Migration, population dynamics, and climate change: can migrants save the world?

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Migration, Population Dynamics, and Climate Change: Can Migrants Save the World?

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Abstract

This paper explores how migration flows between developing and developed regions affect future paths of three determinants of CO_2 concentrations in the atmosphere: population size, per capita consumption, and carbon intensity of output. Migration can reduce the future size of the human population by affecting the fertility decisions of those who migrate, but it can also increase per capita consumption by improving the living conditions of migrants. This paper implements an OLG model to quantify the future impact of migration flows on poverty reduction, fertility decisions, and climate change. We find that migration reduces total population and increases per capita consumption. Hence, the net effect of migration on CO_2 concentration depends on the future decoupling from CO_2 emissions, especially in the Global North.

Keywords climate change, population, fertility, migration, quantity-quality tradeoff

JEL Codes J11, J13, J61, Q54, F22

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1 Introduction

Climate change is one of the more complex and urgent challenges that humankind has faced in its history. Therefore, environmental agreements and policies must reconcile the urgency of their primary objective with other fundamental policy goals such as poverty reduction, the development of lower-income economies, among others. In this case, there is a dilemma because reducing poverty requires increasing per capita consumption (and, thus, emissions). This can be seen from the perspective of the Kaya Identity (Kaya and Yokobori, 1997), which can be written as

$$M = L\,\frac{Y}{L}\,\frac{E}{Y}\,\frac{M}{E} \tag{1}$$

where M are emissions, L is total population, Y/L is GDP per capita, E/Y is the energy intensity of GDP, and M/E is the carbon intensity of energy use. Reducing poverty requires an increase in Y/L, which triggers an increase in emissions. Said increase should be offset by reductions in L, E/Y, and/or M/E. This is particularly relevant in large developing economies such as India, China, or Nigeria.

It is undeniable that the excess in CO_2 concentrations in the atmosphere caused by human activity is causing climate change, that those changes are already happening in the atmosphere, ocean, biosphere and cryosphere, and that they have a global scale and a relatively fast pace (IPCC, 2021). These changes affect the continuity of life on Earth and the stability of the global economy. It is therefore necessary that policymakers address the causes and consequences of climate change.

Climate change impacts are not equal among countries. International allocation of resources, geography, and cooperation among countries play an essential role in this heterogeneity. Investment in mitigation and adaptation is more limited in developing countries, and therefore they may face more significant risks in the future.

In this context, addressing population growth may be one of the best ways to reduce the human race's environmental impact in the next century. Admittedly, this is a contentious issue since Malthus because it often brings to the table questionable social policies. Nevertheless, if policymakers carefully consider the implications and nuances of these policies regarding social equality and their global impact, managing population growth may reduce the potential negative impact of climate change and other societal issues.

It is undeniable that population growth curbs when economic conditions improve. Nowadays, developed economies have reached fertility rates lower than two births per woman, i.e., lower than the replacement rate. In contrast, low-income countries have fertility rates of between 2.3 and 5 births per woman. It is also expected that as countries develop, they will converge to the replacement rate in the long term (see Figure 1). One of the most common explanations for this stylized fact is the quality-quantity trade-off.

At a global scale, migration plays a significant role in the income, population growth, and emissions interplay. Migrants look for better economic opportunities, and in doing so, they may decide to have fewer children. Lower fertility leads to a lower steady-state global population, reducing the potential environmental impact of humanity as a whole as the Kaya identity in (1) suggests[1].

Another important interaction between migration and the environment, is that climate change may increase the flows of migrants, who will have to flee from more frequent and harsher natural disasters. Other causes of migration can be exacerbated with a changing climate, such as violence and conflicts (Burke et al., 2015). Additionally, although relocating to another country may help to improve the socioeconomic status of an individual household, in the aggregate it may affect international patterns of capital accumulation, accelerating research and growth in the receiving country at the expense of the labor and human capital stock of the country of origin.

Figure 2 shows graphically the relations mentioned above. Migrants looking for better living conditions may potentially increase global warming through higher income. However, thanks to the change in their fertility decisions, they may reduce their long-term impact on the environment[2]. In addition, governments can design policies addressing

[1] In addition to this outcome, there are other effects that are beyond the scope of this paper. For instance, as developed economies face aging populations and shrinking labor forces, migrants counterbalance the adverse effects of this demographic transition, reducing the pressure on pension systems.

[2] Another way migrants may help reduce their impact on climate change is by contributing to developing new ideas in the receiving country, inventing cleaner technologies. This work will not include this last consideration. Chen (2009) studies how migration flows may affect innovation and

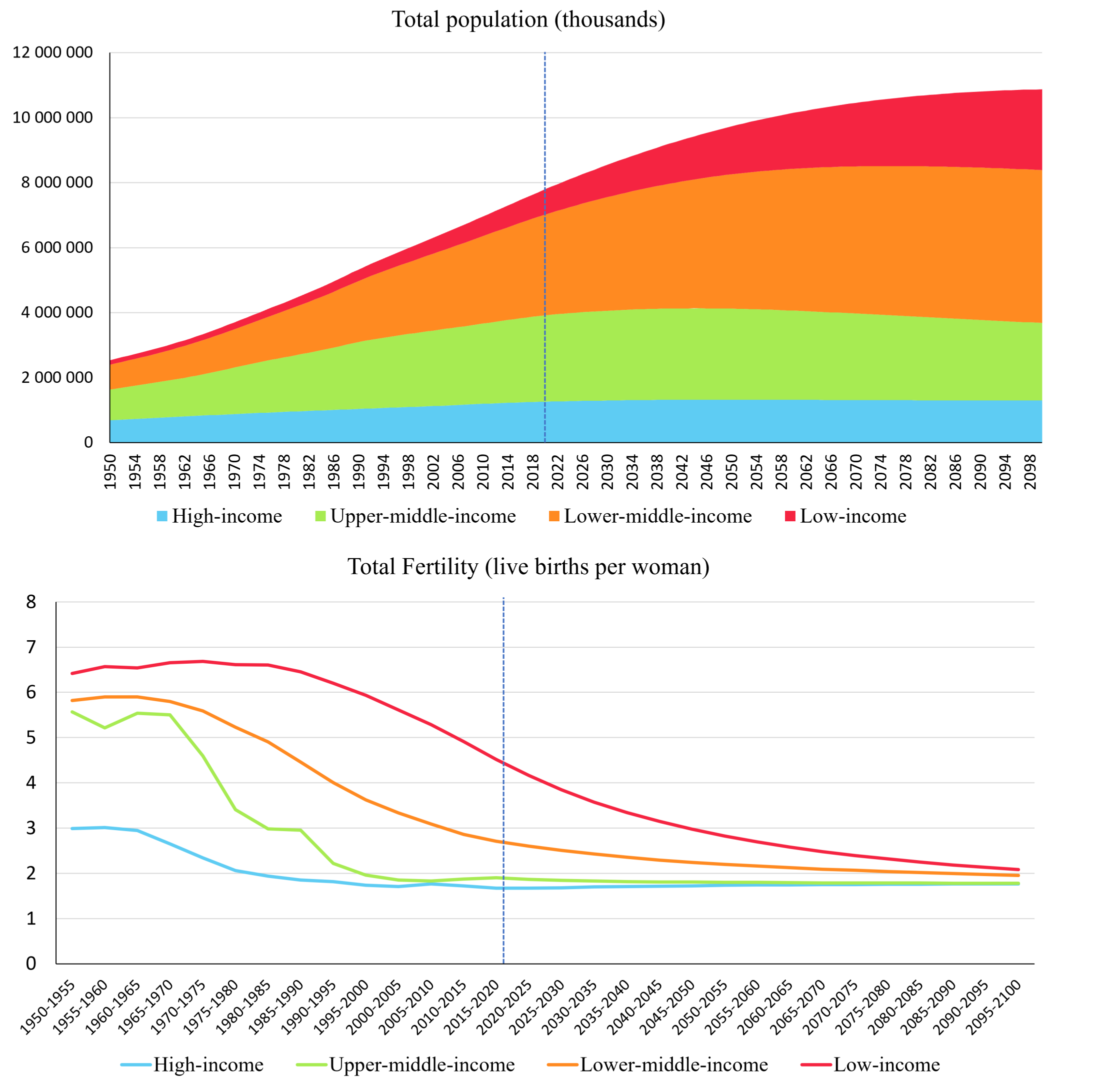

Figure 1: Population dynamics since 1950 and UN medium variant projections to 2100 depending on World Bank income groups. Source: United Nations (2019).

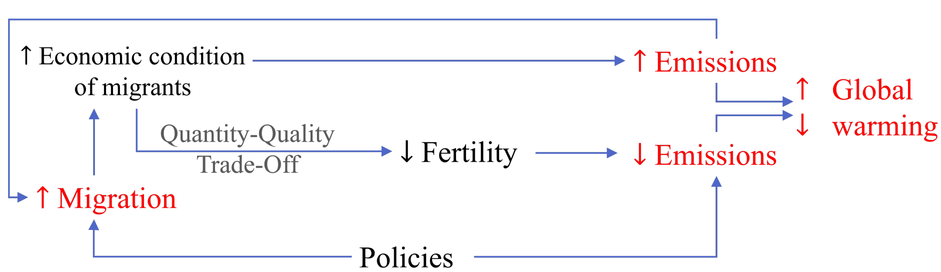

Figure 2: Our proposed relations and pathways between migration, fertility decisions, and climate change.

climate change directly (such as a carbon tax) or indirectly by altering the international flow of migrants. Finally, climate change can intensify migration flows through its differential impact on developing and more vulnerable countries (climate refugees).

Given the significant interplay between migration, economic outcomes, and climate change, this paper focuses on the two mechanisms represented in Figure 2: The contrary effects that an increase in consumption and income of migrants, and a decrease in fertility rates of migrants, have in global warming.

This article is organized as follows: the next section discusses the most relevant ideas in the current literature and how this work contributes to them; the third section presents the mathematical model that represents the relations of Figure 2; the fourth section deals with the calibration procedures; the fifth section discusses the results of the model and its implications; the sixth section concludes.

2 Related Literature

This paper builds on the literature on endogenous fertility, and in particular the hypothesis of the quality-quantity trade-off (Becker and Lewis, 1973; Barro and Becker, 1989; Galor, 2011; Bosi and Seegmuller, 2012; Fanti and Gori, 2014). This hypothesis postulates that households decide whether to have more children with less human capital, or fewer children but investing more in their human capital. Although this hypothesis seems complicated to identify empirically and both fertility and education decisions depend on many more variables (Alidou and Verpoorten, 2019; Zhong, 2017; Riswick and Engelen, 2018; Lawson and Borgerhoff-Mulder, 2016), the trade-off helps reproduce long term demographic patterns such as the demographic transition and how it has behaved in a staggered way across different countries. Nevertheless, the quality-quantity trade-off hypothesis has been tested outside the context of quality-as-education, and it seems like there is evidence for the existence of the trade-off when quality is defined more broadly, i.e., physical fitness and nutrition (Hagen et al., 2006; Zhong, 2017).

We are particularly interested in the fertility decisions of native and migrant populations. Regarding this topic, several hypotheses have been proposed: the adaptation

growth.

hypothesis, the selection hypothesis, the socialization hypothesis, and the disruption hypothesis (Kulu, 2005). Among these, the evidence points to the adaptation hypothesis as the strongest one, which postulates that migrants adapt to the environment in which they arrive, and their fertility rates converge to the fertility rate of the native population (Tønnessen and Mussino, 2020; Andersson, 2021). This does not contradict the fact that the other hypotheses are also relevant for the detailed study of how migrants behave before and after they relocate. For instance, the selection hypothesis postulates that migrants may have a particular fertility rate because they are not a random sample of their country of origin, and if they come from more wealthy and urban backgrounds, they may already have lower fertility rates. Although the other hypotheses are also relevant in the nuanced discussion of women's fertility decisions before, during, and after they migrate, we will consider the credible evidence supporting the adaptation hypothesis to implement it as a stylized fact in the model.

We mainly contribute to the literature of climate change and demography. Most climate change models include an exogenous population size, which is assumed to be constant, exponential, or logistic (such as Acemoglu et al. (2012) Acemoglu et al. (2014), and even the DICE model of Nordhaus and Sztorc (2013)). Nevertheless, it has been long acknowledged that infinite population growth was impossible given resource constraints (Robinson and Srinivasan, 1997).

When endogenous fertility is considered in the context of an externality such as climate change, optimality requires addressing population size (Harford, 1998; Schou, 2002), which means implementing reproductive quotas *à la* one child policy of China, or Pigouvian taxes. Gerlagh et al. (2019) include one such fertility tax in an endogenous fertility context, and obtain estimates of between 30,000€ and 50,000€ per child during this century in a scenario with optimal carbon prices. This approach is regarded by some as restrictive of internationally recognized reproductive rights, especially of women and other vulnerable groups such as ethnic minorities and poor people (Hendrixson et al., 2020; Sasser, 2018). Cafaro (2012) recognizes the ethic issues of population control in the context of global warming, and favors voluntary and non-coercive methods of addressing population size. In this context, migration may become one of such non restrictive alternatives, and we contribute by quantifying the expected effect that migration has on future population growth and CO_2 emissions.

3 Model

3.1 Households

The model is an overlapping generations model, following very closely the design of Gerlagh et al. (2019), but with a world divided in two regions: North and South. Accounting for two regions is important, because it allows to include migration as an additional dimension on models with endogenous fertility. Therefore, in a single framework, we can incorporate the nonlinear relationships between fertility, migration, and the environment. These regions differ in population sizes, human capital levels, total factor productivity levels, and CO_2 emissions intensity levels.

Agents live in three periods (childhood, adulthood and old age) but will only take decisions during adulthood. Every period lasts 30 years, and we will consider adults those 15-45 years old. For now, we will ignore the migration process, but we assume that it occurs only from South to North. At time t there will be a generation of size N_t^j of parents in region $j \in \{N, S\}$ that maximize

$$u_t^j(h_t^j) = \ln(c_t^j) + \gamma \ln(f_t^j) + \beta u_{t+1}^j(h_{t+1}^j) \tag{2}$$

Where h_t^j is the human capital level of the current generation, c_t^j is per parent consumption, $\gamma > 0$ indicates preference for family size, and β is the altruistic weight of children's utility. f_t^j is the fertility rate decided by the current generation, so the size of their descendants will be $f_t^j N_t^j$.

Households are endowed with one unit of labor. We define wages w_t^j, labor l_t^j, schooling investment s_t^j, and lump-sum transfers T_t^j. Based on this, the household faces the following budget constraint:

$$w_t^j h_t^j l_t^j + T_t^j = c_t^j + s_t^j f_t^j \tag{3}$$

The production function of human capital and the time constraint will be given by

$$h_{t+1}^j = (\chi + s_t^j)^\eta \tag{4}$$

$$l_t^j = 1 - \phi f_t^j \tag{5}$$

respectively, where χ is a base level of educational attainment and ϕ is the time dedicated to raise a child.

Every adult individual maximizes (2) subject to (3), (4) and (5) choosing c_t^j, s_t^j, f_t^j, l_t^j and h_{t+1}^j. From the first order conditions, one can obtain an expression for the quantity-quality trade-off:

$$f_t^j = \left(\frac{\gamma}{1+\gamma}\right) \frac{w_t^j h_t^j + T_t^j}{s_t^j + \phi w_t^j h_t^j} \tag{6}$$

Thus, a higher optimal level of investment in education s_t^j implies a lower optimal level of offspring size f_t^j.

We can also find the optimal level of individual consumption:

$$c_t^j = \frac{w_t^j h_t^j + T_t^j}{1+\gamma} \tag{7}$$

There is no closed form for s_t^j, but it is implicitly given by the following intertemporal first order condition:

$$\frac{f_t^j}{c_t^j} = \frac{\beta w_{t+1}^j (1 - \phi f_{t+1}^j) \eta (\chi + s_t^j)^{\eta - 1}}{c_{t+1}^j} \tag{8}$$

3.2 Migration

We assume that every period, a proportion of the population of South will relocate to the North. That proportion p_t is endogenously given by:

$$p_t = \zeta_t \max \left\{ 1 - e^{-\rho\left(\frac{w_t^N - w_t^S}{w_t^S}\right)}, 0 \right\} \tag{9}$$

where ρ is related to the elasticity of the migration flow to the relative wage gap between North and South (this term represents the economic incentive to migrate), and $\zeta_t \in (0,1)$ represents the maximum proportion of Southern natives that would migrate in one period if the wage gap tends to infinity. This exogenous discretionary parameter collects all the cultural, economic, social and political barriers to migration. Therefore, in each period, the quantity of adults in South that migrate to North is given by

$$M_t = p_t N_t^S \tag{10}$$

3.3 Population dynamics

Taking into account the adaptation hypothesis, we will assume that migrants face exactly the same optimization problem of those native to the North, so they end up with the same fertility and schooling decisions. In South, the size of the adult generation that maximizes their utility is $(1-p_t)N_t^S = N_t^S - M_t$. In the North, the adult generation is given by $N_t^N + M_t$. Therefore, the total population in South is given by:

$$P_t^S = \frac{N_{t+1}^S}{2} + (N_t^S - M_t) + \nu_{t-1}^S(N_{t-1}^S - M_{t-1}) \tag{11}$$

and in North is

$$P_t^N = \frac{N_{t+1}^N}{2} + (N_t^N + M_t) + \nu_{t-1}^N(N_{t-1}^N + M_{t-1}) \tag{12}$$

where $N_{t+1}^S = f_t^S(N_t^S - M_t)$ and $N_{t+1}^N = f_t^N(N_t^N + M_t)$ describe the size of the future generations in each region. Equations (11) and (12) include half the size of the next generation, because we assume that when P_t^j is measured, half of this generation has been born[3].

The variable ν_t^j represents the survival rate of the current generation to the third stage of life, and is closely related to life expectancy.

3.4 Production

We assume that each region produces their own consumption goods, so that there is no trade between them. We will also abstract from physical capital, and focus only on the interplay between human capital, education, and fertility. These assumptions keep the model tractable, and allows us to focus on the specific channels between fertility and migration that were mentioned in Figure 2.

As we mentioned before, migrants will be considered exactly the same as North natives, and therefore their labor is perfectly substitute in the production function. The gross production functions of each region are:

$$Q_t^N = \omega_t^N h_t^N l_t^N (N_t^N + M_t)$$
$$Q_t^S = \omega_t^S h_t^S l_t^S (N_t^S - M_t)$$

where ω_t^j is the level of total factor productivity, and it evolves with an exogenous growth rate: $\omega_{t+1}^j / \omega_t^j = \hat{\omega}$. And net production, after subtracting damages ($d_t^j \in (0,1)$) and abatement costs ($a_t^j \in (0,1)$), is

$$Y_t^j = (1 - d_t^j)(1 - a_t^j) Q_t^j \tag{13}$$

CO_2 emissions are given by

$$E_t^j = (1 - \mu_t^j) \sigma_t^j Q_t^j \tag{14}$$

[3] If we assume that the probability of having a child when one is adult (between 15 and 45 years old) is somewhat uniform, we can say that half the size of the new population, i.e. those with ages between -15 and 15, have not been born yet.

where σ_t^j is the CO_2 emissions intensity in region j, which decreases exogenously towards 0 following the process $\sigma_{t+1}^j / \sigma_t^j = \hat{\sigma}^N$.

Parameter $\mu_t^j \in [0, 1]$ is the emission control rate, which is related to the abatement effort as in Nordhaus and Sztorc (2013) as follows:

$$a_t^j = \theta_1 \mu_t^{j\,\theta_2} \tag{15}$$

Firms are in competitive markets, and their profits are given by

$$\Pi_t^j = Y_t^j - w_t^j h_t^j L_t^j - \tau_t^j E_t^j$$

where $L_t^N = l_t^N (N_t^N + M_t)$ and $L_t^S = l_t^S (N_t^S - M_t)$.

Firms choose μ_t^j to maximize said profits, and w_t^j is such that $\Pi_t^j = 0$. These conditions yield:

$$\mu_t^j = \min \left\{ 1, \left(\frac{\tau_t^j \sigma_t^j}{(1 - d_t^j)\theta_1 \theta_2} \right)^{\frac{1}{\theta_2 - 1}} \right\} \tag{16}$$

$$w_t^j = \left[(1 - d_t^j)(1 - a_t^j) - (1 - \mu_t^j)\tau_t^j \sigma_t^j \right] \omega_t^j \tag{17}$$

Climate damages depend on cumulative emissions CE_t:

$$d_t^j = 1 - e^{-\delta^j CE_t} \tag{18}$$

$$CE_{t+1} = CE_t + 30(E_t^N + E_t^S) \tag{19}$$

Given the interplay between carbon sinks and temperature adjustment, climate damages and their abatement can be treated as almost immediate (Dietz and Venmans, 2019); in other words, we can postulate a relationship between current damages and current CO_2 concentrations in the atmosphere. Thus, equation (18) does not require us to describe what happens with temperature, or with past/future carbon concentrations in the atmosphere.

Said concentration increases in equation (19) by what each region emits yearly (recall that the length of each period is 30 years), but we will not consider the behavior of carbon sinks or the depreciation of CO_2 in the atmosphere (in the short term that we are considering here, those effects are relatively irrelevant).

3.5 Competitive Equilibrium and Welfare

As was mentioned before, we will assume autarky. Therefore, what the adult population of every region consumes is equal to what it produces:

$$(c_t^N + s_t^N f_t^N)(N_t^N + M_t) = Y_t^N \tag{20}$$

$$(c_t^S + s_t^S f_t^S)(N_t^S - M_t) = Y_t^S \tag{21}$$

The price of the final goods of each country are normalized to 1; therefore, when migrants compare wages, they compare their purchasing power.

Given initial values of h_t and N_t for both countries, and of M_t and CE_t; and given the trajectories of ω_t, ζ_t and σ_t for each country as well, a competitive equilibrium consists of sequences of $\{c_t, f_t, s_t, l_t, h_t, N_t, M_t, E_t, Y_t, w_t, \tau_t\}_{t=1}^{\infty}$ such that households maximize their utility at each period, firms maximize their profits in competitive markets at each period, and markets clear in autarky.

When analyzing policy scenarios, we will compare the Business as Usual (BAU) scenario in which $\tau_t = 0$ for each t, to a social optimum (SO) scenario in which a benevolent planner chooses a $\tau_t^N = \tau_t^S$ (so that there are no arbitrage possibilities) such that it equals the net present value of future marginal damages maximizing the average utility[4]

[4] We make the same consideration as Gerlagh et al. (2019). We use average utility instead of total utility, because in the second case we can arrive to the ”repugnant conclusion” that a very large population of miserable individuals is preferred to a normal-sized population of better-off individuals.

of the population, yielding:

$$\tau_t = \frac{30}{N_t^N + N_t^S} \left(\delta^N (N_t^N + M_t)^2 c_t^N \sum_{i=1}^{\infty} \left(\beta^i \frac{Y_{t+i}^N l_{t+i}^N}{L_{t+i}^N c_{t+i}^N} \right) + \delta^S (N_t^S - M_t)^2 c_t^S \sum_{i=1}^{\infty} \left(\beta^i \frac{Y_{t+i}^S l_{t+i}^S}{L_{t+i}^S c_{t+i}^S} \right) \right) \tag{22}$$

This tax is transferred directly to households. In this case, every household in North and South will receive the same amount:

$$T_t^j = \tau_t \frac{E_t^N + E_t^S}{N_t^N + N_t^S}$$

4 Calibration

In order to evaluate the different policy scenarios, we need to fix numerically some starting values and parameters. In order to divide the world in North and South, we need to have a working definition. Thus, "North" will be composed of the OECD countries without Mexico, Chile, Colombia and Turkey. "South" will consist of the rest of the world.

Parameter ϕ represents the proportion of time dedicated to raise one child. We will fix it at 0.15, that is, having one child takes 15% of a parent's time. This is in line with Gerlagh et al. (2019) parameterization, and statistical evidence (Bianchi, 2011).

Parameter β, the altruistic weight of next generation's utility, will be set at 0.74. This corresponds to a 2% yearly pure rate of time preference, with a 1% growth rate in consumption.

The parameters that define the abatement technology are set equal to those of Gerlagh et al. (2019); that is, $\theta_1 = 0.07$ and $\theta_2 = 2$. The parameters that govern the relationship between damages and emissions, δ^N and δ^S, will be calibrated to reproduce the same global effect as in Gerlagh et al. (2019), but taking into account the disproportional effect that climate change has on the global South (Stern (2007) mentions, for instance, frail living conditions, a vulnerable agricultural sector, higher occurrence of extreme weather events, diseases, and the possibility of mass migration and conflict), we will calibrate δ^N and δ^S such that damages over GDP in South are double those in North.

Although this assessment may be subject to many considerations, in general there is consensus that developing countries, especially island nations and African countries, are more vulnerable to the effects of climate change (Closset et al., 2017; Sarkodie and Strezov, 2019).

Finally, ρ will be set at 0.2, to reproduce closely the relationship between migration flows in 2017, and income gaps between the countries of origin and destination. This value allows us to reproduce what Esipova et al. (2018) report on in our model, if all barriers to migration are removed (i.e., when $\zeta_{2020} = 1$).

4.1 Long-run parameters

We assume a long-run yearly growth rate of income of 1.5%. In a balanced growth path (BGP), in which growth rates of consumption, education expenditure and income should converge (so that (20) and (21) hold), this means that $\hat{y} = \hat{c} = \hat{s} = 1.56$, where $\hat{y} = y_{t+1}/y_t$, $\hat{c} = c_{t+1}/c_t$, and $\hat{s} = s_{t+1}/s_t$.

We will define the share of income dedicated to education expenses as i_t^j. Therefore,

$$i_t^N = \frac{s_t^N f_t^N (N_t^N + M_t)}{Y_t^N}$$

$$i_t^S = \frac{s_t^S f_t^S (N_t^S - M_t)}{Y_t^S}$$

In the long-run BGP, i and f become constant. We can, therefore, set $i_\infty^j = 0.25$ and $f_\infty^j = 0.9$, to reproduce the behavior seen in Figure 1 as countries develop (note that fertility in our model is number of children per adult, not number of births per woman, so as women represent half the human population, we divide the total fertility ratio by 2). These long-run values will be the same for both regions.

Using (6), (17), and assuming that in the long-run $\tau = T = \sigma = 0$ because when there are no emissions climate policy becomes unnecessary, we get the following relationship:

$$\gamma = \frac{1}{(1 - i_\infty)(1 - \phi f_\infty)} - 1 \tag{23}$$

which will let us calibrate γ. Furthermore, if we use (8) and consider that in the long-run i_t^j is constant and that $\chi << s$, then we find that

$$i_\infty^j = \eta\beta \tag{24}$$

which will let us calibrate η. Given that we already know $\hat{s}$ and $\hat{y}$, and that $y = Y/L$ for each country, then $\hat{\omega}\hat{h} = \hat{y}$. Given the production function of human capital, this equals $\hat{\omega}\hat{s}^\eta = \hat{y}$. Finally, as we set $\hat{s} = \hat{y} = 1.56$, we calibrate $\hat{\omega} = 1.34$, and this value will be equal for North and South.

Finally, although the dynamics of the model depend only on the amount and decisions of the adult population (N_t and M_t), we will consider values of future life expectancy to calibrate paths of ν_t^j and calculate the total population in each scenario. To do that, we will consider life expectancy paths as shown in Figure 3, taking values from the UN medium variant projection up to 2100, and projecting a slow convergence towards 95 years of age. Given life expectancy at year t, le_t^j, we can calculate the survival rate up to 75 years, as

$$\nu_t^j = \frac{le_t^j - 45}{30}.$$

4.2 Initial values

As was mentioned in the setup of the model, each period will cover 30 years. Therefore, our model will start at 2020, but we will need some values from 1990 in order to identify all the parameters and initial values.

We will measure emissions in teratons of CO_2 and GDP in trillions of 2017 international USD (PPP). Using the World Bank World Development Indicators, we will set initial values for emissions (E) and GDP (Y) as shown in Table 1. Total population P is also

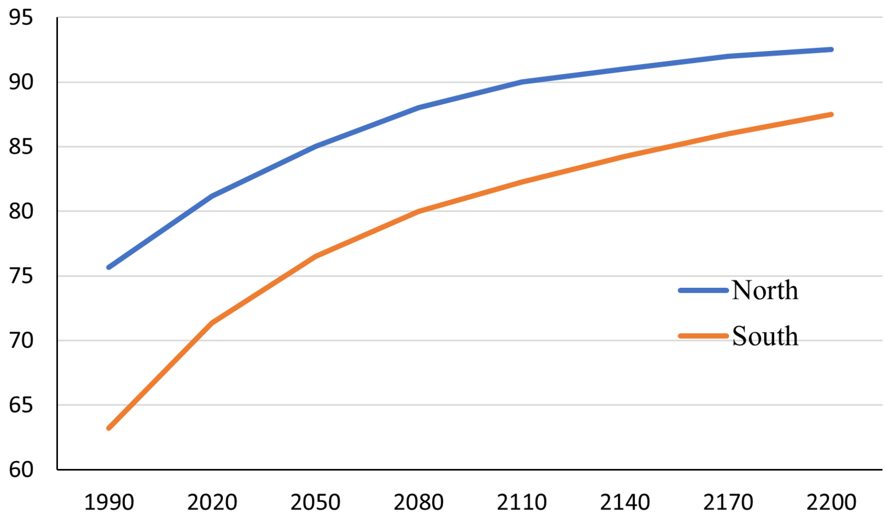

Figure 3: Values of life expectancy to 2200, calibrated using UN medium variant projection to 2100, and extrapolating to 2200.

needed to find starting values for N^N and N^S.

In order to identify migration flows, we used bilateral migration matrices from the World Bank, taken in 1970, 1980, 1990, 2000, and 2017. Using said matrices, we found that in 1990, 6 million people had migrated from North to South, while 37.7 million people had migrated from South to North. In 2017, these figures were 10.4 million and 93.4 million people respectively. Therefore, we took the net amount of migrants for each year, and then took a percentage of that stock of migrants to represent the fact that M_t corresponds to those migrants who are 15-45 years old. This percentage was set to 70%, given the population pyramids of Castro and Rogers (1983). Therefore, $M_{1990} = 0.023$ and $M_{2020} = 0.055$. This also fixes the values of $\zeta_{1990} = 0.057$ and $\zeta_{2020} = 0.076$.

The world emitted about 1.3 $TtCO_2$ between 1750 and 2005. Including carbon budget projections up to 2020, we will fix $CE_{2020} = 1.48$ $TtCO_2$. Using this value, we can figure out the initial values of ω^j and s^j. We just need to solve the following system of

Parameter	Units	Value in 1990	Value in 2020
E^N	$TtCO_2$	0.0108	0.0109
E^S	$TtCO_2$	0.0098	0.0231
Y^N	Trillions 2017 USD, PPP	30.04	50.21
Y^S	Trillions 2017 USD, PPP	20.91	73.41
P^N	Billions of people	0.923	1.088
P^S	Billions of people	4.357	6.665
f^N	Children per adult	1	0.9
f^S	Children per adult	1.8	1.25

Table 1: Initial values, calibrated using the World Bank's WDI Database. Values for E were not available in 2020, thus we took the closest available value, i.e., 2018.

equations, that come from (13), (20), (21), and the definition of $\hat{\omega}$:

$$\begin{cases} \left(e^{-\delta^N C E_{1990}}\right) \omega^N_{1990} h^N_{1990} (1-\phi f^N_{1990})(N^N_{1990}+M_{1990}) = Y^N_{1990} \\ \left(e^{-\delta^S C E_{1990}}\right) \omega^S_{1990} h^S_{1990} (1-\phi f^S_{1990})(N^S_{1990}-M_{1990}) = Y^S_{1990} \\ \left(e^{-\delta^N C E_{2020}}\right) \omega^N_{2020} h^N_{2020} (1-\phi f^N_{2020})(N^N_{2020}+M_{2020}) = Y^N_{2020} \\ \left(e^{-\delta^S C E_{2020}}\right) \omega^S_{2020} h^S_{2020} (1-\phi f^S_{2020})(N^S_{2020}-M_{2020}) = Y^S_{2020} \\ \left(e^{-\delta^N C E_{1990}}\right) \omega^N_{1990} h^N_{1990} \frac{(N^N_{1990}+M_{1990})}{1+\gamma} + \left({h^N_{2020}}^{1/\eta} - \chi\right) f^N_{1990}(N^N_{1990}+M_{1990}) = Y^N_{1990} \\ \left(e^{-\delta^S C E_{1990}}\right) \omega^S_{1990} h^S_{1990} \frac{(N^S_{1990}-M_{1990})}{1+\gamma} + \left({h^S_{2020}}^{1/\eta} - \chi\right) f^S_{1990}(N^S_{1990}-M_{1990}) = Y^S_{1990} \\ \omega^S_{2020} = \omega^S_{1990}\hat{\omega} \\ \omega^N_{2020} = \omega^N_{1990}\hat{\omega} \end{cases} \tag{25}$$

Solving this system of equations should give us values for ω^N_{1990}, ω^S_{1990}, ω^N_{2020}, ω^S_{2020}, h^N_{1990}, h^S_{1990}, h^N_{2020}, and h^S_{2020}. The only remaining parameter is χ, which is calibrated by minimizing the quadratic distance between the fertilities in North and South in 1990 and 2020 of the model, and those in Table 1.

The summary of all the calibrated values can be found in Table 2, and the values that solve the system of equations (25), can be found in Table 3.

Par.	Description	Value	Source
ϕ	% of time needed to raise a child	0.15	Bianchi (2011)
β	Intergenerational altruism	0.74	Pure rate of 2% /year
$\hat{\omega}$	TFP growth rate	1.344	Long-run GDP growth of 1.6%
θ_1	Abatement technology parameter	0.07	Abatement would cost 7% of GDP
θ_2	Abatement technology exponent	2	Quadratic function
CE_{2020}	Cumulative emissions since 1750	1.48	Historic Data
M_{1990}	Net migrants S to N, 15-45 years	0.023	Mig. matrix 1990
M_{2020}	Net migrants S to N, 15-45 years	0.055	Mig. matrix 2017
f_∞	Long-run fertility	0.9	Target - Fig. 1
i_∞	Long-run education expenditure	0.25	Assumption
δ^N	Damages' exponent	0.00275	Gerlagh et al. (2019)
δ^S	Damages' exponent	0.00565	Gerlagh et al. (2019) doubling damages
γ	Preference for fertility	0.541	Equation (23)
η	Elasticity of human k. to education	0.338	Equation (24)
σ^N_{1990}	Initial value of emissions' intensity	0.00036	Emissions and GDP in 1990, Table 1
σ^S_{1990}	Initial value of emissions' intensity	0.00046	Emissions and GDP in 1990, Table 1
$\hat{\sigma}^N$	Growth of emissions' intensity	0.6038	Emissions and GDP, Table 1
$\hat{\sigma}^S$	Growth of emissions' intensity	0.674	Emissions and GDP, Table 1
ρ	Elasticity of migration to wage gap	0.2	2017 data on migration and income gaps
ζ_{1990}	Migration policy and barriers	0.057	Target M_{1990}
ζ_{2020}	Migration policy and barriers	0.076	Target M_{2020}
χ	Base education level	1.006	Minimize distance to initial values of f

Table 2: Calibrated parameters and relevant initial values.

Parameter	Definition	Value in 1990	Value in 2020
ω^N	Total factor productivity, North	36.38	48.89
ω^S	Total factor productivity, South	16.79	22.56
h^N	Human capital, North	2.557	2.737
h^S	Human capital, South	0.897	1.192

Table 3: Initial values of ω and h, identified as solutions of the system of equations (25).

5 Results and discussion

We will consider a baseline scenario that will be called Business as Usual (BAU), in which there is no climate policy, and migration flows continue as normal (that is, they continue their upward trend seen between 1990 and 2020 but decelerating and converging to a constant proportion). We will compare this scenario, to one in which migration is stopped just after 2020 (Mig0). This is not meant to predict a potentially real future

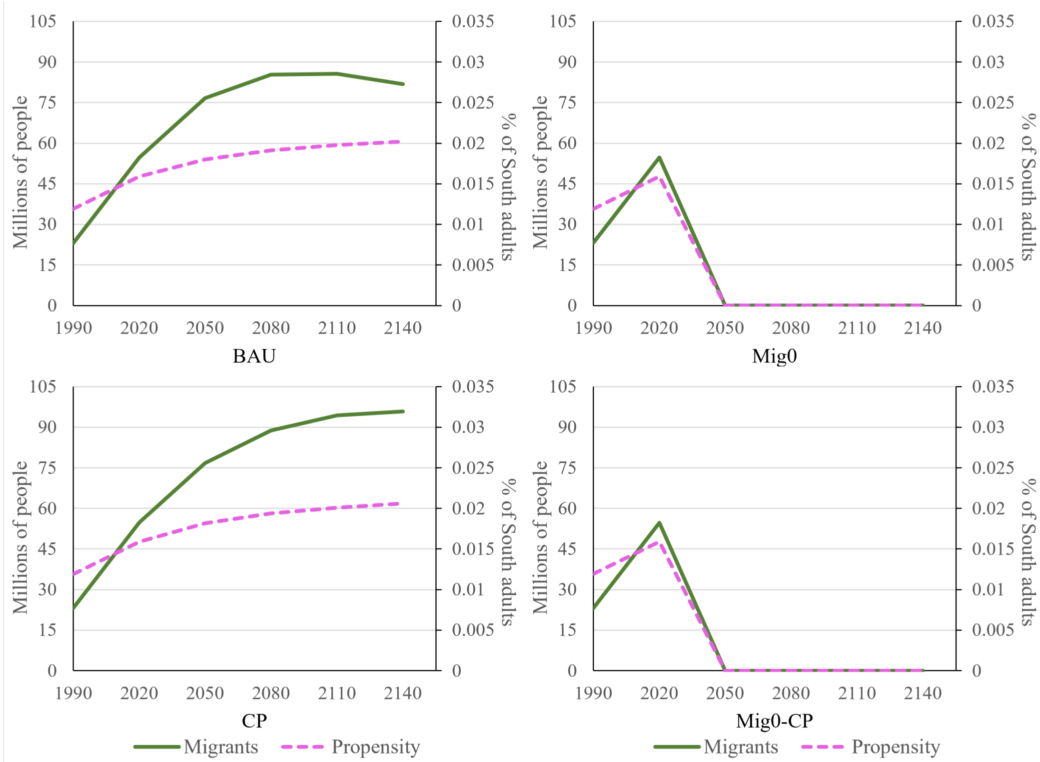

Figure 4: Migrants (M_t) and propensity to migrate (p_t) in each of the four scenarios.

outcome. Instead, it helps us to understand and quantify the role of migration in reducing population growth, increasing standards of living, and ultimately affecting the rate of emissions of CO_2 to the atmosphere.

We will consider other two scenarios: a third one (CP) with a migration pattern such as in BAU, but with a global carbon price equal to the formula (22). The fourth scenario (Mig0-CP) combines this carbon price with a total shutdown of migration between North and South from 2020 onwards.

5.1 Population growth

Regarding population, the main difference between scenarios is in their different migration patterns. Figure 4 shows the total amount of adult migrants (M_t) and the propensity of a southern native to migrate (p_t) in each of the four scenarios. Obviously these variables go to 0 in the scenarios in which migration is shut down after 2020. In the case of the BAU scenario, and the scenario in which a carbon price is implemented

(CP), the propensity to migrate converges slowly towards 2%; in other words, each 30 year period, 2% of the South's mass of adults migrate to the North (this number does not include offspring). Given that the population of the South is also expected to increase, the number of migrants should increase as well: M_t would be 85.7 million adults by 2110 in the BAU scenario, and 94.4 million adults by 2110 in the CP scenario. This last difference depends on the total amount of South inhabitants in each scenario, as we will explore later.

We first compare the total population of the four scenarios. Figure 5 shows total population trajectories for each of the four scenarios. These population trajectories are in line with those of the UN medium variant projection and the UN high variant projection from United Nations (2019) (the former predicts a total population of 11 billion in 2100, while the latter predicts a population of 15.6 billion). Figure 5 also shows that the difference in total population between BAU and Mig0 is minuscule relative to the total size of the population; nevertheless, Figure 6 shows this population difference. As expected, when migration is curbed, a higher population of adults in the long-run generates a higher long-run total population. In the case in which there are no carbon taxes, the extra population by 2110 when migration is stopped is of 20.5 million adults, or 4.5 million people in total.

In order to understand the different behavior between the number of adults and the number of total population, we have to analyze the age composition of the population. As Figure 7 shows (although only for the no-carbon-tax scenarios), life expectancy plays an important role in making that the difference in population between BAU and Mig0 is so small. For instance, almost half the world population is expected to be ”old” (i.e., older than 45 years) for the year 2110. In the scenario with no migration, those would-be migrants would stay in the south with higher fertility rates, but less of them will survive to old age (because of lower life expectancy).

When a carbon price is implemented, we also find that the global population when migration is allowed, is lower when compared to a scenario with no migration. In this case, the difference is even visible in Figure 5, and it is also expanded in Figure 6. In this case, the difference in the number of adults between scenarios is starker than when there is no carbon price: if migration stops in 2020, there would be 45 million more adults in 2110. Provided this, the effect that life expectancy has is smaller in comparison, and therefore there would be 63 million more people in total in 2110.

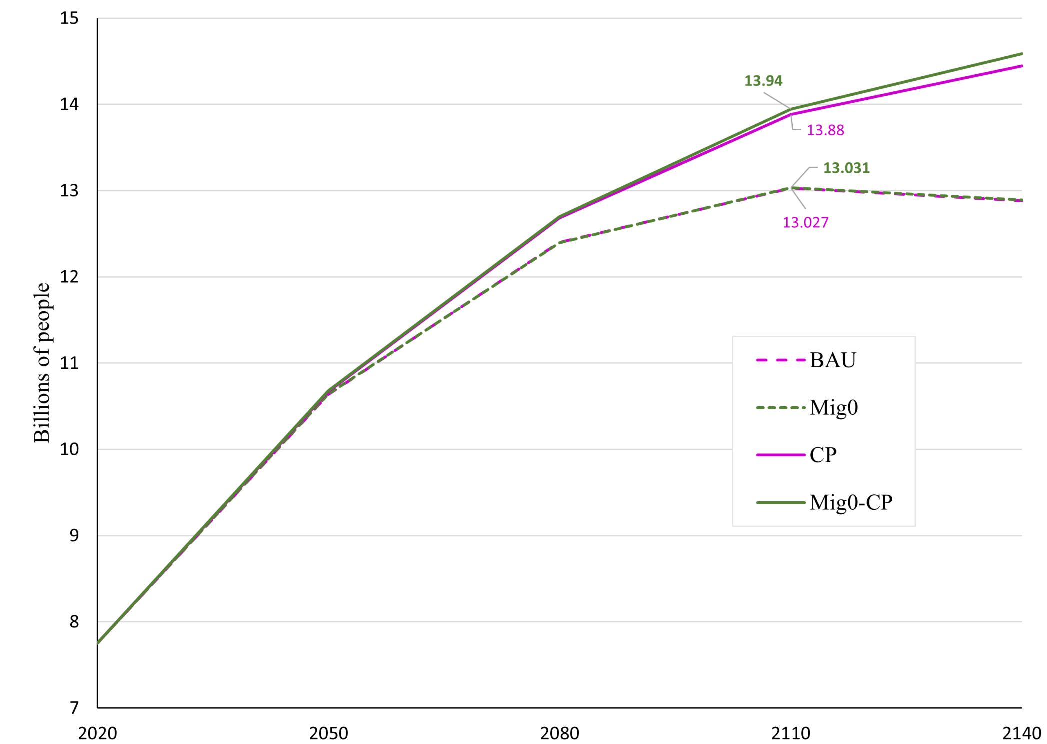

Figure 5: Total population for each of the four scenarios.

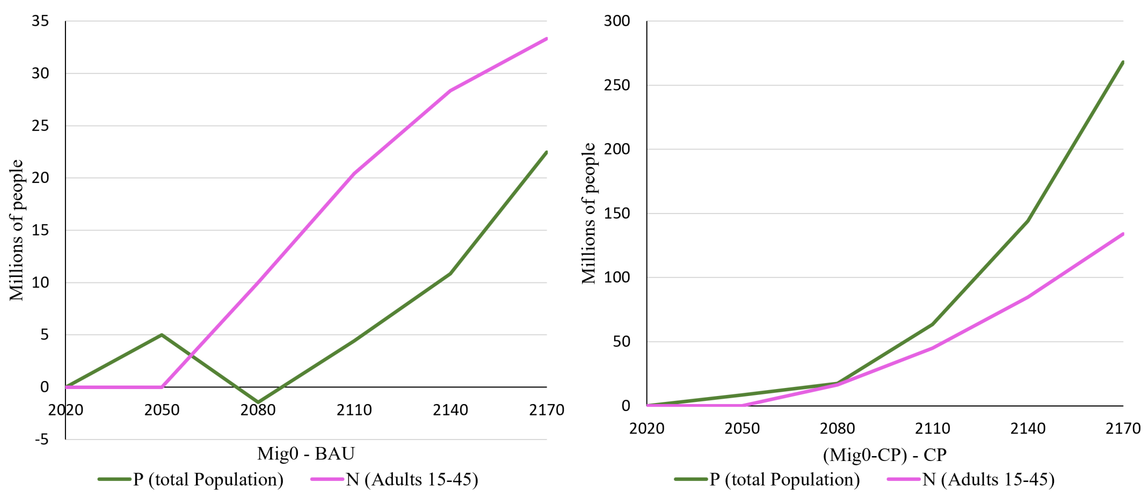

Figure 6: Population difference when migration is shut down after 2020.

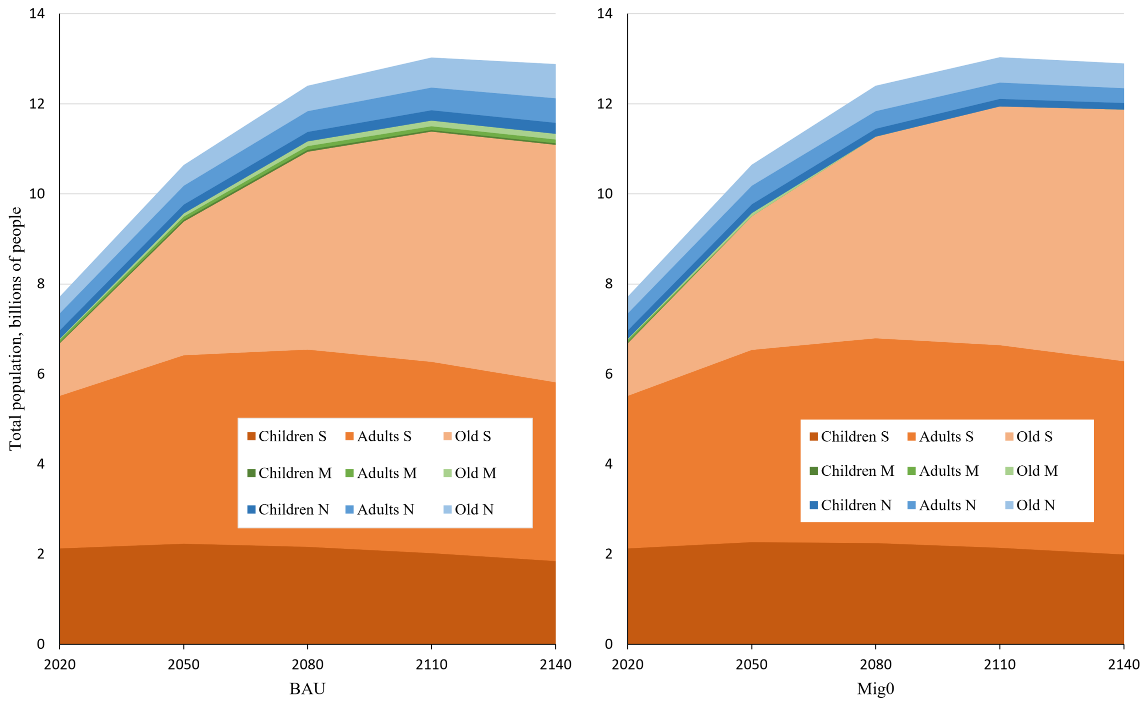

Figure 7: Population composition for scenarios BAU and Mig0.

Figure 5 also shows a remarkable difference of almost 1 billion more people when a carbon price is implemented. Given the global wealth transfer that this carbon tax represents (considering that it is a lump-sum transfer equal for both North and South households), we should expect higher fertility rates, especially in the South.

5.2 Climate and Emissions

In Figure 8, we represent the future pathways of emissions up to 2140. All four scenarios predict yearly emissions between 50 and 65 $GtCO_2$ in 2100, which is consistent with the RCP6 of IPCC (2021). show that a carbon tax is an effective way of reducing annual emissions. Nevertheless, we find that the reduction in emissions when a carbon tax is implemented is modest compared with studies such as Gerlagh et al. (2019).

In contrast, we do see that migration causes higher levels of annual emissions. This means that, regarding the contrary effects of migration described in Figure 2, an increase in emissions due to higher standards of living in the North is higher than the reduction in emissions due to lower population sizes. This represents an extra of 84.3 $GtCO_2$

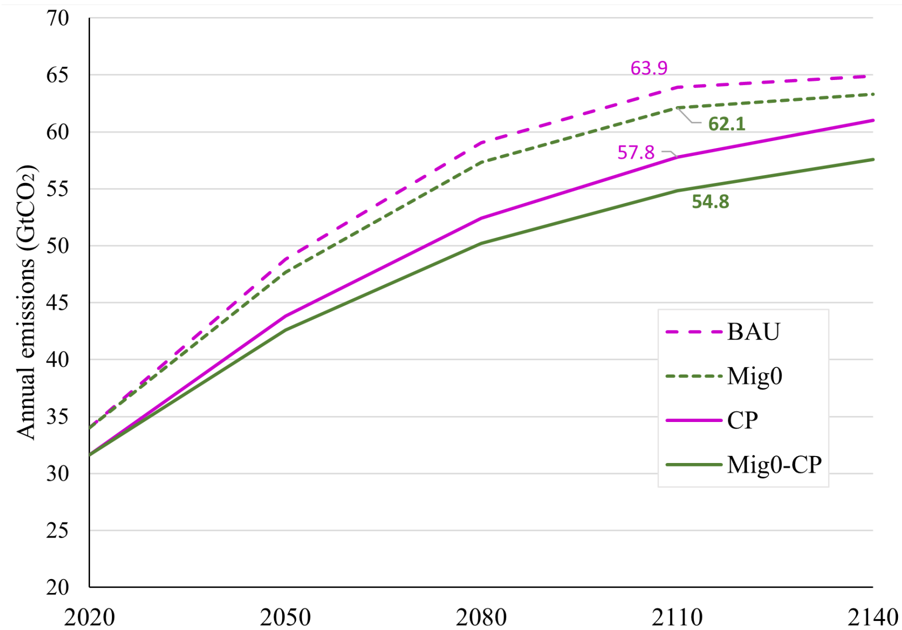

Figure 8: Annual global emissions.

accumulated in the atmosphere in 2110. When a carbon price is implemented, curbing migration represents 102 $GtCO_2$ less in the atmosphere by 2110. In the next section we will describe how robust this result is.

In any case, carbon prices seem to work. When migration is allowed, they reduce the CO_2 presence in the atmosphere by 419 $GtCO_2$ in 2110. And when migration is shut down after 2020, this figure rises to 437 $GtCO_2$. Carbon prices in each of these two scenarios can be found in Figure 9. In both cases they start at 34 USD/tCO_2 in 2020, and rise approximately proportional to income in each case. When migration is halted, the carbon price rises faster than when migration is allowed.

These carbon prices agree with what several countries are implementing nowadays. According to the World Bank's Carbon Pricing Dashboard, countries like the UK, Portugal, the Netherlands, Iceland, Ireland, or Canada, are implementing rates close to 30 USD per tCO_2 equivalent. And countries such as Norway and Finland are using values closer to 70 USD per tCO_2 equivalent, although some countries such as Sweden and Switzerland are using higher values. Other countries are using prices between 0 and 20 USD/tCO_2e, but they intend to increase them gradually, such as Argentina.

Another way in which we can compare the different scenarios, is through the present

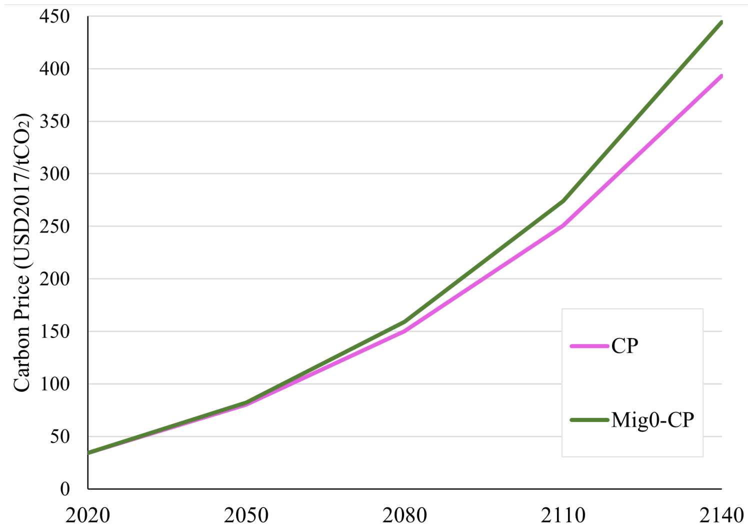

Figure 9: Carbon prices in 2017 international USD (PPP) per tCO_2, with and without migration.

		BAU	Mig0	CP	Mig0-CP
Present value of damages, 2020-2110 (Tr. of USD2017)	North	5.9	3.6	5.7	3.4
	South	23.7	24.8	24.2	25.3
	World	29.6	28.4	29.9	28.7
Present value of damages per capita, 2020-2110 (1000 USD2017)	North	10.1	10.02	9.4	9.2
	South	5.7	5.7	5.3	5.2
	World	15.9	15.7	14.7	14.4

Table 4: Present value of aggregate yearly climate damages every 30 years (in trillions of 2017 intl. USD) and climate damages per capita (in thousands of 2017 intl. USD), for each scenario.

value of the total damages that climate change causes on the economy, using the damages function in (18). Table 4 adds and compares the present value of yearly damages in 2020, 2050, 2080 and 2110 (the total over the whole period should be larger, but proportional to the totals in Table 4, and their values depend on how the variables are interpolated within every period). All figures are in 2017 international USD. The present value of aggregate climate damages between 2020 and 2110 amount to 29.58 trillion USD in the BAU scenario, and to 28.39 trillion USD when migration is halted. If a carbon price is implemented, these values go up: 29.93 trillion USD and 28.67 trillion USD respectively. Does this mean that the carbon price is ineffective? No. Given that fertility is endogenous and that in the circumstances in which a carbon tax is implemented there is higher population and, therefore, higher GDP, the present value of damages between 2020 and 2110 may increase. That is why we include an estimation of the present value of damages per capita during the same range of years.

Using this measure, we find that climate change between 2020 and 2110 would cost an average of 15 910 USD per person in the BAU scenario, and 15 700 USD per person in the Mig0 scenario. Implementing a carbon tax reduces this value, to 14 700 USD per person when there is migration, and to 14 410 USD per person when migration is halted. Therefore, the carbon price reduces the present value of climate damages per person.

If we compare the scenarios with and without migration, we find that damages are greater when there is migration. This makes sense, given that Figure 8 indicates that emissions increase with migration. We will evaluate how this fact changes when we change the speed at which countries decarbonize their production in the next subsection.

5.3 Sensitivity to changes in emissions' intensity

We find evidence that when migrants arrive to the North, they consume more and end up producing higher CO_2 emissions. What happens if the North pursues a more aggresive decarbonization policy, becoming more carbon efficient or energy efficient?

Parameter $\hat{\sigma}^N$ governs the speed at which production in the North becomes less carbon intensive. It is currently set at 0.6038, which means that the carbon intensity of the North (σ_t^N) decreases by 1.67% per year. We can set different values of this parameter, and evaluate what happens with the difference in cumulative emissions over time.

The results of changing the parameter $\hat{\sigma}^N$ since 2020 are represented in Figure 10. In each case, $\hat{\sigma}^N$ decreased by 0.05, leaving everything else constant. In the last case, in which $\hat{\sigma}^N = 0.3538$, it means that σ_t^N decreases by 3.4% each year. This acceleration in the decline of σ_t^N is enough to change the effect that migration has on CO_2 emissions: while $\hat{\sigma}^N = 0.6038$ implies an extra 84.3 $GtCO_2$ in the atmosphere by 2110 in the BAU scenario compared to the Mig0 scenario, a value of $\hat{\sigma}^N = 0.3538$ implies 34.5 $GtCO_2$ less in the atmosphere by 2110 in the BAU scenario compared to the Mig0 scenario. And faster processes of carbon decoupling in the North, *ceteris paribus*, should imply larger beneficial effects of migration in the atmosphere.

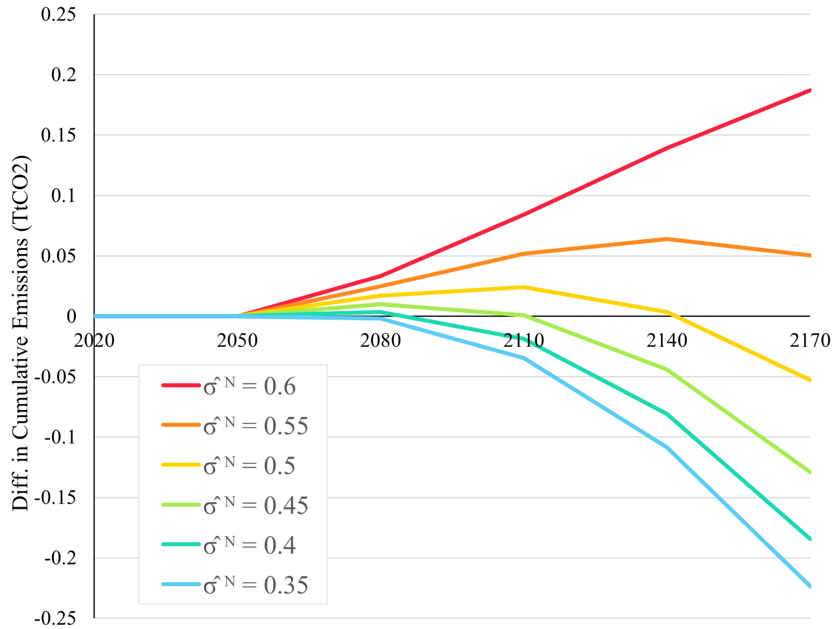

Figure 10: Sensitivity of the CE gap between scenarios BAU and Mig0, for different values of $\hat{\sigma}^N$.

Nevertheless, intermediate scenarios of Figure 10 show that it is common that a decrease in cumulative emissions (comparing the BAU and Mig0 scenarios) is preceded by an immediate increase in cumulative emissions. This is because the increase in migrant's standards of living happens in the short term, whereas the reduction in population size happens more slowly, but ends up having a higher effect in the long-run. Therefore, the seemingly negative effect that migration had on the environment in Table 4 when comparing the BAU and Mig0 scenarios, depends also on the time horizon.

In order to understand if the values presented in Figure 10 are realistic, we will compare them to the observed paths of CO_2 intensities between 1990 and 2020. Also, using the World Bank's Mitigation Content Database, we will compare these projections with the Intended Nationally Determined Contributions (NDC's) that most countries have made to 2030.

Figure 11 represents the observed paths between 1990 and 2018 of the CO_2 emissions intensity of GDP, for the United States, the European Union, China, and India; as well as for the aggregate of the upper-middle income and lower-middle income countries. We contrast these paths with the values of σ_t^N and σ_t^S used in the model. For σ_t^N we even include alternative paths if we assume different values of $\hat{\sigma}^N$, which are the ones

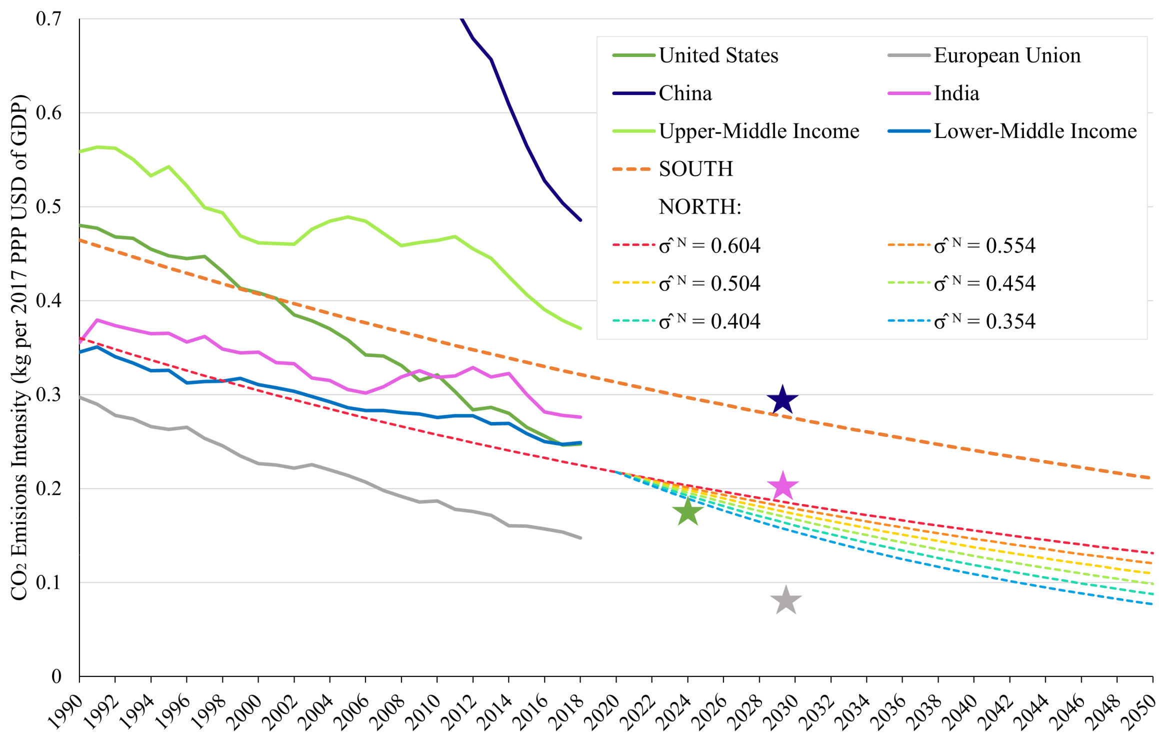

Figure 11: Kg of CO_2 emitted per intl. USD of 2017 of GDP, for selected countries and World Bank country groups, as well as the values of σ_t^N and σ_t^S used in the model. For σ_t^N, we include the six different values of $\hat{\sigma}^N$ considered in Figure 10 since 2020. Stars represent the NDC's of China, India, United States and the EU (for the last two, we assumed an annual GDP growth rate of 2%.)

considered in Figure 10. This graph shows that the last case, in which $\hat{\sigma}^N$ is reduced from 0.60 to 0.35, is not as big of a deviation in terms of the short-run behavior of σ: in other words, all scenarios between the $\hat{\sigma}^N = 0.6$ scenario and the $\hat{\sigma}^N = 0.35$ scenario seem reasonable up to 2050 given the wide range of possibilities.

We also include the NDC's of the four countries represented in Figure 11 using stars. In the case of China and India, they pledged to reduced their 2005 CO_2 emissions intensity by a percentage to 2030. India announced a reduction of 34%, while China mentioned a reduction of 60% - 65%. This sounds ambitious, but taking into account the very high level of Chinese dependence on CO_2 emissions (as Figure 11 indicates), their NDC seems plausible given their current decarbonization trajectory.

The European Union and the United States did not announce a reduction in σ, but in E, their future total CO_2 emissions. In order to plot their NDC's in Figure 11, we assumed that both their GDP grow at 2% each year. The EU wants to reduce their 1990 emissions by 40% by 2030. Meanwhile, the US wants to reduce their emissions by 26% - 28% in 2025, compared with those in 2005. Figure 11 shows that these selected NDC's are reasonable given the most recent behavior of σ for all countries. Finally, the negative effect that migration had on climate change, as seen on Figure 8 and Table 4, is highly dependent on the short term speed of decarbonization in developed and developing economies.

Regarding the gap between rich and poor countries, there are two opposing forces. On the one hand, rich countries can decarbonize faster, given that they have more resources and as technology innovators, they tend to implement more efficient technologies first; also, developed countries have more effective regulation capabilities, so it is easier for them to achieve their environmental goals. On the other hand, developing economies that originally were highly dependent on CO_2 emissions (such as China) can reduce their emissions intensity much faster, given that basic technologies already exist and they do not have to invest as heavily in research and innovation.

In conclusion, although faster decarbonizations are good for the environment in any case, a faster decarbonization in the North relative to the South is a necessary condition for migration to be a short term alternative to mitigate the effects of climate change. This can also be interpreted in the following manner: an individual's migration decision contributes more to curb the short-run and long-run effects of climate change, if the

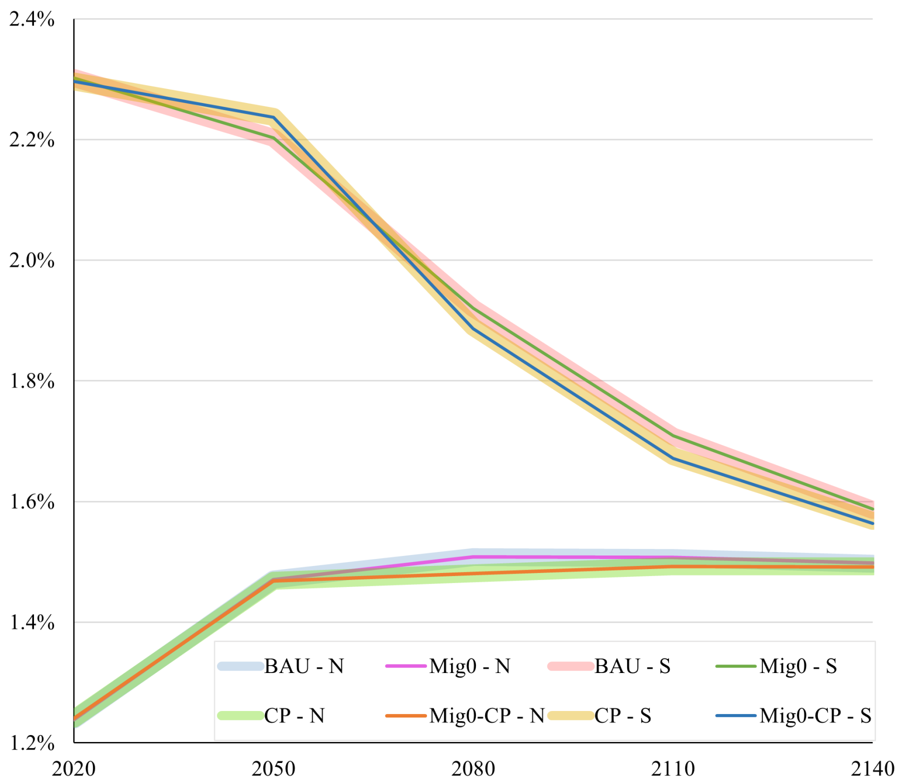

Figure 12: Annual rate of GDP per capita growth, in each of the two regions, for each of the four scenarios.

person comes from a more pollutant and less efficient country, and arrives to a relatively clean and rapidly decarbonizing country.

5.4 Effect of migration on international inequality

Finally, we can check if the reduction in the South's work force because of migration, has a substantive effect on the wealth gap between the North and the South. Figure 12 shows that there is almost no difference between the scenarios with and without migration. We do find a difference when a carbon price is implemented, though: with a carbon price, income per capita growth in the North is slightly reduced after 2050, while in the North a carbon price induces higher growth in the first period after 2020, followed by lower growth rates in per capita income.

Even though the difference in income growth seems negligible when comparing the scenarios with and without migration, there is actually a very small difference, that is

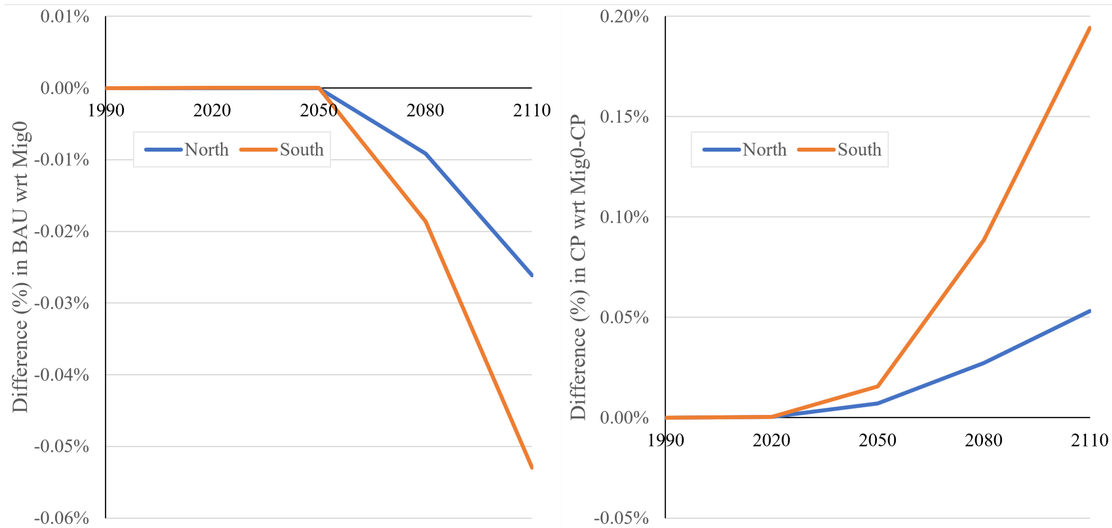

Figure 13: Relative difference between per capita incomes in the North and in the South

reported in Figure 13. When there is no carbon price (left plot), we see that per capita incomes are between 0.02% and 0.06% lower in 2110 when migration is allowed, relative to when migration is shut down. This means that in this scenario, lower levels of per capita income are achieved, and that migration exacerbates international income gaps because the negative gap is wider in the South.

In comparison, the plot in the right of Figure 13 shows that when a global carbon price is implemented, incomes per capita are higher when migration is allowed. We also find that incomes may arise by 0.05% in the North and by 0.2% in the South if migration is allowed. This means that the income gap between the North and the South reduces in this scenario, which makes sense given that the lump-sum transfer of the carbon tax works as a redistribution mechanism between countries.

6 Conclusions and future research

This paper presents migration as a relevant variable in discussions on climate change mitigation and effects. One of the most recent discussions in climate change is related to the externality of larger future populations, and we present the possibility of increasing migration flows from "dirty" countries to clean ones, as an alternative to fertility taxes (such as the one proposed in Gerlagh et al. (2019)) and other more restrictive demographic policies. We also find evidence that migration helps reduce poverty by giving migrants access to higher standards of living. The challenge is that those higher standards of living should not rely heavily on GHG emissions, to avoid causing a short term increase in global emissions.

In regards to this last point, we find that realistic paths of decarbonization may lead to negative contributions of migration to cumulative emissions. However, these future paths depend on the commitment of the world's governments in achieving their NDC's.

Additionally, the interplay between a global carbon price and incentives to migration flows seem beneficial to the environment. We find that when migration is curbed, carbon prices should increase faster with time. And although we reach higher total population levels with a carbon price, we also reach lower per capita damages during this century. Another interesting conclusion is that this global carbon price may work as an international redistribution mechanism, reducing income disparities between countries. We can evaluate what happens when the tax is not rebated equally across regions, but in a way that does not allow for such redistribution.

There are some directions in which the framework of this paper can be extended. For instance, migration should not be only understood as changing the country of residence; the effects of rural-to-urban internal migration should also be acknowledged. Migration flows towards cities with higher returns to human capital should be affected by the same quality-quantity trade-off that is used as the main mechanism in our model. This is relevant for developing countries that are in the middle of an urbanization transition.

In addition, income inequality within countries is as relevant as income inequality between countries. This is relevant because our assumption that migrants consume and behave exactly as the natives of the North, does not hold in reality. And it is also true that migrants are not a random sample of their countries of origin.

This last discussion is also related to the different reasons for which people migrate. Migration is not always a constant flow of people: sometimes migration is highly discouraged, and sometimes conflicts and natural disasters may cause an unexpected flow of displaced people. Our model includes a mechanism in which higher damages affect wages and therefore increases the propensity to migrate, which could be considered climate refugees. In reality, this phenomenon is not a constant flow of some migrants, but it is highly unpredictable in several ways.

Other interesting scenarios related to our setup that can be explored in future research, are related to the interaction between different policies. What would happen if only the North uses a carbon price? In reality, it is probable that most firms in the North would send their CO_2 intensive production processes to the South, which would become a pollution haven. In this case, our assumption of autarky is definitely far from useful. And what happens if we allow trade between both countries? What happens if there is physical capital accumulation? What happens if a fertility tax is also implemented? These expansions should add nuance to the results of this paper.

Finally, there is a way in which migrants could endogenously affect the rate at which the North decarbonizes its economy, through higher research capabilities. In order to explore this possibility, this model can be expanded to include an innovation module, and in which a proportion of the migrants can become scientists. For instance, Gerlagh (2020) includes knowledge creation in an endogenous-fertility climate-change Brock-Mirman model, but without migration.

To conclude, migrants from developing nations to developed ones may increase their standards of living in the short term and possibly increase global CO_2 emissions, but if their own per capita emissions are reduced fast enough (maybe through their own research), a lower long term human population leads to a reduced impact on the environment. However, implementing a carbon price is still an effective policy measure to curb emissions in the short run.

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