On international migration across the Shared Socioeconomic Pathways (SSP)

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October 31, 2019

Abstract

With climate change, migration patterns are expected to change, and will likely depend on future global socioeconomic development. The Shared Socioeconomic Pathways (SSP) represent five narratives of future development, along with quantified projections of population, income levels, inequalities and emissions over the 21^{st} century. The population projections reflect explicit, pathway-specific international migration assumptions. Yet, migration assumptions are implicitly part of other projections. Here, we explicitly quantify the effects of international migration on income levels, inequality, energy consumption and emissions, by comparing original projections to scenarios of zero migration. We model income projections without migration as the difference between original projections and two effects: changed population size, and remittances sent to origin. We base remittances on migrant stocks derived from bilateral migrant flows, modelled with a gravity model. We find that migration tends to make the world richer, on average, in all SSP narratives. Yet the scenario of future development considered significantly influences the nature of migration and remittances corridors. Depending on the narrative and location, the migration effect on income can be substantial, up to +25% and -2% at the continental level. Furthermore, we show that migration tends to decrease inequality between countries, has little effect on domestic inequalities in most origin countries and decreases inequalities in most destination countries. The magnitude of the migration effect on all inequalities is strongly influenced by the SSP narrative. Finally, we show that migration tends to slightly increase energy consumption and emissions, as the induced change in population distribution overrides the reducing effect of wealth in destination countries. This new set of projections ensures consistency with the SSP interdisciplinary framework. This makes it particularly useful for assessing global policy options.

1 Introduction

Migration decisions are often multi-causal and rarely due to environmental stress alone. Environmental change may however influence migration both directly and indirectly through various channels: economic, political, social, demographic, and environmental [1]. Migration patterns

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can respond to extreme weather events (projected to increase in intensity) and long-term climate variability or change (droughts, sea-level rise [2]). Those changes might both enhance and limit migration patterns in the future.

Migration decisions at the individual or household level might not be directly affected by climatic variability for several reasons. First, remittances from earlier migrants may reduce incentives to move. In contrast, established migration networks may increase an individual's propensity to move. Migration may thus be increasingly used as adaptation strategy to climate change [3]. Second, people often do not factor exposure to climate impacts in their choice of destination. Thus, they might move to areas that are more exposed than where they came from. Third, climate change is likely to destroy resources in the most deprived areas, thereby trapping individuals who cannot afford to move [4, 5]. Therefore, higher levels of climate change will likely reduce people's ability to move on their own terms, inducing both an increasing number of people who are forced to move, and an increasing number of people who are forced to stay [6].

As a result, both push and pull factors of migration may change significantly with climate change, although the direction of the overall change is unclear. Gross estimates of future climate-related migrants have been widely criticized in academic circles for their deterministic, non-robust underlying methods [7]. Moreover, changes in migration patterns might strongly affect income levels and their distribution across and within countries, energy consumption and greenhouse gas emissions.

The Shared Socioeconomic Pathways (SSP) represent five qualitative narratives of future global development and have proven to be useful tools to study heterogeneous futures in the context of climate change research. They highlight different combinations of challenges to mitigation and adaptation to climate change, structured into five scenarios (see Figure 1 [8]). Embedded in these narratives are assumptions on future international migration. The first scenario, SSP1 ("Sustainability"), describes a sustainable future, focused on strengthening well-being, where the world features low inequalities and strong international cooperation. In this world, migration is assumed to stay at medium levels, i.e. similar to historical patterns. The SSP2 (" Middle of the Road") scenario features a world where historical patterns and trends are assumed to persist in the future, in a context of political stability but with limited social cohesion. In this scenario, migration is also assumed to stay at medium levels. SSP3 ("Regional Rivalry") showcases a fragmented world with regional conflicts occurring and a strong emphasis on security, in particular on closed borders; in such a scenario for future developments, a low level of migration is assumed. SSP4 ("Inequality") assumes a highly unequal world, with strong inequalities both across and within countries, and the emergence of a global elite. For this scenario, migration is assumed to stay at medium levels. Note that the characteristics of migrants (in terms of, for example, income levels or skills) in this scenario is quite different from those of migrants in more optimistic scenarios such as SSP1 and SSP2. Finally, SSP5 ("Fossil-fueled Development") represents a future of strong resource-intensive technological progress and economic growth, featuring a sustained use of competitive markets and widespread globalization. In this world, migration is assumed to be high [9].

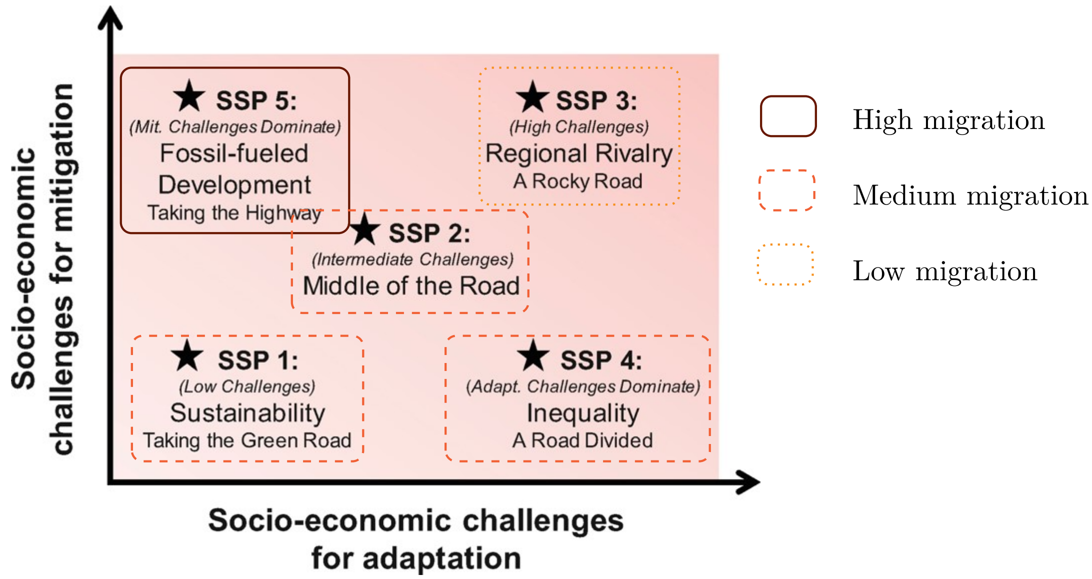


Figure 1: The five SSP narratives and their embedded assumptions on international migration. Sources: [8, 9]

The scenarios embodied within the SSP framework have been quantified as projections of population by age and educational attainment [9, 10], GDP [11, 12, 13], inequality [14], final energy consumption and greenhouse gas emissions [15, 16, 17, 18, 19, 20] up to the year 2100. The population component reflects explicit, pathway-specific migration assumptions and is used as input to all other components. On the other hand, migration assumptions are only implicit in the other components for which quantitative projections exist.

In this contribution, we explicitly quantify the effects of international migration on the SSP's GDP , inequality, energy consumption and emissions projections by comparing original projections to scenarios where zero migration is assumed. We show that migration tends to make the world richer, on average, in all SSP scenarios. Furthermore, the scenario of future development considered significantly influences the nature of migration and remittances corridors. Depending on the narrative and location, the migration effect on income can be substantial, up to +25% and -2% at the continental level. Moreover, we show that migration tends to make the world slightly more equal in most SSP scenarios, has little effect on domestic inequalities in most major economies and origin countries, increases inequalities in few origin countries and reduces inequalities in most destination countries. The development scenario sigificantly influences the magnitude, if not the sign, of the migration effect on inequality. Finally, we show that migration tends to slightly increase energy consumption and emissions, as the induced change in population distribution overrides the reducing effect of wealth in destination countries. Most importantly, since the conceptual nature of the SSP framework implies that the projections are not meant to be accurate predictions as much as they are internally consistent scenarios, the new set of projections developed here, ensuring consistency with original projections, fits perfectly in the SSP's interdisciplinary methodological framework. In combination with other existing projections, our set of projections is particularly useful for the assessment of global policy options.

2 Methods

2.1 Population component

We focus on the integration of international, permanent migration in the GDP projections. In the second version of original population projections[1] [9], the medium migration scenario (used in SSP1, SSP2 and SSP4) assumes constant in-migration and out-migration rates for the coming century. The high migration scenario (SSP5) essentially assumes migration rates double by 2030 and then remain constant, while the low migration (SSP3) assumes migration rates go to zero by 2030. The number of people moving to another country in any 5-year period of the projection period stays under 1% of global population.

More recently, population projections under a zero migration assumption have been developed.[2] Some features of these new projections are illustrated in Figure 2. In Figure 2a, original and zero migration population projections are shown for Mexico as an example. The strong effect of migration on population dynamics for SSP5, as well as the lack of effect for SSP3 are noticeable. Mexico tends to be an origin country for migration, which explains that projections imply a smaller population with than without migration. In Figure 2b, the relative changes in population for scenarios with and without migration at the end of the 21^{st} century under the SSP2 scenario are depicted. Countries in shades of blue represent majority destination countries, while countries in shades of red represent majority origin countries. Net destination countries include Western Europe, Northern America, the Arabic Peninsula, South Africa, Russia and Australia, while net origin countries are rather located in parts of Latin America, the Caribbean, Northern Africa, Eastern Europe and Central Asia. Note that for several large developing countries such as China, India, Brazil and Nigeria, international migration has virtually no effect on population size.

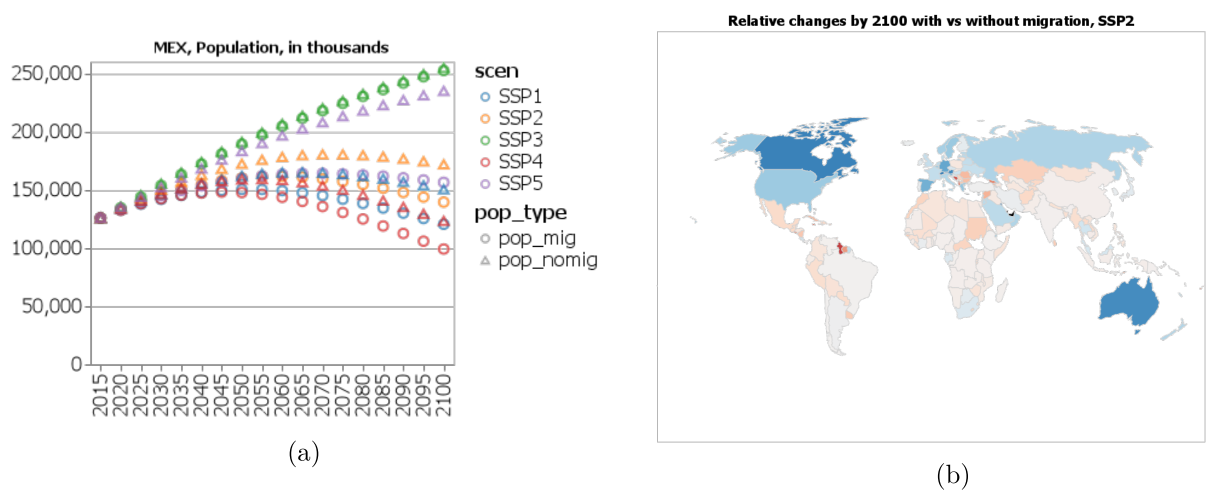


Figure 2: Original population projections with migration and new projections without migration. 2a The 5 SSP over the 21^{st} century for Mexico. 2b Relative changes for SSP2 ("middle-of-the-road") by end of the century for all countries.

These population projections are used to develop new projections of GDP which can be used to explicitly assess the role played by migration dynamics as a driver of income differences in SSP

[1]Version 2 of the SSP population projections are forthcoming, and can be made available upon request by Samir KC. A description is available in [21]

[2]These are not yet publicly available, but can be made available upon request by Samir KC.

projections.

2.2 GDP component

We make use of the GDP projections developed by [11] for SSP scenarios. Migration is included implicitly in these GDP scenarios, as the original population projections are used as an input to construct them. We construct counterfactual income projections under the zero migration assumption by correcting the original projected income data based on two effects of migration on GDP per capita dynamics. First, the change in population at the country level affects GDP per capita through the denominator of the expression. In addition to this effect, remittances sent by migrants to their origin countries also need to be incorporated into GDP figures in the projection period. Incorporating these effects in the GDP projection implies that the income variable under migration is given by

$$\begin{aligned} GDP_{mig} &= GDP_{nomig}\left(1+\frac{pop_{mig}-pop_{nomig}}{pop_{nomig}}\right)+rem \\ ypc_{mig} &= ypc_{nomig}+\frac{rem}{pop_{mig}}, \end{aligned} \tag{1}$$

where pop represents the population size of a given country, GDP the income, ypc the per capita income, and rem the net remittances flow into the country, while the subindices mig and $nomig$ denote the scenarios with migration flows and assuming zero migration, respectively.

Adjusting GDP data for net remittances flows require the computation of estimates of bilateral remittance flows. The original SSP population projections do not provide bilateral migrant flows, although in and out-migrant flows are included in them. In order to obtain projections of flows of remittances, we use an estimated gravity model that summarizes the quantitative effects of push and pull factors of migration flows. The number of people moving from a country to another in this framework is assumed to depend on a measure of importance in origin and destination countries (population sizes *pop* and per capita incomes *ypc* in our specification), and on proximity between the two countries (here featured as the geodesic distance between capitals *dist*). We therefore compute bilateral migrant flows between countries i and j (mig_{ij}) following the gravity model

$$mig_{ij}(t)=\beta_0 pop_i(t)^{\beta_1} pop_j(t)^{\beta_2} dist_{ij}^{\beta_3} * \left(\frac{ypc_j(t)}{ypc_i(t)}\right)^{\beta_4}. \tag{2}$$

The parameters in equation (2) are estimated using data on the variables in the gravity model for the period 1990-2015 (see Section 3.1) and their point estimates are used to obtain migration projections. The total number of migrants leaving a given country at time t is given by $leave_i(t)=\sum_j mig_{ij}(t)$, while those entering are given by $enter_j(t)=\sum_i mig_{ij}(t)$.

Consistency with the original population projections is ensured by rescaling the bilateral flows derived from our gravity model so that for each country the number of immigrants over a given 5-year period equals that in the original SSP projections. We also compute a state variable *stock* that keeps count of how many migrants from one region are present in another region at a given time and assume that only first generation migrants send money back to their origin country in the form of remittances, for the duration of their life. This duration is computed as life expectancy λ at birth in the destination region minus median age of migrants at time of migration μ,

$$stock_{ij}(t) = stock_{ij}(t-1) + move_{ij}(t) - \mathbb{1}_{t>\lambda_j-\mu}[enter_j(t-\lambda_j(t)+\mu(t))] \quad (3)$$

We derive remittance flows from bilateral migrants stocks by assuming that migrants send a share ρ of their income to their origin region, for a cost ϕ. We use this state variable to calculate remittances (rem) circulating at each time period,

$$rem_i(t) = \sum_j stock_{ij}(t)ypc_j(t)\rho_{ij}(1-\phi_{ij}) - \sum_k stock_{ki}(t)ypc_i(t)\rho_{ki}(1-\phi_{ki}). \quad (4)$$

The calibration of the parameters in equations (3) and (4) is described in section 3.2.

3 Data

3.1 Calibration of gravity equation

We use the SSP projections from the Wittgenstein Center database for population and the IIASA SSP database for GDP. Data are available for 2010-2100 in 5-year intervals.

We estimate the parameters in our gravity model (equation (2)) using data on migration flows between countries for 1990-2015 from [22] as compiled in [23]. For robustness, we also estimate parameters based on data for the same period from [24]. We use population data for the same period from the Wittgenstein Centre and GDP per capita data from the World Bank's World Development Indicators. We compute distances between countries as distances between their capitals' coordinates. We drop all origin/destination/period observations that present zero migration and estimate the model based on 76,795, respectively 95,108 observations.

We find that migration flows between two countries increase with origin and destination population size as well as GDP per capita ratio, and decrease with distance between countries, as suggested in other studies using similar models (e.g. [25]). We test several combinations of fixed effects for robustness. Results for other fixed effects combinations can be found in the appendix (see section C). While some migrants and remittances flows differ, the overall conclusions are not modified. We provide a further robustness check by estimating parameters using data from [24]; our GDP projections are virtually not affected by the data source.

3.2 Calibration of remittance parameters

Our remittances estimation is based on the assumption that only first generation migrants send remittances, in a constant share of their income, for the rest of their lives. Remaining lifetime duration is equal to life expectancy λ in the destination country, minus the age of migrants μ at time of migration. For λ, we use the SSP scenarios for life expectancy available from the Wittgenstein Centre for the period 1970-2100. Values vary from 34.2 to 74.9 years across countries in 1970, then span 58.7 to 92.2 years in the most pessimistic scenario (SSP3) and 79.6 to 110 years in the most optimistic scenarios (SSP1 and SSP5). For μ, we first use immigration flows from the SSP population projections, available per 5-year age group. Note that the resulting age distribution of migrants at time of migration is very similar across countries, periods, and SSP narratives, thus ensuring consistency [9]. In particular, 17% of migrants are under 15 years old when migrating, 50% is between 15 and 30 years old, 24% is between 30 and 45 years old and 9% above 45. Data on the initial (current) stock of migrants by age group are also required for the exercise. We derive an estimate of migrant stocks using bilateral migrant stocks from the World Bank from the year 2017. We apply to the current stocks data an average of two age distributions in each destination country:

age distribution of migrants at time of migration in the period 2015-2020, and age distribution of overall destination population in the same period. Both are sourced from the SSP population projections.

In equation (4), remittances flows and costs are calibrated using data from the World Bank for 2017. Calibrations are maintained constant over time and across SSP narratives, but are specific to each origin/destination pair. For ρ, the share of income sent as remittance, we use bilateral remittances estimates, bilateral estimates of migrant stocks, and per capita GDP data for 2017, the last year for which all three data types are available. For each origin/destination pair with missing data, we assign zero remittance. We find a 10%-90% range of [0.01,1.02]; note that $\rho > 1$ indicates that migrants are able to send more money than the average per capita income in their destination country. For ϕ, the cost of sending remittances, we use total cost of transactions in percentage of GDP from the Remittance Prices Worldwide database for 2017. For each origin/destination pair with missing data, we use the mean cost of all available pairs. We find a 10%-90% range of [0.03,0.10].

4 Results

4.1 Bilateral migrant flows

We use our gravity model (equation 2) to generate bilateral migrant flows between countries, which we rescale to SSP totals for the period 2015-2100, for each one of the five SSP scenarios. We present these flows in the form of a heat map aggregated at the continental level for 2095 in Figure 3. The first row shows the number of migrants between pairs of regions; the second row shows how these totals relate to population size in origin regions, and the third row depicts the same variable for destination regions. Columns represent the five SSP narratives.

Independently of the scenario chosen, we find that most migrants move within continents, as highlighted by the dark colors along the diagonal. Migration corridors from Africa to Asia and Europe and from Latin America and the Caribbean to Northern America are also present in the projected migration patterns. Migrant numbers increase from SSP1 to SSP2 and to SSP5 in a similar fashion across migration corridors. For SSP4, bilateral migration patterns are somewhat different. A smaller amount of migrants are observed relatively to other SSP in certain corridors (e.g. within Africa), while some others present more migrants (e.g. from Africa to Northern America). As expected, there is little effect of migration on population dynamics within the SSP3 scenario. When relating absolute migrant numbers to population sizes in origin regions, we find that migration to Northern America from all continents but Asia is the most significant one (while still staying under 0.1% of the origin region population). The high share of migrants within Europe is not surprising given the free movement policy within the Schengen Area. When relating absolute migrant numbers to destination region population sizes, migration within Northern America stands out, while migration from Asia to Oceania reaches significant levels. Similarly, migrants as share of destination population stay under 0.1% worldwide.

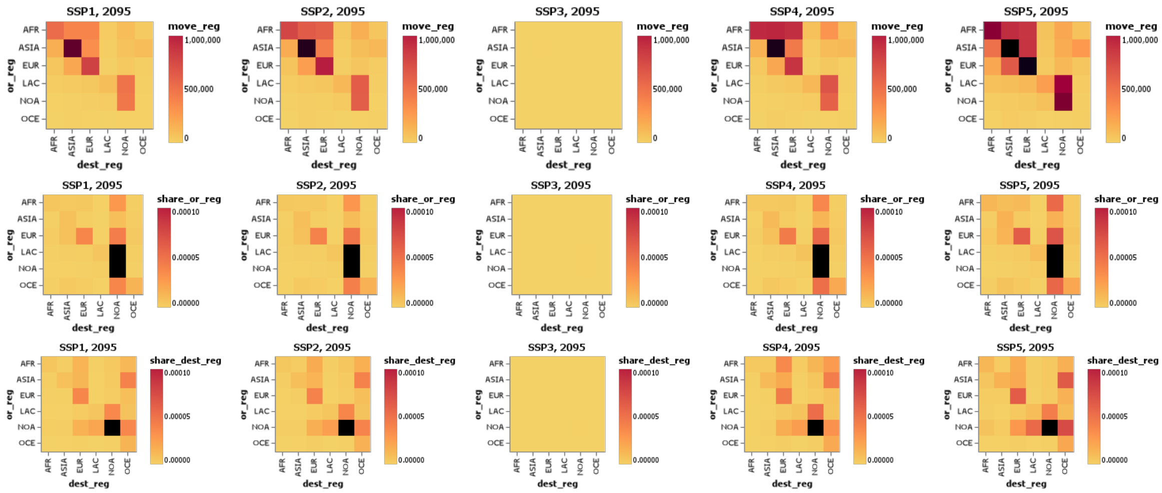


Figure 3: Bilateral migrant flows aggregated at the continental level in 2095, for all SSP narratives. Top: Absolute values, in number of migrants. Middle: Number of emigrants as share of population in origin. Bottom: Number of immigrants as share of population in destination. The five columns illustrate the five SSP narratives. World regions on the y axis are origin regions, whereas world regions on the x axis are destination regions. World regions considered, following [9]: Africa (AFR), Asia (ASIA), Europe (EUR), Latin American and the Caribbean (LAC), Northern America (NOA), Oceania (OCE).

4.2 Bilateral remittance flows

As for the case of remittances, we present remittance flows aggregated at the continental level for 2095 in Figure 4. The first row shows the amount of remittances transferred between two regions, the second row shows how these totals relate to total GDP in receiving regions and the third row normalizes remittances by the GDP of the sending region. Columns represent the five SSP narratives.

We find that most remittances are sent within continents, as highlighted by the dark colors along the diagonal. Remittance corridors from Asia and Europe to Africa, and from Northern America to Latin America and the Caribbean can be recognized in the data, in line with the results for migration flows. The flow of remittances within Northern or Latin America is relatively small. Remittances increase from SSP2 to SSP1 and to SSP5. The inversion between SSP1 and SSP2 in terms of the relative amounts of migrants and remittances in the Asia-Africa corridor is due to both regions being richer yet less populated in SSP1 than in SSP2. For SSP4, bilateral remittance patterns are somewhat different. Some corridors see less transfers relatively to other SSP scenarios (e.g. within Africa), while some others present more transfers (e.g. from Northern America to Africa). As expected, there is a relatively small flow of remittances in SSP3. When relating absolute remittance amounts to GDP in receiving regions, we find that remittances sent from Northern America to Latin America and the Caribbean, as well as remittances sent within Africa, Asia and Europe are the largest ones (although under 2% of the origin region GDP). When relating absolute remittance amounts to sending regions GDP, remittances sent from Oceania, in particular to Asia, reach significant levels. Similarly, remittances as share of destination GDP stay under 2%.

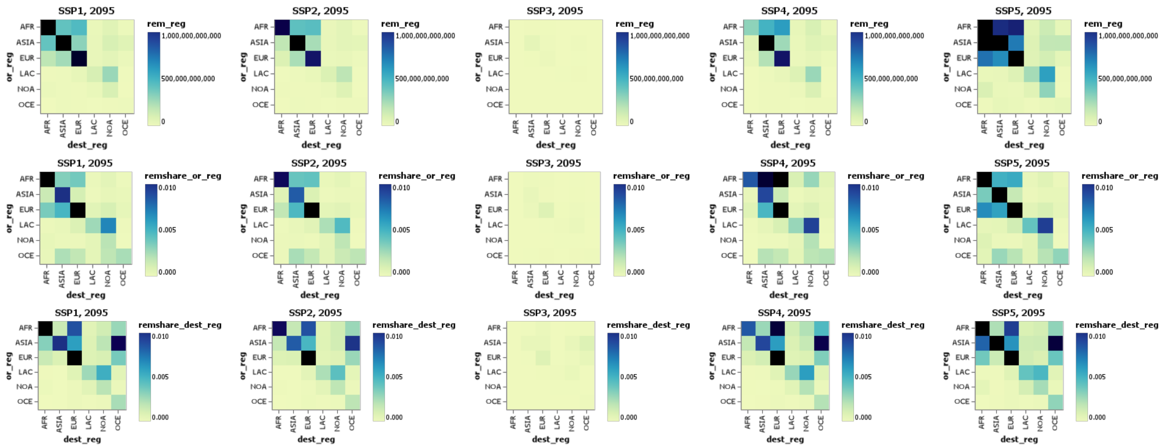


Figure 4: Bilateral remittances flows aggregated at the continental level in 2095, for all SSP narratives. Top: Absolute values, in USD 2005. Middle: Remittances as share of GDP in origin region. Bottom: Remittances as share of GDP in destination region. The five columns illustrate the five SSP narratives. World regions on the y axis are origin regions of migration and receiving regions of remittances, whereas world regions on the x axis are destination regions of migration and sending regions of remittances. World regions considered, following [9]: Africa (AFR), Asia (ASIA), Europe (EUR), Latin American and the Caribbean (LAC), Northern America (NOA), Oceania (OCE).

4.3 GDP per capita projections for zero migration: global outlook

Finally, based on our estimates applied to equation (1), we produce country-specific projections of GDP and GDP per capita for the period 2015-2100 for each of the five SSP narratives under the assumption of zero migration. Our results at the global scale are illustrated in Figure 5 (see section B in the appendix for country-level projections). Figure 5a shows average world per capita GDP with (circles) and without (triangles) remittances, for all SSP narratives. While the effect of migration dynamics is visible, it stays moderate and does not modify the ranking of income levels among SSP narratives: SSP5 ("Fossil-fueled Development") is still the scenario with the consistently highest per capita GDP, and SSP3 ("Regional Rivalry") the lowest.

Figure 5b shows relative changes in average world per capita GDP with migration compared to our zero-migration projections. We find that for all SSP, the average world per capita GDP is consistently higher with migration than without. The effect becomes substantial in the second half of the century for SSP4, where income levels increase above 5% by 2065. Unsurprisingly, the effect of migration is almost non-existent for SSP3, since the original projections already include low migration levels. However, for SSP1, SSP2 and SSP5, by the end of the century migration stops making the world richer, and limits its wealth increase to 2-3%. This stark contrast in the evolution of the migration effect on income levels reflects the underlying hypotheses on worldwide convergence of income levels across narratives. In an SSP4 world, dominated by global inequalities, strong differences in per capita income between countries persist all along the century. Migrants have therefore a strong incentive to move to a richer country, even in cases where that destination is far away. The remittances sent will tend to amount to a significant share of their family's income back home, thus contributing to income convergence across countries. In such a world, international migration is strongly beneficial from an income perspective. On the other hand, in a world of rather strong globalization such as the ones depicted by SSP1, SSP2 and SSP5, by the end of the century income levels are not substantially different across countries. Thus migrants will move, but to nearby countries, which will not have much higher per capita GDP than their origin country.

Figure 5c shows relative changes in country-level per capita GDP with migration compared to our zero-migration projections for the "middle of the road" SSP2 scenario. We find that the scale and direction of the migration effect are highly country-specific. In general, destination countries (e.g. Canada, United Arab Emirates) fare slightly higher income levels with migration. For origin countries, the migration effect is less unidirectional. Some countries (e.g. Guyana, Montenegro, Nigeria) also display higher per capita income with migration as remittances received from significantly richer countries are able to compensate for the loss of inhabitants contributing to the national economy. Yet for the majority of origin countries (e.g. Nicaragua, Central African Republic, Romania), this compensation does not take place as emigrants leave to countries that are not richer enough to provide high remittances to the origin economy.

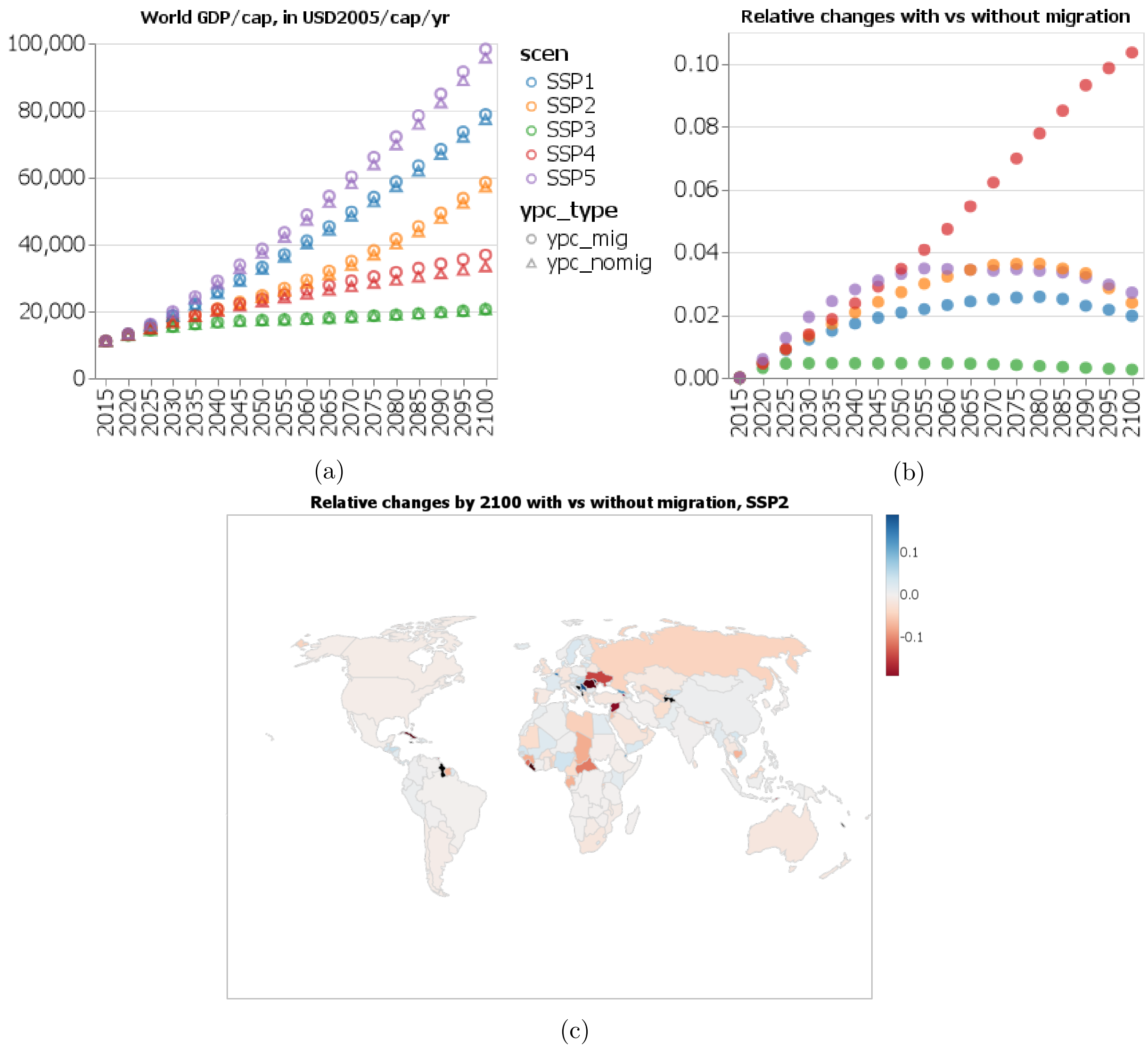


Figure 5: Per capita GDP with and without migration, for all SSP narratives. 5a Average world absolute values, in US dollars 2005 per capita per year. 5b Average world relative changes with vs without migration. 5c Country-specific relative changes with vs without migration for SSP2 ("middle-of-the-road") by the end of the century.

4.4 GDP per capita projections for zero migration: continental outlook

Figure 6 shows a decomposition of our GDP per capita projections at the continental level (see Figure A.1 in the appendix for our definition of world regions). The effect of migration is particularly pronounced in Oceania. For Asia and Oceania, migration increases per capita income for all SSP narratives over the century by up to 5% and 25% respectively. For Northern America, migration very slightly decreases per capita income by about 1% by the end of the century. For Latin America and the Caribbean and Europe, while migration starts by slightly increasing income levels for all narratives, this effect changes direction and migration ends up decreasing income levels by 1% for SSP1 and by 3% in 2100 for SSP4 in Europe. Finally, for Africa the effect of migration strongly depends on the SSP narrative considered. While the migration effect stays positive throughout the century for SSP4, it becomes null by 2090 for SSP1 and SSP2, and negative by 2070 for SSP5.

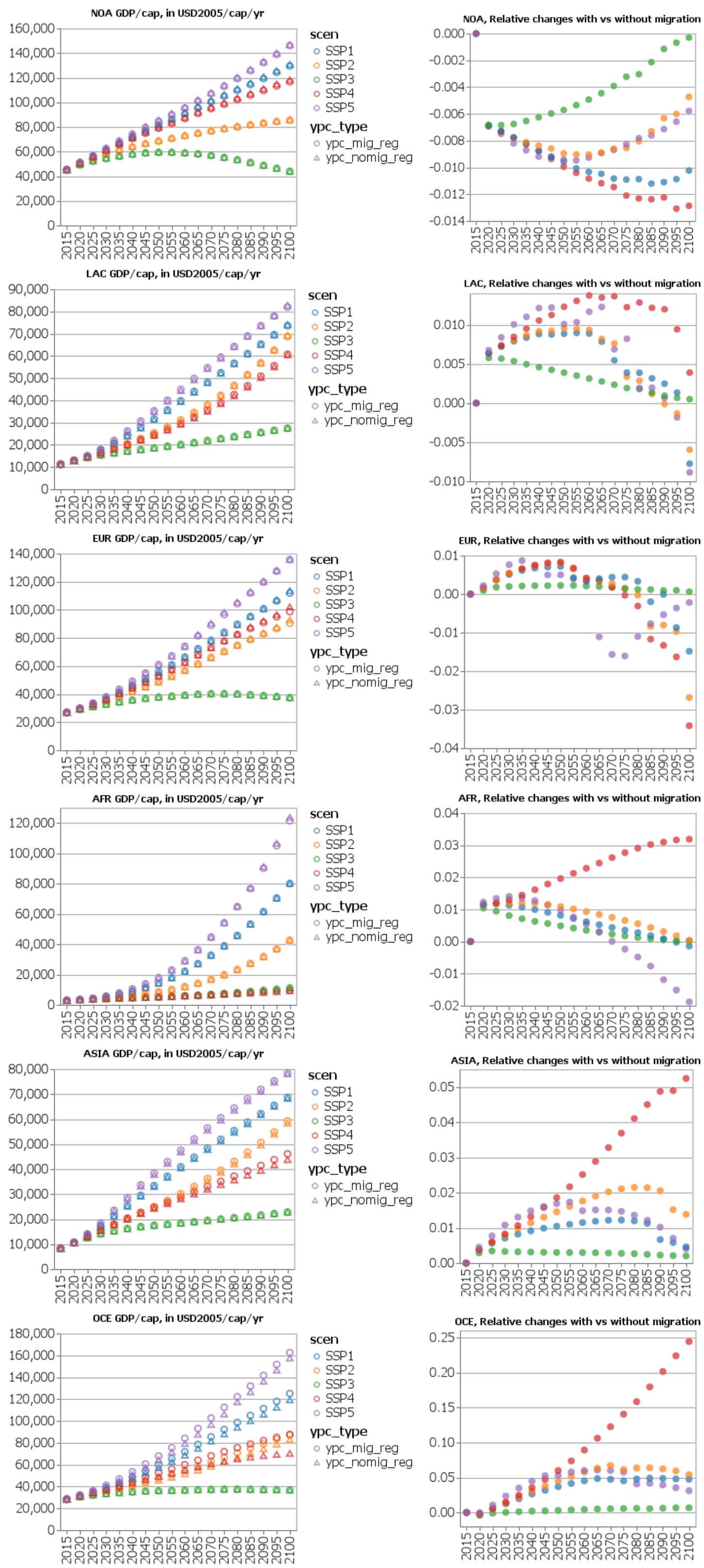
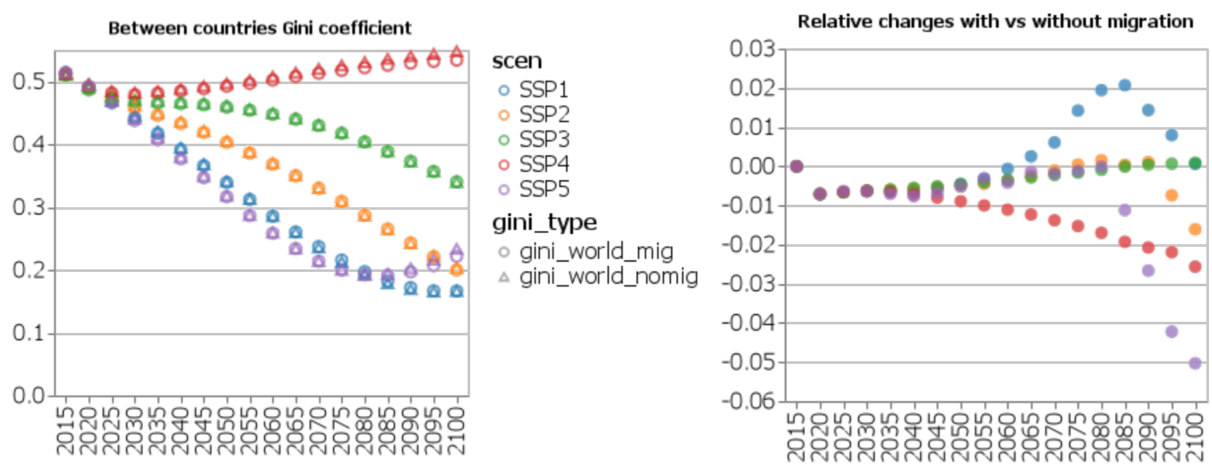


Figure 6: Per capita GDP with and without migration, for all SSP narratives, averaged for major world regions. Left: Absolute values, in US dollars 2005 per capita per year. Right: Relative changes with vs without migration. From top to bottom: World regions considered, following [9]: Northern America, Latin American and the Caribbean, Europe, Africa, Asia, Oceania.

4.5 Migration effects on between-countries inequality

With our new GDP projections for zero migration, we are now able to compare how migration affects income inequality between countries. To that aim, we use the Gini coefficient, a commonly used measure of inequality considering the population-weighted repartition of income between countries. We project global Gini coefficients, for all SSP narratives, both with and without migration using our population and GDP projections. We show results in Figure 7. Figure 7a illustrates the between-countries Gini coefficient with (circles) and without (triangles) migration, for all SSP narratives. While the effect of migration dynamics is visible, it stays moderate and by and large does not modify the ranking of inequality levels among SSP narratives: SSP4 (“Inequality”) is still the scenario with the consistently highest inequality, while SSP5 (”Fossil-fueled Development”) and then SSP1 (”Sustainability”) starting around 2080 are the least unequal.

Figure 7b shows relative changes in between-countries Gini coefficient with migration compared to our zero-migration projections. We find that for SSP2, SSP4 and SSP5, inequality is consistently lower with migration than without. The effect becomes notable in the second half of the century for SSP5, where the Gini coefficient decreases by over 5% by 2100. Unsurprisingly, the effect of migration is almost non-existent for SSP3, because the original projections already include low migration levels. However, for SSP1, by the end of the century migration increases inequality by up to 2% around 2085 and then reduces its effect to zero by 2100. This inversion of the migration effect on between-countries inequality happens at a time when inequality stops decreasing; migration slightly reenforces this stop in inequality change. Again, this contrasted effect of migration on inequality by the end of the century reflects the underlying hypotheses on migration levels and on worldwide convergence of income levels across narratives. For instance in an SSP5 world of strong, fossil-fueled globalization, by the end of the century income levels are not substantially different across countries, yet migration levels are still high. Thus migration plays a very significant role in regulating inequality between countries, much more so than when strong income differences persist.



(a) (b)

Figure 7: World inequality as measured by between-countries Gini coefficients, for all SSP narratives. 7a Absolute Gini values with and without migration. 7b Relative changes in Gini coefficients for with compared to without migration.

4.6 Migration effects on within-country inequality

For a more complete picture of the effect of migration on inequality, we also look at inequality within each country. To that aim, we project within-country Gini coefficients under a zero-migration assumption. In particular, we directly use the method proposed in [14] (see their equation (1)) and compute changes in Gini only stemming from migration-driven changes in education drivers (education levels and share of public spending), using estimated coefficients (see their Table 2). Note that here, we do not use our GDP projection for zero migration, but use the SSP population projections without migration, available with detailed education levels. As in [14], we also use data on education in 2010 from the Wittgenstein Center[3], as well as data on per capita education spending from [26]. For the latter, we use regional averages for countries with missing data. We show results in Figures 8 and 9.

Figure 8 illustrates within-country Gini projections with and without migration, for all SSP narratives, aggregated at the regional level (continent-specific median and interquartile range). The left column displays projections with migration by [14]. Unsurprisingly, SSP3 ("Regional Rivalry") and SSP4 ("Inequality") present the starkest inequalities and SSP1 ("Sustainability") and SSP5 ("Fossil-fueled Development") the lowest across continents. Latin America and the Caribbean and Africa present the widest range of within-country inequality. The middle column displays our projections without migration. Looking at regional aggregates, migration seems to have little effect on within-country inequality, even for SSP5 which presents the highest migration. The right column displays relative changes in Gini coefficients in scenarios with migration compared to without migration. We find that the effect of migration on within-country inequality varies significantly depending on the country and the SSP narrative considered. The starkest relative changes with migration happen for SSP5, which displays both the highest migration and the lowest Gini. In general, within-country inequality appears to decrease with migration in Northern America and Europe, increase in Latin America and the Caribbean and Africa, and displays moderate changes in both directions in Asia and Oceania.

Figure 9 provides a more country-specific picture by illustrating relative changes in Gini coefficients by 2100 for SSP2 ("middle-of-the-road") without compared to with migration. Note that countries in shades of blue present a decrease in inequality with migration, while countries in shades of red present an increase. Most large economies (USA, China, India, Brazil, Russia) appear to be little affected by migration. Many destination countries (Canada, Australia, Western Europe, Saudi Arabia) see their inequalities reduced with migration. For some origin countries (Mali, Burkina Faso, Sudan, Afghanistan), migration appears to strongly increase inequality. Yet for most origin countries, the effect of migration stays limited to under 5% in either direction.

[3]Source: Wittgenstein Centre for Demography and Global Human Capital (2018). Wittgenstein Centre Data Explorer Version 2.0. Available at: www.wittgensteincentre.org/dataexplorer

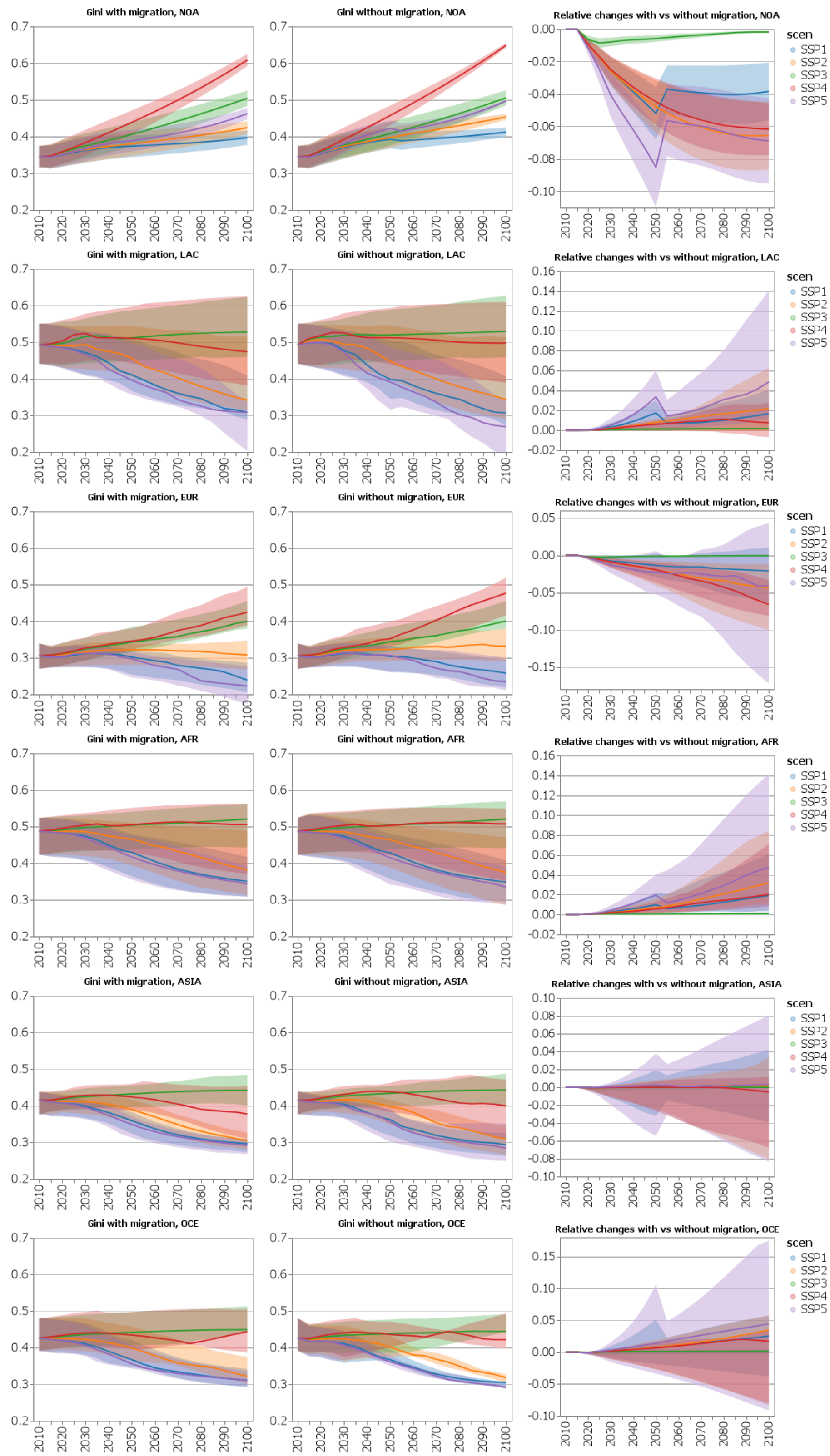


Figure 8: Within country inequalities as measured by within-country Gini coefficients with and without migration, for all SSP narratives. Median and interquartile range for major world regions. Left: Gini with migration. Center: Gini without migration. Right: Relative changes with vs without migration. From top to bottom: Northern America, Latin American and the Caribbean, Europe, Africa, Asia, Oceania.

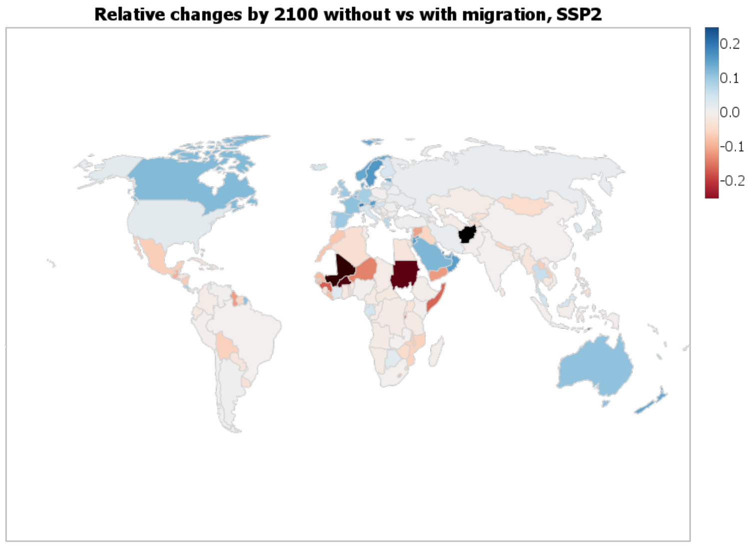


Figure 9: Within-country Gini coefficient. Country-specific relative changes without vs with migration for SSP2 ("middle-of-the-road") by the end of the century. Countries in shades of blue present an increase in Gini without migration, thus a decrease in inequality with migration; countries in shades of red present an increase in inequality with migration. Missing data for the following countries: Barbados, Brunei Darussalam, Djibouti, Eritrea, Lybia, Mauritania, Papua New Guinea, Uzbekistan.

4.7 Migration effects on final energy consumption and greenhouse gas emissions

We further analyze the effects of migration assumptions on projections more directly relevant to climate policies, namely projections of final energy consumption and greenhouse gas emissions. For these projections, five "marker" quantifications have been developed by five modeling teams (one for each of the SSP narratives), both for the energy and the emissions components [16, 17, 18, 19, 20]. Those baseline quantifications do not take into account any climate policy. In line with the Coupled Model Intercomparison Project for the upcoming IPCC Assessment Report (CMIP6) [27], we focus on different combinations of SSP narratives and radiative forcing scenarios (or Radiative Concentration Pathways, RCP), illustrative of various climate policy efforts. We choose the following five combinations (see Figure 10): SSP1 + RCP1.9; SSP2 + RCP4.5; SSP3 + RCP7.0; SSP4 + RCP6.0; SSP5 + RCP8.5.

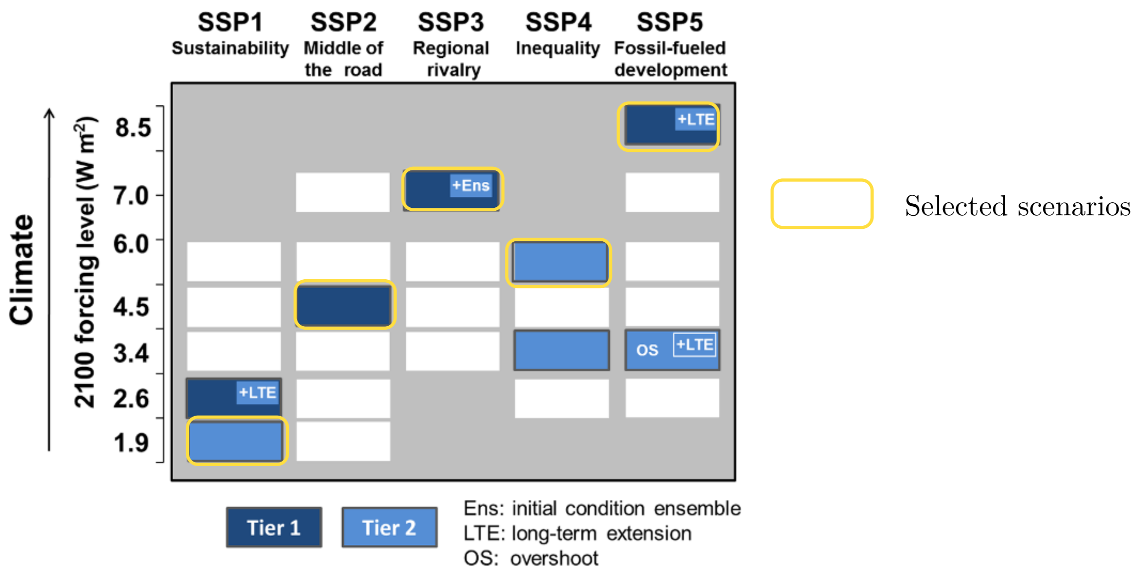


Figure 10: Combinations of SSP narratives and radiative forcing scenarios selected for our final energy consumption and greenhouse gas projections for zero-migration. Scenarios selected among the CMIP6 exercise. Source: [27]. CMIP6 data: [28]

The projections for final energy consumption, freely available on the IIASA SSP database, are only provided at the level of five world regions. Therefore, following what was done for the emissions projections [29], we downscale the projections to the country level so that $\frac{En}{ypc}$ converges within each region, with the year of convergence being specific to each SSP narrative. Projections of greenhouse gas emissions, thanks to the CMIP6 exercise, are available at the country level [28].

We construct counterfactual energy consumption and emissions projections under the zero migration assumption by correcting the original projected quantities only so far as to adjust for changes in GDP and in population sizes. In other words, we assume that neither climate policies, nor technological innovation, nor consumption behavior are affected by migration dynamics. To that aim, we consider the country- and SSP narrative-specific relation between per capita energy consumption, respectively emissions, and per capita GDP (see equation 5).

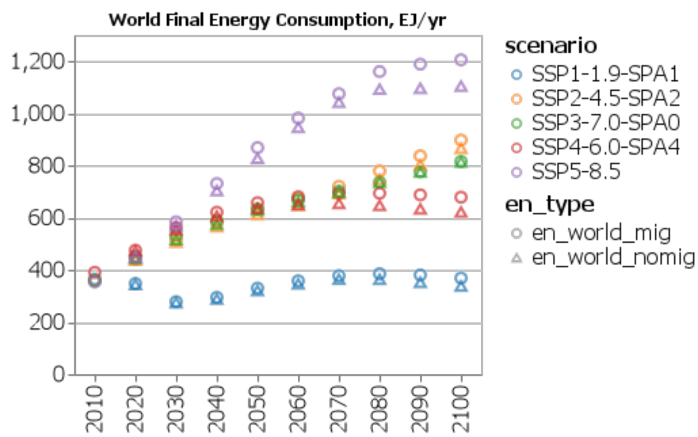
$$\begin{aligned} Enpc_{i,SSP} &= f(ypc_{i,SSP}) \\ Empc_{i,SSP} &= f(ypc_{i,SSP}), \end{aligned} \tag{5}$$

where *Enpc* represents the final energy consumption per capita of a given country, and *Empc* the emissions per capita. We linearly interpolate and/or extrapolate the final energy consumption, respectively emissions amount related through equation 5 to our per capita GDP projection for zero migration, for each country and SSP narrative. For countries with non-monotopic per capita GDP, representing less than 2% of global energy consumption and global emissions, we approximate equation 5 by a linear regression. Note that this approach ensures continuity for negative emissions, and maintains the level of economic activity for which each country, in a given context, is able to go negative on its emissions.

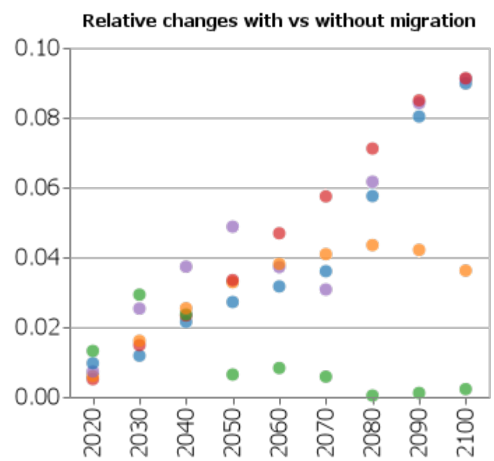
We produce country-specific projections of final energy consumption for the period 2015-2100 for the five SSP narratives under the assumption of zero migration. Our results are illustrated in Figure

11. Figure 11a shows average world energy consumption with (circles) and without (triangles) migration, for all SSP narratives. Figure 11b shows relative changes in average world energy consumption with migration compared to our zero-migration projections. Figure 11c shows relative changes in country-level energy consumption for the "middle of the road" SSP2 scenario coupled to RCP 4.5. Countries in shades of blue have increased consumption with migration compared to without, and countries in reds have decreased consumption.

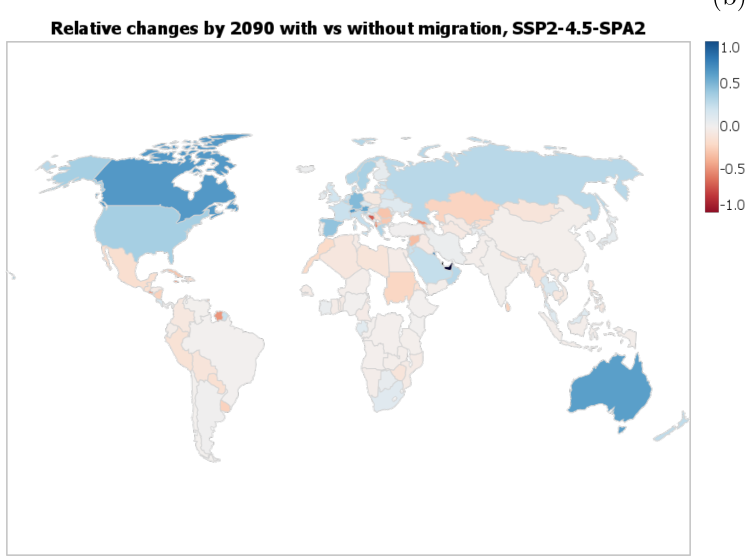
Overall, migration has a moderate but discernable effect on final energy consumption. By and large, migration appears to increase world energy consumption across the board, by close to 10% by the end of the century for three very different climate policy scenarios: SSP1 with RCP 1.9, SSP4 with RCP 6.0, and SSP5 with RCP 8.0 At the country level, developed and destination countries appear to increase their energy consumption with migration, while some origin countries decrease it.



(a)



(b)

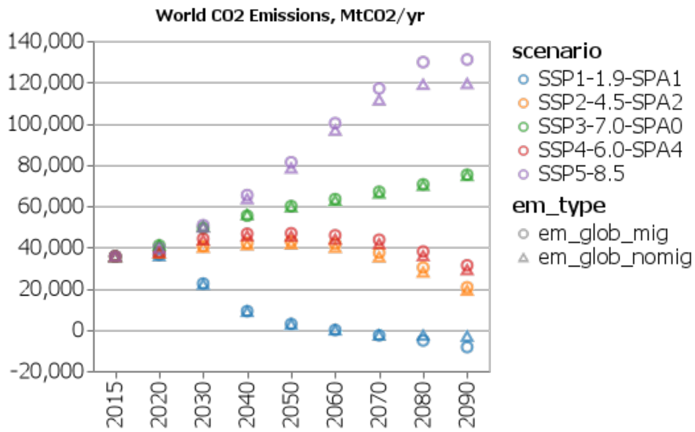


(c)

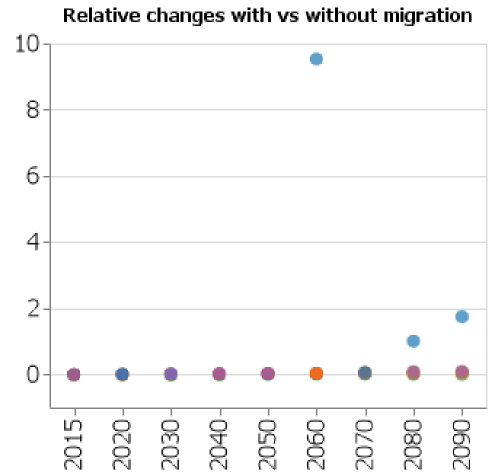
Figure 11: Final energy consumption with and without migration, for all SSP narratives. 11a Average world absolute values, in EJ per year. 11b Average world relative changes with vs without migration. 11c Country-specific relative changes with vs without migration for SSP2 ("middle-of-the-road") by the end of the century.

We also produce country-specific projections of CO_2 and CH_4 emissions for the period 2015-2100 for the five SSP narratives under assumption of zero migration. Our results for CO_2 are illustrated in Figure 12. Figure 12a shows average world emissions with (circles) and without (triangles) migration, for all SSP narratives. Figure 12b shows relative changes in average world emissions with migration compared to our zero-migration projections. Figure 12c shows relative changes in country-level emissions for the SSP2 scenario coupled to RCP 4.5. Countries in shades of blue have increased emissions with migration compared to without, and countries in reds have decreased emissions.

We find that migration has a moderate effect on emissions. Furthermore, migration appears to increase emissions but also increase negative emissions for strong climate policies (SSP1-RCP 1.9). These results are visible at the country level. For SSP2-RCP4.5, the effect of migration on emissions is starkly stronger than on income in many destination countries. This highlights the fact that the increased population size dominates the decreasing emissions per capita with income. On the other hand, origin countries have fewer people with migration; many of them have a decreased GDP with migration, and tend to still increase their emissions as their wealth grows at that time and for this climate scenario; thus for them migration decreases GDP hence decreases emissions. Overall, global emissions increase slightly with migration in this scenario.



(a)



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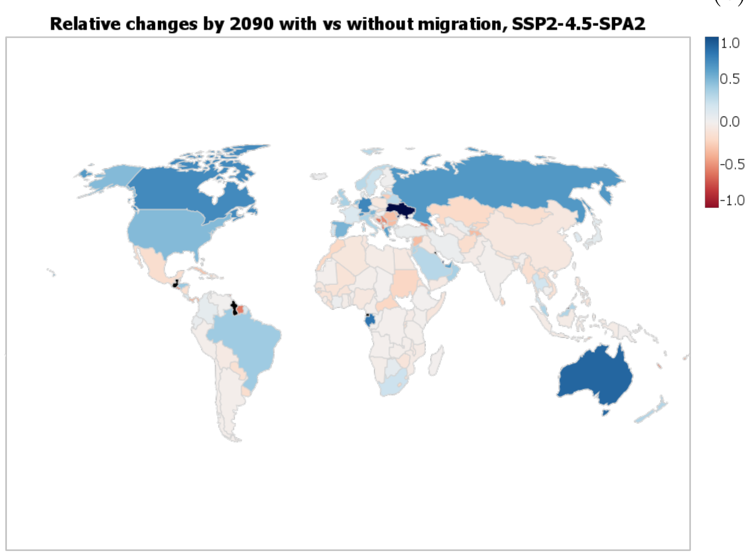

(c)

Figure 12: CO_2 emissions with and without migration, for all SSP narratives. 12a Average world absolute values, in Mt CO_2 per year. 12b Average world relative changes with vs without migration. 12c Country-specific relative changes with vs without migration for SSP2 (”middle-of-the-road”) by the end of the century.

5 Discussion and Conclusion

This study provides the first quantification of international migration effects on GDP projections in the SSP framework. It highlights the strong dependence on context of migration effects, both in terms of countries and of projection narratives considered. We show that migration tends to make the world richer, on average, in all SSP scenarios. Furthermore, the choice of narrative – hence the scenario of future development considered – significantly influences the nature of migration and remittances corridors. Depending on the narrative and location, the migration effect on income can be substantial, up to +25% and -2% at the continental level. Moreover, we derive migration effects on inequality both between and within countries. We show that migration tends to make the world slightly more equal in most SSP scenarios, has little effect on domestic inequalities in most major economies and origin countries, increases inequalities in few origin countries and reduces inequalities in most destination countries. The development scenario sigificantly influences the magnitude, if not the sign, of the migration effect on inequality. Finally, we show that migration tends to slightly increase energy consumption and emissions, as the induced change in population distribution overrides the reducing effect of wealth in destination countries.

Limitations to this study derive from the characteristics of the model and data employed. We calibrate our gravity model to past and current data, but maintain the calibrated parameters constant over time and across SSP narratives, since those dimensions are not quantified in the original SSP projections. Similarly, in our remittances model, we use current data for corridor-specific calibration, but keep the calibrated parameters constant over time and across narratives. More importantly, we do not consider any heterogeneity of migrants or non-migrants within countries and abstract from the effects of potential differentials in productivity between migrants and local population. Future research aimed at including such dimensions in our model should help shed light on particular aspects of international migration dynamics (the role of skill mismatch, for instance) in projection exercises.

Our aim for developing projections of various SSP components for zero migration is not to provide realistic forecasts of what might happen – any scenario with no international migration whatsoever is highly unrealistic. However, our analysis has direct policy implications. In particular, this study strongly suggests that any one-size-fits-all approach to projecting future international migration in a climate change context can be highly misleading , and lead to misplaced policy answers. In such differentiated circumstances, a scenario framework is helpful, perhaps even necessary, to think about appropriate policy responses. Furthermore, our zero-migration projections fit perfectly in the interdisciplinary methodological framework that the SSP framework has developed and offer consistency with the original projections. This makes them particularly powerful in combination with other existing projections for policy.In a next step, we plan to make use of these zero-migration projections as input scenarios in a climate-economy model with explicit migration dynamics, with the aim of investigating interactions between migration and climate policies. Indeed, in such models input scenarios with no migration are required, so as to not double count the migration effect.

Acknowledgements

The authors thank Samir KC and Guy Abel for data and extremely valuable comments. Part of this research was developed in the Young Scientists Summer Program at the International Institute for Applied Systems Analysis, Laxenburg (Austria) with financial support from the National Science Foundation through the National Academy of Sciences as the US National Member Organization.

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A World regions definition

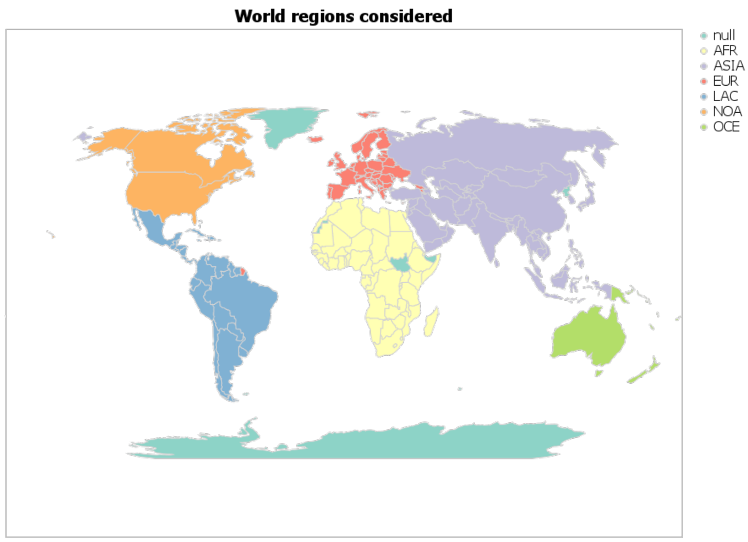

Figure A.1: World regions used to present results: Africa (AFR), Asia (ASIA), Europe (EUR), Latin American and the Caribbean (LAC), Northern America (NOA), Oceania (OCE). Groupings based on [9]. We do not include Antarctica, and consider Greenland as part of Denmark, South Sudan as part of Sudan and Somaliland as part of Somalia.

B Detailed projections at country level

Detailed projections at country level over 2015-2100 for all SSP narratives are available upon request to the authors for the following quantities:

- GDP for zero migration
- GDP per capita for zero migration
- Bilateral migrant flows
- Bilateral remittance flows
- Between-countries Gini coefficients for zero migration
- Within-country Gini coefficients for zero migration

C Robustness check: gravity model with origin and destination fixed effects

As discussed in section 3.1, we also estimate parameters from our gravity model using origin and destination fixed effects, on top of year fixed effects. We find slightly different bilateral migrant and remittance flows after rescaling in order to match SSP projections. For migration flows (see Figure C.1 compared to Figure 3), there is a moderate increase of migrants within Northern America and Europe, as well as a slight decrease in migrants from Latin America and the Caribbean to Northern America, and from Africa to Asia and Europe. In terms of share of emigrants in origin population, compared to the calibration with year fixed effects only, we find a moderate decrease for emigrants from Africa, Europe and Latin America to Northern America. In terms of share of immigrants in destination population, we find a slight increase in immigrants within Europe and from Northern to Latin America and Oceania.

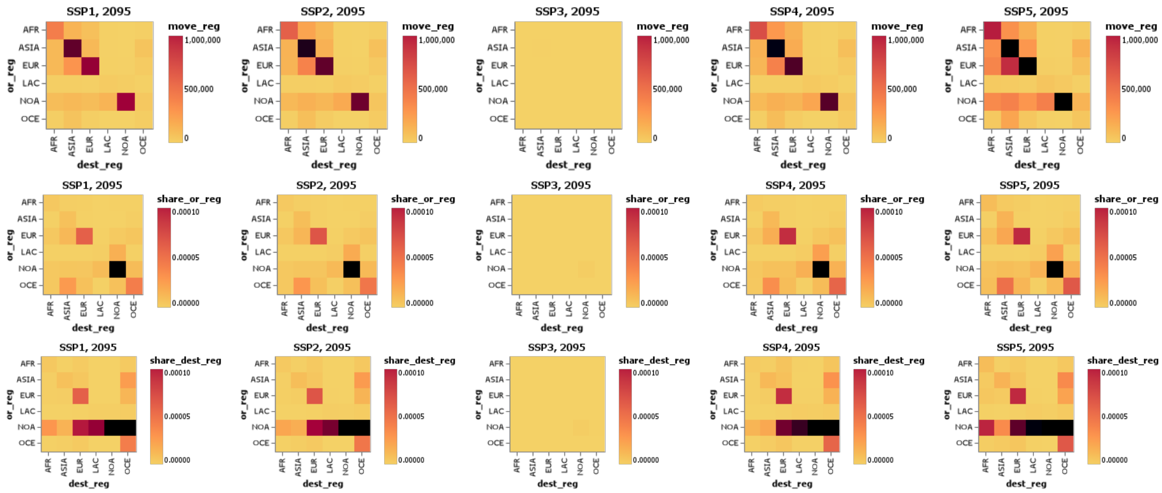

Figure C.1: Bilateral migrant flows aggregated at the continental level in 2095, for all SSP narratives, for estimated parameters of the gravity model including origin and destination fixed effects. For complete legend, see Figure 3.

For remittance flows (see Figure C.2 compared to Figure 4), we find a slight increase in remittances sent from Africa to Europe, as well as a decrease in remittances sent in the other direction. This is reflected in the increased share of remittances in GDP of sending country for remittances sent within Europe, Africa and Asia, and the decreased share from Northern to Latin America and from Europe to Africa. We find similar changes for the share of remittances in the receiving country's GDP.

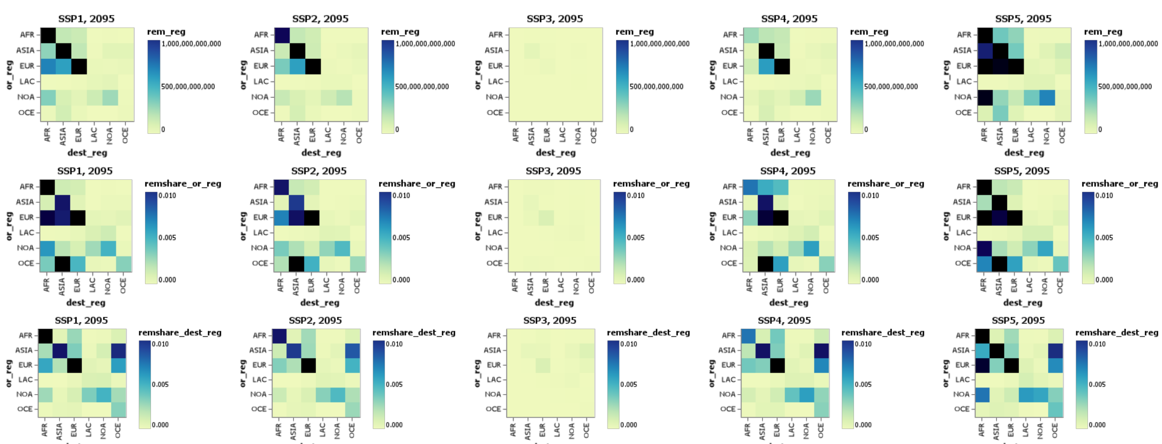

Figure C.2: Bilateral remittances flows aggregated at the continental level in 2095, for all SSP narratives, for estimated parameters of the gravity model including origin and destination fixed effects. For complete legend, see Figure 4.

However, the overall conclusions regarding our GDP projections at the world (Figure 5) and continental levels (Figure 6), as well as the resulting inequality distribution between countries (Figure 7), are not affected by the changed calibration.