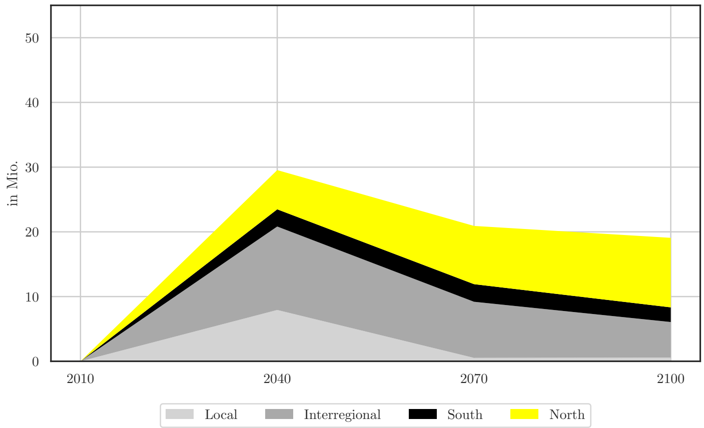
Our results clearly suggest that forced displacements due to sea level rise are mostly local (i.e., from flooded to non-flooded areas within the same region), while inter-regional and international mobility responses are overwhelmingly governed by the TFP responses to temperature changes.

Table 3 translates our international migration prospects into country-specific emigration rates (left panel) and immigration rates (right panel). Emigration rates are expressed as the ratio of the stock of international emigrants to the native population aged 25-65 in the origin country. Immigration rates are expressed as the ratio of foreigners to the total population aged 25-65 in destination countries. In each panel, the first four columns give the evolution of migration rates in the *No CLC* scenario; the next two columns gives the variation in migration rates induced by climate change in the *RCP-4.5*, *Higher T* and *Higher SL* scenarios, respectively. Countries are ranked by decreasing order according to the variation obtained in the *RCP-4.5* scenario.

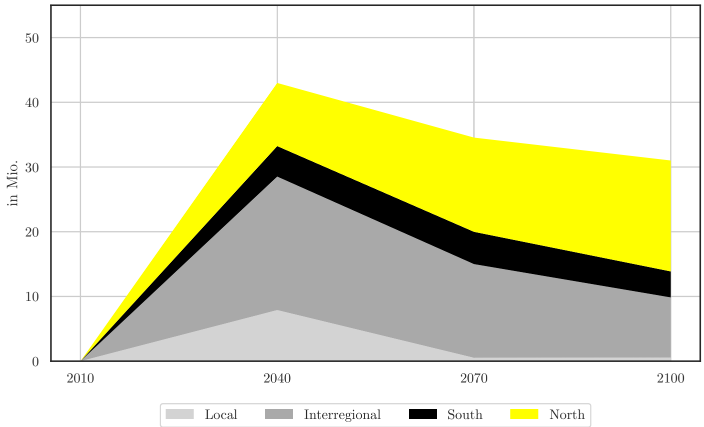
The left panel lists the 30 countries exhibiting the largest climate-related variations in international emigration rates by the end of the century. These mostly include small countries and island developing states located in the Pacific, the Caribbean, and Central America. Hence, although the variation in emigration rates are substantial (+8.3 percentage point in Federate States of Micronesia in the *RCP-4.5* scenario, and +14.4% in the *Higher T* scenario), the number of people involved is rather small. Conversely, the right panel lists the 30 countries exhibiting the largest climate-related variations in immigration rates by the end of the century. These include OECD countries. Note that the immigration rates reported for the year 2010 are roughly twice as large than those reported in official statistics. This is because our immigration rates are computed as proportion of the population aged 25-65 and not as proportion of total population. As immigrants mostly belong to this age group, their share in the working-age population is much greater than their share in total population. Under constant migration policies and without climate change (i.e., in the *No CLC* scenario), the share of immigrants in the total population increases by factor comprised between 2 and 3 in most OECD countries. These variations are induced by population growth differentials between South and North countries, as well as by the progress in education in the South. Climate change contributes a little to the rise in migration pressures to the North. In most European countries, the *Moderate* scenario increases the share of foreigners by 1 to 2 percentage points, whereas socio-demographic imbalances increase it by 20 to 30 percentage points. In the United States, climate change increases the immigration rate by 2.4 percentage point, against 30 percentage points for socio-demographic imbalances. Compared to the *RCP-4.5* scenario, the effect of climate migration is 1.5 times as large in the *Higher T* scenario.

Figure 3: Climate Migration Worldwide

(a) Δ *RCP-4.5*



(b) Δ *Higher T*



(c) Δ *Higher SL*

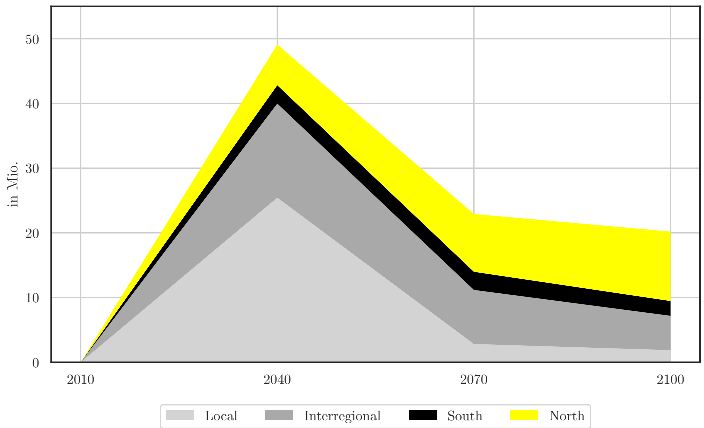


Table 3: Effect of Climate Change on Migration Rates

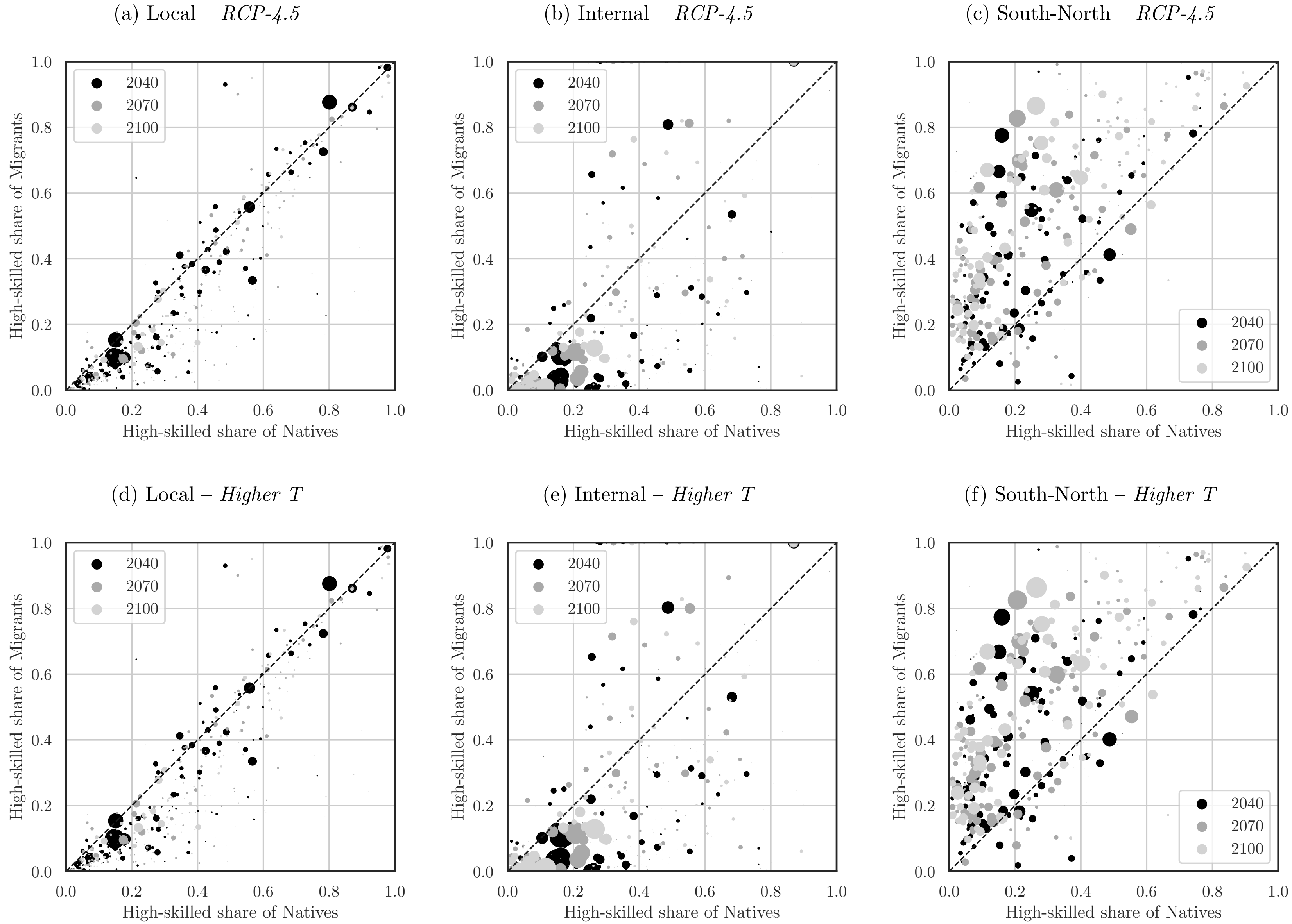
	Average Emigration Rate [% of Natives]								Average Proportion of Foreigners [% of Residents]						
	No CLC				*RCP-4.5*	*Higher T*	*Higher SL*		*No CLC*				*RCP-4.5*	*Higher T*	*Higher SL*
Orig.	**2010**	**2040**	**2070**	**2100**	**2100**	**2100**	**2100**	**Dest.**	**2010**	**2040**	**2070**	**2100**	**2100**	**2100**	**2100**
FSM	35.93	35.37	34.12	34.21	8.31	14.40	8.09	**ISL**	13.44	23.68	34.63	49.32	2.52	3.89	2.51
STP	36.68	45.22	49.04	52.16	7.94	14.54	7.94	**USA**	25.14	43.84	49.88	54.64	2.38	3.65	2.38
SLV	34.69	43.94	45.27	46.39	7.71	12.88	7.76	**BEL**	27.61	41.90	54.19	68.67	1.68	2.62	1.68
GUY	55.58	64.16	63.54	66.36	7.22	12.74	7.16	**DNK**	16.71	24.99	33.02	41.62	1.67	2.58	1.66
CAN	9.70	28.07	29.34	30.54	6.56	11.67	6.56	**ITA**	15.03	27.93	35.33	44.20	1.65	2.62	1.71
SUR	49.15	58.79	57.68	56.08	5.18	8.04	5.16	**NLD**	17.69	36.12	45.73	54.19	1.57	2.31	1.25
FJI	31.29	43.97	45.78	47.59	4.92	8.07	4.91	**CAN**	38.86	70.63	82.67	90.04	1.24	2.48	1.24
JAM	44.68	55.81	57.12	58.60	4.32	6.84	4.33	**NZL**	41.20	71.03	76.83	80.09	1.17	1.80	1.46
NIC	17.15	21.43	21.56	21.76	4.24	7.47	4.25	**KOR**	3.28	7.48	11.08	14.60	1.08	1.69	1.11
BLZ	29.53	41.51	42.47	44.12	4.13	6.55	4.12	**PRT**	12.80	36.75	68.05	88.41	1.00	1.55	1.01
NPL	11.01	13.25	13.57	14.15	3.51	9.09	3.50	**ESP**	20.68	40.20	45.71	50.53	0.99	1.58	0.98
COM	17.07	18.27	17.61	17.72	3.47	6.17	3.47	**DEU**	23.32	40.76	48.18	55.19	0.93	1.43	0.88
LBR	16.14	18.85	19.43	20.21	3.44	6.03	3.44	**JPN**	3.53	8.08	10.64	12.69	0.90	1.42	0.90
DOM	19.90	29.56	30.34	31.46	3.01	4.71	3.01	**AUT**	27.02	36.37	42.89	50.93	0.88	1.46	0.88
PHL	10.86	18.18	20.65	22.82	2.84	4.75	2.84	**GRC**	21.96	34.86	36.75	39.25	0.87	1.35	0.86
HND	16.56	24.62	26.35	28.15	2.76	4.34	2.77	**FRA**	23.66	40.30	53.50	67.48	0.82	1.32	0.81
GMB	11.20	15.43	18.52	21.99	2.72	4.50	2.72	**AUS**	45.55	66.79	75.61	82.05	0.79	1.25	0.78
CUB	17.42	25.61	25.70	26.01	2.70	4.23	2.70	**FIN**	8.27	11.10	15.21	20.94	0.77	1.21	0.77
GTM	14.31	20.76	21.22	21.76	2.35	3.69	2.36	**ISR**	51.74	64.92	72.73	79.99	0.62	0.89	0.59
ECU	13.24	19.35	19.11	19.05	2.35	3.78	2.35	**GBR**	24.55	51.47	69.63	83.30	0.49	0.81	0.49
TLS	9.60	11.42	12.29	13.36	2.34	4.32	2.34	**HUN**	7.21	10.50	11.66	13.24	0.42	0.65	0.42
COG	9.75	14.69	16.00	16.56	2.16	3.65	2.17	**SVN**	19.72	21.46	20.26	19.38	0.39	0.71	0.39
PRY	14.16	15.86	15.59	15.25	2.16	3.69	2.16	**CZE**	5.13	7.71	8.97	10.70	0.35	0.58	0.36
PAN	7.18	9.51	9.59	9.58	1.93	3.22	1.87	**NOR**	20.99	30.67	39.63	50.16	0.29	0.54	0.30
GNQ	22.34	25.32	26.22	26.71	1.91	3.20	1.91	**IRL**	28.82	47.77	57.00	66.88	0.21	0.56	0.18
LAO	17.32	26.75	29.62	31.68	1.90	3.01	1.90	**CHL**	2.67	4.06	4.53	5.03	0.15	0.24	0.15
RUS	9.84	11.36	11.06	10.62	1.81	2.86	1.82	**POL**	1.42	1.46	1.65	2.08	0.07	0.11	0.07
WSM	30.65	45.03	43.42	43.61	1.81	2.71	1.84	**TUR**	2.30	1.57	1.32	1.24	0.03	0.04	0.03
TJK	16.06	18.90	19.25	19.65	1.79	3.05	1.79	**MEX**	0.83	0.75	0.82	0.90	0.02	0.04	0.02
HTI	19.40	35.56	40.13	43.46	1.79	2.78	1.75	**SWE**	27.67	40.12	51.94	62.14	-0.00	0.07	-0.01
LKA	12.47	11.41	11.35	11.79	1.63	2.82	1.63	**LUX**	70.63	87.13	93.43	97.03	-0.06	-0.06	-0.05
TON	56.77	61.51	59.02	58.79	1.57	2.33	1.52	**SVK**	4.75	5.31	5.63	6.35	-0.10	-0.10	-0.10
MYS	11.16	18.94	21.78	24.87	1.51	2.50	1.51	**CHE**	43.86	65.97	75.79	84.51	-0.46	-0.45	-0.45
YEM	10.80	15.22	15.62	16.07	1.45	2.38	1.48	**EST**	30.27	49.68	62.55	73.59	-0.98	-1.39	-0.98

4.2 Skill Structure of Climate Migration

We turn next to the self-selection of climate migrants in terms of education level. For each region of origin and for each period, Figure 4 compares the share of college graduates among natives (X-axis) with the shares of college graduates among climate emigrants (Y-axis). Bubble sizes increase with the stock of migrants concerned, while colors refer to periods. The number of climate migrants is defined as the difference between the number of emigrants in the *RCP-4.5* (top panel) or *Higher T* (bottom panel) scenario and the number of emigrants in the *No CLC* one. We focus on the three categories of migrant that are strongly impacted by climate change – namely local movers (left panel), rural-to-urban movers (central panel) and South-North migrants (right panel) – and exclude region-wave observations with negative number of climate migrants. This mostly pertains to rural-to-urban migration in high-income countries, as agricultural productivity increases in countries located above the 35th parallel. Hence, the central panel includes 140 observations only.

Self-selection varies across region. However, whatever the climate scenario, we find that local movers from a majority of regions are slightly less educated than the native population. The process of negative selection is stronger among internal (i.e., rural-to-urban) migrants. Natives born in rural regions of the poor countries are usually poorly educated; those deciding to emigrate within their country are even less educated. On the contrary, South-North climate migrants are positively selected along education levels. The share of college graduates among South-North migrants exceeds the natives' share by a factor of 2 to 3 in most regions. In particular, in relative terms, the intensity of positive selection is large in low-income regions. Hence, high-skilled people from poor regions exhibit much greater propensity to emigrate to industrialized countries than the less educated when they are confronted to the damages resulting from climate change. The fact that international climate migration is of the brain drain type reinforces the adverse impact of climate change in low-income countries.

Figure 4: Self-selection in Climate Migration



Notes: Figure 4 compares the share of college graduates among climate migrants (Y-axis) and natives (X-axis). It distinguishes between 3 categories of migrants (local, internal and South-North) and 2 climate scenarios (*RCP-4.5* in a-c, and *Higher T* in d-f). Bubble sizes are proportional to the squared root of the number of movers.

4.3 Extreme Poverty and Migration Policies

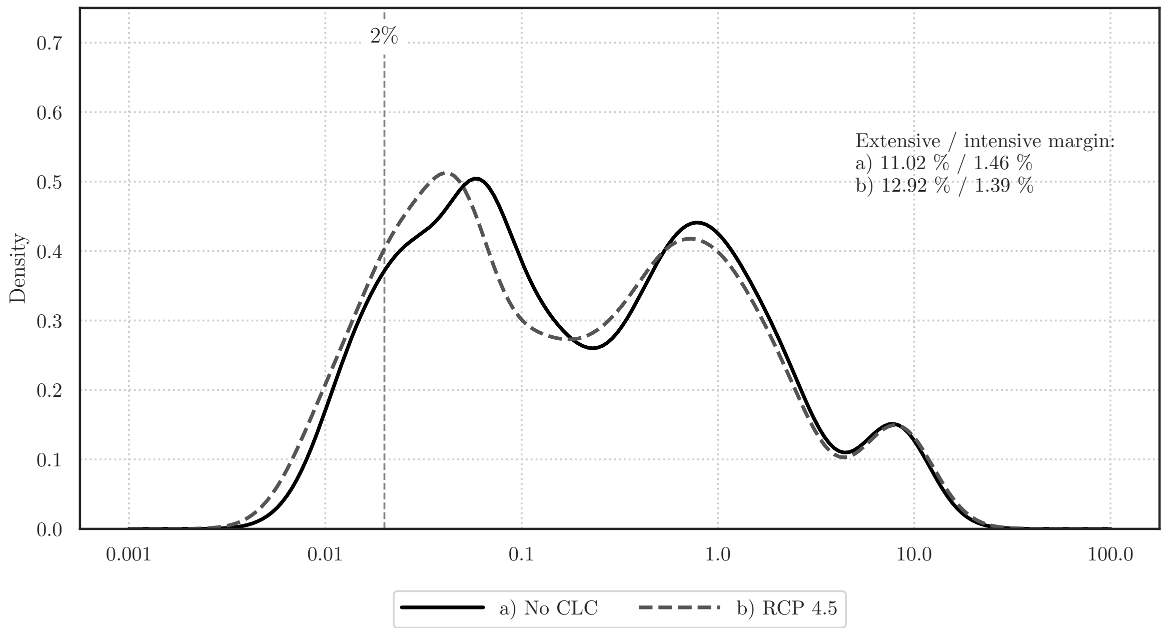
As stated above, climate change makes the world distribution of income more unequal. The income loss is even greater for low-skilled workers trapped in the poorest regions (i.e., rural regions). In our long-term context with sustained TFP growth, we define *Extreme Poverty* in relative terms as the percentage of workers earning less than 2% of the worldwide average level of income per worker. Figure 5 compares the world distribution of income in 2100 across climate change scenarios. The income level of all types of worker is expressed as percentage of the world average. By considering four types of worker per country (two skill groups times two regions) and by ignoring within-group heterogeneity, the density in Figure 5 is an approximation of the actual income distribution. The model predicts three peaks by the end of the 21st century: one at around 5% of the world average, one slightly below the world average, and one at 10 times the world average. The relative poverty line is represented by the vertical dashed gray line.

Climate change affects the distribution of income below the worldwide average level. We focus here on the extensive margin of poverty, measured by the share of world population below the relative poverty line, as well as on the intensive margin of poverty, computed as the mean income of workers in extreme poverty expressed as percentage of the worldwide average income level. Figure 5 shows that climate change adversely impacts extreme poverty. In the *RCP-4.5* scenario, the share of the world population living in extreme poverty increases by 1.9 percentage points (from 11.0 to 12.9%), and the relative income of the extreme poor decreases by 0.07 percentage point compared to the world average. In the *Higher T* scenario (not shown on Figure 5), the extensive margin increases by 6 percentage points (from 11.0 to 17.0%) and the relative income of the extreme poor decreases by 0.15 percentage points.

It is thus natural to explore whether a change of immigration and urbanization policies can help limit the effect of climate change on extreme poverty. Predicting mobility responses to a partial or total liberalization of international migration is a complex task (see Delogu et al., 2018; Docquier, Machado, & Sekkat, 2015). Hence, to shed light on the potential effect of future international migration and urban development policies, we compare the *RCP-4.5* scenario with two extreme (and rather unrealistic) mobility variants. The first one consists of preventing people to migrate internationally from 2040 onwards ($x_{b,s,t}^{jr,j'rj'} = 1 \; \forall j \neq j'$). The resulting income distribution corresponds to the dark gray dashed curve in Figure 6. Our second counterfactual consists of preventing people to migrate between regions within their country from 2040 onwards ($x_{b,s,t}^{jr,jr'} = 1 \; \forall r \neq r'$), while re-opening the external borders. The resulting income distribution corresponds to the light gray dotted curve in Figure 6.

We find that closing the external borders reduces poverty at the extensive margin (6 percentage points) and at the intensive margin. This is due to skill-selection in inter-

Figure 5: Effect of Climate Change on Income Distribution in 2100 (under *RCP-4.5*)

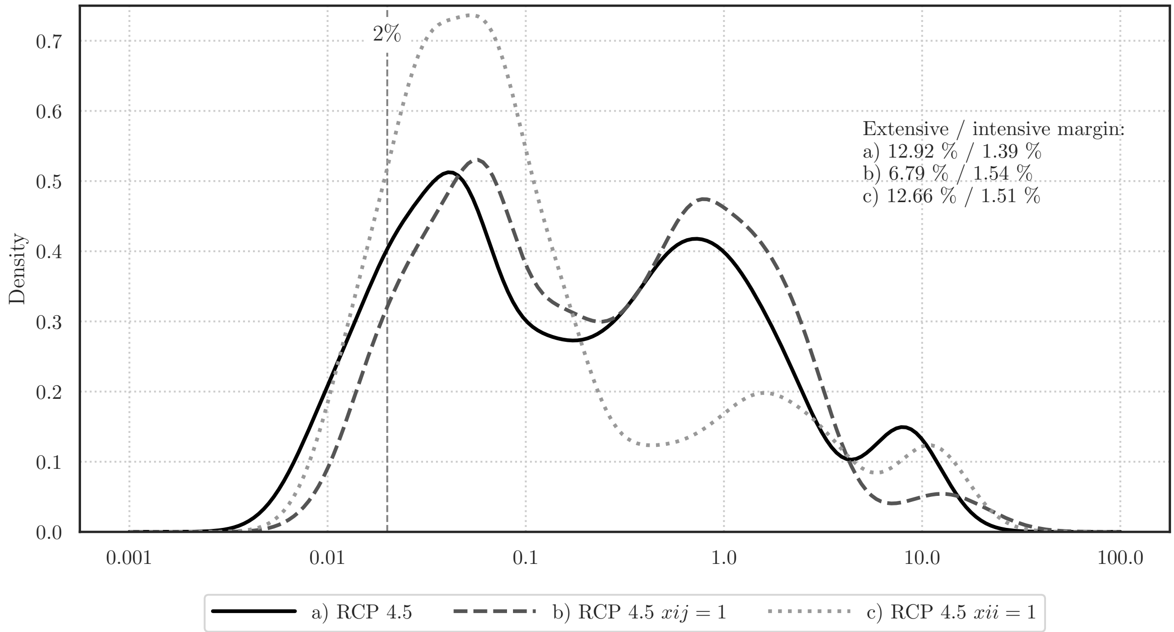


Notes: Figure 5 depicts smoothed predicted distributions of income in 2100 under the *No CLC* (black solid curve), and *RCP-4.5* (gray dashed curve) scenarios. The gray vertical line represents the relative poverty threshold (2% of average income).

national migration responses to climate change. International migration opportunities mostly benefit high-skilled workers from urban regions. The resulting "brain drain" reduces the low-skilled wage rate in this sector, which slows down urbanization and increases the number of low-skilled workers "trapped" in the rural sector. This implies that relaxing international migration restrictions may exacerbate the poverty responses to climate change. Leaving aside the discussion of the political economy of removing migration barriers as well as integration issues involved by the skill selectivity of migrants, our simulations suggest that the poverty implications of a climate-related migration policy is highly sensitive to the target group. If the policy affects the poorest individuals from the poorest countries (i.e., low-skilled workers in agriculture), opening borders and issuing new "climatic visas" may be good for mitigating the poverty response to climate change in the origin regions. On the contrary, if the policy does not impact the self-selection of international migrants or if the screening of potential migrants is imperfect, it is likely to reinforce extreme poverty at origin.

As for internal movements, Figure 6 shows that preventing people from migrating from rural to urban regions has ambiguous effects on extreme poverty. In the poorest regions (where income per capita is below 1% of the world average income), internal migration is a costly option and low-skilled workers are trapped in their region of birth. Preventing the very few high-skilled workers to leave slightly reduces extreme poverty. In poor region

Figure 6: Climate Change and Inequality without Migration (under *RCP-4.5*)



Notes: Figure 6 depicts smoothed predicted distributions of income in 2100 under the *RCP-4.5* climate scenario and alternative migration policies. The gray vertical dashed line represents the relative poverty threshold (2% of average income). The black solid curve gives the inequality responses under current migration costs and policies. The dark gray dashed curve gives the effects obtained after closing all borders. The light gray dotted curve shows the effect obtained after preventing people from migrating between regions/sectors within their country.

where income per capita is between 1% and 2% of the world average income, internal migration allows low-skilled people to escape poverty; preventing them to leave increases extreme poverty. Quantitatively speaking, these two effects balance each other out. Note that preventing internal migration dramatically increases the share of the population living with 2 to 20% of the worldwide average income level, and polarizes the world distribution of income. In line with the Sustainable Development Agenda, our analysis suggests that policies targeting sustainable urban development and smaller internal mobility frictions are key to mitigate the poverty impact of climate change.

5 Conclusion

Climate change is regarded as a significant shock that will visibly change the global economic environment in the coming decades. Indeed, our results strongly support this statement. A gradual increase in average temperature levels and the sea level rise constitute a source of welfare redistribution across individuals, regions, and countries. Climate change is likely to boost productivity in the rich economies, and strongly harm the poorest countries located close to the equator. This, assuming no changes to global migration policies, induces movements from rural to urban regions and from less developed to highly developed countries. The simulations of our model indicate that the overall magnitude of these climate-induced flows reaches 70 million (108 million) workers in the *RCP-4.5* (*Higher T*) scenario over the course of 21st century. Interestingly, a significant proportion of these migrants (27% by 2040 and 13% over the whole century) will choose to move locally, and many others (44% by 2040 and 39% over the whole century) will move across regions of their home country. The rest (29% by 2040 and 48% over the whole century) will decide to cross borders. When it comes to international migration, we find that South-North migrants constitute an overwhelming part of total flows, while South-South migration is of lesser importance. We predict almost no changes to emigration from North, OECD countries. When looking at the education levels of climate migrants, the model predicts a stark dichotomy of self-selection patterns. While internal movers are predicted to be negatively selected from their home region populations, international migrants are strongly positively selected. The latter indicates that climate change boosts the brain drain of less developed countries, which, along with adverse impact on productivity, reinforces divergence in income per capita across the globe.

Significant redistribution of income across regions and countries that widens the inequality gap, calls for policy interventions to save people from encountering economic losses. Experimenting with migration policies only, we find that closing international borders might reduce aggregate inequality at the cost of individual utility of potential climate emigrants (positively selected) who cannot leave their homelands. On the contrary, closing down the regional migration significantly deteriorates the welfare in the poor regions, and accelerates the rise in inequality, as the low-skilled climate migrants become stuck in their regions of birth.

As temperatures and sea level continue to increase, economic prosperity of dozens of millions is under threat. Climate change, one of the major challenges for humankind in the next decades, is supposed to induce significant global mobility of people. Our quantitative results only support this statement, but give it a slightly different flavour, as the most intensive response is predicted to take place at the local and regional scale. Thus, our results reinforce the call for efficient global policies, but, more importantly, highlight the importance of local and regional context in fighting with the effects of climate change on migration.

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