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Warming with Borders:
Forced Climate Migration and Carbon Pricing

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Abstract

As climate changes and natural disasters intensify, the threat of human displacement increases. This paper studies carbon taxation in the presence of international climate displacement. After providing evidence on the migration response to disasters, forced climate migration is introduced into a quantitative climate-macroeconomic model to theoretically characterize the global and local social cost of carbons—SCCs, equivalently, optimal carbon taxes. These change substantially when this type of migration is considered. A North-South calibration reveals that, while migration increases the local SCC in host regions—more so if political conflict is considered—the global and origin region's SCCs remain largely unaffected.

Keywords: Climate change; social cost of carbon; forced climate migration; optimal and unilateral policy

JEL classification: E60; F22; O44; Q54

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1 Introduction

The scientific literature has found that climate change increases the frequency and intensity of natural disasters (Fischer and Knutti 2015). These events affect people living in developing regions more severely (Closset et al. 2018), which makes them potential triggers for massive migrations of population (IDMC 2019). Disaster displacement is considered one of the most relevant consequences of climate change because of its potentially devastating effects on communities and individuals. However, human displacement has received little attention from the economic analysis of optimal climate policy. This paper jointly considers climate change and migration, two of the top public policy concerns in Europe ("Eurobarometer 98.1 2022"), to study optimal carbon taxation and countries' strategic reactions under different degrees of international cooperation.

This paper develops a quantitative multi-region macroeconomic model with climate change and theoretically analyses the impact of climate displacement on the social cost of carbon[1] (SCC)—or, equivalently, the optimal carbon tax—providing the first analytical characterization of the SCC with migration. After documenting empirically the effect of natural disasters on forced migration from developing to developed countries, it simulates the world economy and quantifies carbon taxes. In addition, it investigates strategic interactions between countries with various degrees of international agreement on climate policy. I find that taking into account forced climate migration strongly enhances the incentives of developed countries to unilaterally fight climate change. In other words, the local SCC in developed countries is higher when accounting for climate displacement. This stands in contrast to the globally optimal SCC and the SCC for developing countries, both of which show minimal changes in magnitude. In what follows, I discuss these contributions in detail.

I use the term 'forced climate migration' (FCM) to describe a specific subset of climate migrants: individuals who are forced to move internationally due to climate change-induced natural disasters. To document this phenomenon, I use a global annual panel dataset on natural disasters and population flows from developing to developed countries. I find a strong positive relationship between natural shocks and contemporaneous migration from developing to developed countries, with a semi-elasticity of 2%. Although existing studies typically target migration triggered by slow and progressive changes in climate such

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[1] The SCC is the monetary value of current and future damage caused by a marginal increase in emissions.

as temperature, I instead analyse displacement resulting from warming-related natural disasters as a measure of unavoidable and forced migration. I further relate the estimated effect with the increase in carbon concentrations.

Informed by the empirical findings, I examine how displacement shapes the SCCs, by developing an integrated assessment model (IAM) with FCM.[2] The model features multiple regions, classified into host and origin, that are differently affected by climate change. The use of a dirty energy resource contributes to climate change, which affects origin regions more severely. Following an increase in global carbon concentrations, some individuals from origin regions are forced to move to host regions. Hence, energy emissions are the source of two distinct externalities: i. they damage the economic productivity following the approach in Golosov et al. (2014) (GHKT), and ii. they generate population flows.[3] Apart from considering the economic impacts of displacement, this framework is able to account for a dimension often overlooked by the climate and migration literatures: the social cost of migration—or anti-immigrant sentiment. Recent electoral outcomes in Europe and the United States suggest that citizens sometimes have negative views of immigrants.[4] In fact, the first Intergovernmental Panel for Climate Change report highlighted that future flows of climate migrants could have social impacts in the form of political conflict or social instability (IPCC 2014). The model can account for this social cost under different intensities, if any. These are not normative preferences that I would endorse, but are hypothetical positive preferences of a local planner.

The theoretical findings include novel analytical expressions of optimal carbon prices under three different levels of international policy cooperation: i. when only host countries undertake climate action unilaterally; ii. when a global agreement is in place; and iii. under a Nash equilibrium with non-cooperative policies in all regions. I first focus on the setting with unilateral climate action in host regions and show that FCM changes considerably the theoretical characterization of the unilateral carbon tax. On the one hand, FCM can lead to a less stringent unilateral policy because they increase the labor force in host regions and

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[2] The model can be expanded to incorporate micro-founded climate migration, though this comes at the cost of theoretical tractability. This extension is presented in Online Appendix F.

[3] Since these externalities stem from the same source, a unique policy tool is enough to correct them.

[4] "Brothers of Italy", known for its strong opposition to migration, emerged as the largest party in Italy's 2022 general elections. In the 2020 presidential elections, Donald Trump secured 48.5% of the popular vote running on a clear anti-immigration agenda. The political economy literature has also documented misperceptions about immigrants (Alesina, Miano, and Stantcheva 2023)(Alesina, Miano, and Stantcheva 2023).

the emissions in origin regions decrease, improving welfare in host regions. On the other hand, FCM can also lead to a more stringent unilateral policy, reflecting the fact that they reduce welfare in host regions, and thus governments are more willing to abate emissions. This happens for three reasons. First, emissions per capita are usually higher in developed regions; hence, migration increases emissions and environmental damage. Second, a larger population lowers per capita consumption as it reduces the per capita availability of the environmental good, which is finite and deteriorates with pollution. The same dilution happens with capital, which cannot be adjusted costlessly. Third, in occasions there may be a direct utility cost of immigration.

In my quantitative analysis, I find that in the absence of FCM, the unilateral SCC for host regions is around USD 44 per ton of carbon, in line with existing studies. However, in the presence of FCM the negative welfare impact dominates, leading to a 22 percent higher unilateral SCC, or slightly higher when the social cost of immigration is considered.[5] These findings may appear contradictory to real-world political dynamics, as politicians generally do not yet advocate for climate policies aimed at reducing migration, with some exceptions.[6] However, note that this exercise is the result of combining a normative and a positive assessment. It is normative because it features a planner that internalizes the climate externality for its citizens. At the same time, we observe countries acting unilaterally to fight climate change, hence its positive nature.

I then derive analytical expressions and quantify the globally optimal SCC and the non-cooperative SCCs under a Nash equilibrium. Again, I find that the theoretical characterizations change compared to the existing ones, which do not account for FCM. For instance, the global planner accounts for the cost of pollution borne by individuals in both host and origin regions, as well as the adaptation benefits from reallocating individuals to less vulnerable areas. In the quantitative exercise I find that, when a global agreement is in place, the magnitude of the first-best policy remains almost unchanged. This is because the benefits of reallocating people to less vulnerable areas are more or less compensated by the costs of having higher global emissions when more people live in areas with high

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[5] Results hold under border control policies. I extend the model allowing host countries to invest in border control to reduce the inflow of migrants. I find that border control is preferred to a carbon tax increase only when deportation costs are unreasonably low. However, under realistic border control costs, host countries' best strategy is to use a more stringent tax to mitigate the economic costs of FCM.

[6] Turner and Bailey (2022) document a growing trend among far-right European parties, which traditionally marginalized the issue of climate change, to blame immigration for national environmental degradation.

emissions per capita. Interestingly, the Nash equilibrium setting reflects that host and origin regions are affected by FCM in opposite ways. Without migration, the local SCC is 1.6 times higher in origin regions because those regions are more vulnerable to climate change and are more populated. However, with migration, the gap between the host and the origin SCC shrinks.

This paper contributes to the development of integrated climate-economy modeling by introducing climate displacement into a model of optimal climate policy that is both analytically tractable and quantitatively comprehensive. It is novel in assessing the strategic interactions between countries. The most popular IAMs analysing optimal carbon taxation tend to abstract from climate migration (Nordhaus and Boyer 2000; GHKT; Cai and Lontzek 2019, Acemoglu et al. 2012; Barrage 2019; Hillebrand and Hillebrand (2019); Van der Ploeg and Rezai 2019; Van Den Bremer and Van Der Ploeg 2021). There is a recent literature of spatial climate models that study the long run interactions between warming and the economy. Cruz and Rossi-Hansberg (2024) quantify the welfare costs of climate change using a highly spatially disaggregated model with migration. While they consider the welfare impacts of an exogenous global carbon tax, this paper, in contrast, derives optimal carbon taxes—both global and regional. In contrast to their approach, this paper does not microfound the migration decision, which essentially means that it focuses exclusively on FCM.[7] This complementary approach allows me to go further in the study of the interactions between climate change, labor migration and regional climate policies, by providing analytical derivations and quantitative estimates of optimal taxation. Other studies have analysed the interaction of long-run climate change and migration but have not derived optimal or unilateral carbon policies either analytically or quantitatively.[8] Bretschger and Xepapadeas (2021) develop an endogenous growth model with North-South migration and find that developed countries could reduce migration using a supply side climate policy,

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[7] This is relaxed in Online Appendix F.

[8] Benveniste, Oppenheimer, and Fleurbaey 2022 focus on the adaptation dimension of climate migration, showing that warming can reduce the ability of migrants to move out of vulnerable regions. Burzyński et al. (2022) account for internal and international migration in a non-IAM dynamic overlapping generations model, considering a rich set of exogenous scenarios of climate change. Mason (2017)'s working paper derives a non-IAM dynamic model with climate migration to theoretically analyse the abatement incentives of host regions. Shayegh (2017) studies the impact of exogenous carbon concentrations on climate migration and the living conditions of those who cannot migrate, finding that since stayers may change their fertility and education decisions as a consequence of population outflows, their welfare conditions may improve. I complement this literature by providing novel characterizations of—global and unilateral—optimal carbon policies, and their numerical quantifications, for the case of FCM.

namely by decommissioning fossil fuel resources. Conte (2023) uses a static quantitative framework to project the welfare and migration consequences of climate change focusing on sub-Saharan countries with and without migration policies. This paper also relates to the literature on unilateral policies (Elliott and Fullerton 2014, Hémous 2016, among others), which commonly analyse the emissions leakage effect of unilateralism or the international diffusion of knowledge, but abstract from population flows. Finally, this is the first IAM to allow for and quantify the potential migration disutility from the observed policies, such as the "Pay-to-Go" programs.

As a secondary contribution, this paper provides reduced form evidence of the migration response to climate change—see Kaczan and Orgill-Meyer (2020) or Millock and Withagen (2021) for recent reviews. Most studies in this field focus on internal and non-forced migration as a result of slow and progressive changes in climate (Gröger and Zylberberg 2016; Partridge, Feng, and Rembert 2017; Peri and Sasahara 2019; Barrios, Bertinelli, and Strobl 2006). Fewer studies analyse international migration (Coniglio and Pesce 2015; Cai et al. 2016; Missirian and Schlenker 2017; Schutte et al. 2021), typically identifying an intermediary trigger for international migration such as agricultural deterioration (Cattaneo and Peri 2016), wages (Beine and Parsons 2015) or conflict (Burke, Hsiang, and Miguel 2015; Bosetti, Cattaneo, and Peri 2020). While most—not all—of them find evidence that slow-onset climate change causes migration, a consensus on the appropriate empirical methodology to ensure estimates are causal remains elusive. In addition, climate change-related natural disasters are either not accounted for or used as second-order covariates (Beine and Parsons 2015), despite the value of its semi-random nature. The few studies that analyse the migration response to rapid-onset events either focus on internal migration (Bohra-Mishra, Oppenheimer, and Hsiang 2014) or on a small subset of contiguous countries (Naudé 2010), finding a small or even no migration response in these contexts. Like this paper, Gröschl and Steinwachs (2017) also exploit a global panel of migration and natural disasters, but, instead of using annual migration flows, the authors calculate decennial flows using stock data.[9] My paper modestly contributes to this literature by, first, exploiting a global and annual flows panel dataset; second, providing reduced form esti-

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[9] While my theoretical and empirical approach focus on south-north migration, which is considered the most relevant one in the climate change context, Alexeev and Reuveny (2018) also include north-north bilateral flows. Mahajan and Yang (2020) also find a migration response to natural disasters, focusing exclusively on hurricanes and US inflows.

mates of the effect of climate-related natural disaster on displacement from developing to developed countries, that is, focusing on the push factors; and, third, linking the effects to global warming—i.e., carbon concentrations increase.

The rest of the paper is organized as follows. Section 2 presents empirical evidence on forced climate migration. The theoretical model is described in Section 3. Section 4 presents the theoretical results, calibration, and simulation results under a host-origin region setting with climate action in the host region only. Section 5 analyses the global optimum and the Nash equilibrium. Section 6 presents the extensions and Section 7 concludes.

2 Empirical Evidence on Forced Climate Migration

This section describes the empirical approach used to measure FCM, which leverages the unpredictability of natural disasters to isolate global warming from other reasons for migration, such as economic opportunities or socio-political issues. The results inform the calibration of the relationship between forced migration and warming in the quantitative analysis.

2.1 Data

I combine annual country-level natural disasters data from the Emergency Events Database (EM-DAT)[10] with international migration data from the United Nations (UN) migration flows tables. The total number of recorded natural disasters has increased from 363 between 1970 and 1974 to over 1,600 between 2010 and 2014. This increase is primarily driven by hydrological events (floods, landslides, coastal flooding) and meteorological events (storms, heatwaves)—see Figure A.1 in the Online Appendix (OA). The number of people affected by disasters has also increased, especially during the 1980s and 1990s—see Figure A.2 in the OA.[11] Since geophysical events are not related to climate change, they

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[10] EMDAT is provided by the Center for Research on the Epidemiology of Disasters and is considered a fairly comprehensive record of natural disasters, used in several previous studies including Van Reenen and Norris Keiller (2024) and Cavallo et al. (2013). It includes all events since 1900 that caused at least 10 deaths, affected at least 100 people, or triggered a declaration of a state of emergency or a call for international assistance.

[11] The increase is not mechanically driven by population growth because, after normalizing the number of people affected by the country population in 1970, the variable evolves very similarly for all disasters.

are excluded from the analysis.

To assess the potential threat of reporting bias behind these trends attributed to under-recording of disasters in the early years of the period of interest, I conduct two different checks. First, I exploit the non climate change-related nature of geophysical events. One may reasonably assume that if reporting bias is present it would be orthogonal to the type of disaster. In that case, by calculating the ratio between the frequency of warming-related types and geophysical disasters, any potential reporting bias can be canceled out. Figure A.3 in the OA illustrates these ratios, which maintain the upward trend for hydrological and meteorological ratios. Second, I follow Thomas and Lopez (2015) by excluding events with fewer than 100 deaths or affecting less than 1,000 people, which are more prone to bias, and find consistent patterns—Figure A.4 in the OA.

The migration dataset reports the flow of international migrants as documented by 43 destination countries—including most OECD countries—and identifies their countries of origin. I classify countries into host (destination) or origin countries based on the Annex I parties of the Kyoto Protocol. The host group comprises most European countries, the United States, Canada, Australia, and New Zealand.[12] The number of disasters has increased in both groups since the 1970, but the increase in origin countries is substantially higher—see Figure A.5 in the OA, left panel. Additionally, most affected people live in origin countries—see Figure A.5 in the OA, right panel. In order to exploit the variation in the number of disasters in origin countries, host countries are combined into one destination region, while the rest of the world remains unpooled.

2.2 Empirical specification and regression results

To identify the impact of natural disasters on migration flows from origin to host countries, I use the following model specification:

$$I_{it} = \beta_0 + \beta_1 ND_{it} + \beta_2 X_{it} + \alpha_i + \delta_t + u_{it}, \tag{1}$$

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[12] The host group comprises: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, the Russian Federation, San Marino, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom, and the United States. France, Andorra (not included in Annex I), Malta, Monaco, and Japan are excluded due to insufficient data. Although the United States signed Annex I, it has not ratified it, and Canada withdrew from it in 2012. Turkey joined the Protocol later but is included in the origin group.

where I_{it} represents the unilateral migration flow from origin country i to the group of host countries at time t. The dependent variable has a small share of zero values because destination countries are pooled. ND_{it} denotes the frequency of natural disasters in origin country i at time t. X_{it} includes controls such as population, conflict or GDP per capita. α and δ capture country and year fixed effects, respectively. This specification exploits the random nature of natural disasters and includes fixed effects to estimate the relationship of interested, captured by β_1.[13]

Table 1 reveals that there is a strong positive relationship between disasters in origin countries and migration to host countries. With the exception of column (1), I apply the natural logarithm transformation to the dependent variable. Columns (1) and (2) use the independent variable in levels, while columns (3)–(7) use the logarithmic form. To account for zeros in the independent variable, columns (3) and (4) add a constant of one to each value—$log(1 + \#dep.\ var)$, and columns (5) and (6) replace all zeros with one and introduce a dummy variable that takes the value of one when the initial value of the independent variable exceeds zero. Columns (4) and (6) control for the first lag of GDP per capita and population,[14] ensuring that the results are not mechanically driven by population growth in origin countries.[15] Column (7) replicates column (4) for the number of people affected by disasters.[16] Results indicate that a unit increase in the occurrence of natural disasters is associated to a 2.3% rise in population flows to host regions (column 2).[17] The positive and highly significant estimate of the dummy coefficient in columns (5) and (6) highlight the relevance of the extensive margin. Additionally, column (7) shows that out-migration also increases when more people are affected by disasters, which further bolsters the plausibility

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[13] Although disasters may lead to migration in the years that follow, my focus is on the immediate migration response to natural disasters. This approach ensures that the relationship I capture is primarily driven by the disaster itself, rather than by the interaction of the disaster with other economic factors such as agricultural decline or income reductions. Therefore, these relationships should be interpreted as lower bounds.

[14] Contemporaneous GDP and population could be endogenous due to the impact of natural disasters. Hence, the first lag is used.

[15] Merely controlling for time-invariant origin country fixed effects would overlook the influence of demographic pressures on migration.

[16] In the EMDAT database, variables like the number of affected people and monetary damages and are self-reported. Hence, the estimates might be affected by reporting bias if, for instance, poorer countries reported higher damages to obtain international aid. For that reason, the estimates of these variables are not used for calibrating the model.

[17] Given that the observational unit is at the year level, disasters occurring towards the end of the year could potentially impact next year's migration. However, assigning natural disasters from November and December to the next period does not significantly alter the results presented in Table 1.

of migration as a response to climate shocks.

Table 1: Migration response to natural disasters

Dep. var:	*# migrants*	*log(# migrants)*					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Nat. Disasters	1984.7**	0.023*					
	(783.01)	(0.01)					
Dummy (>0 Nat. Dis)					0.175***	0.143***	
					(0.05)	(0.05)	
log(Nat. Disasters)			0.163***	0.125**	0.041	0.025	
			(0.05)	(0.05)	(0.05)	(0.05)	
log(People Affected)							0.012***
							(0.00)
FE (C, T)	Y	Y	Y	Y	Y	Y	Y
Controls	N	N	N	Y	N	Y	Y
Observations	5219	4977	4977	3905	4977	3905	3905
Adj. R^2	0.557	0.863	0.863	0.877	0.863	0.877	0.877
Dep. var. mean	10989	7.364	7.364	7.704	7.364	7.704	7,704
Countries	165	165	165	156	165	156	156

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors, in parentheses, are clustered at the country level. Main sources: UN migration flows tables and EM-DAT. Sample period: 1980–2013. Independent variables: number of natural disasters (columns (1)–(6)); number of affected people (column (6)). Columns (3), (4) and (7) use a log(x+1) transformation of the independent variable. Columns (5) and (6) use a log transformation of the independent variable after replacing zero values with one and include a dummy that equals one when disasters are strictly positive. Column (4)–(6) control for the first lag of population and GDP per capita. The sample size with controls is smaller due to missing population and GDP data for some countries.

Section B in the OA examines robustness using zero-inflated negative binomial models, bilateral flows with origin-destination fixed effects, and various other specifications and checks such as excluding low-severity disasters, including additional controls like conflict or analysing whether results are driven by certain countries.

3 A Climate-economy Model with Forced Climate Migration

The analysis of optimal carbon policies requires a general equilibrium structure to account for the interrelationships between pollution, FCM and the economy. I build a neoclassical growth model with a climate module a la GHKO, multiple countries, and FCM—see Figure C1 in the OA for a graphical summary. Each country produces a final good combining capital, labor, and energy. An intermediate sector uses labor to produce energy, which releases emissions and contributes to global warming. Changes in temperature adversely affect the economy, damaging final production. Moreover, warming heightens the frequency and severity of natural disasters. Consistent with the empirical findings, this forces individuals to migrate to less affected areas, modifying regions' labor force. Social welfare depends on individuals' consumption and immigrants, which affect welfare in two ways: i. migrants must bear migration costs; and ii. host regions' domestic (native) population may bear a social cost of immigration.[18] Regions operate in semi-autarky, as final goods and capital are immobile. Throughout, the terms 'forced climate migrant' and 'migrant' are used interchangeably. Time is discrete and extends infinitely.

3.1 Preferences, production, and capital accumulation

The world comprises $R > 1$ regions indexed by $r \in \{1, ..., R\}$.[19] Regions share similar fundamental mechanisms but vary parametrically in size, technological level, and climate change vulnerability. They are grouped into host and origin regions, $r \in \{H, O\}$. Host regions are inhabited by natives and migrants. Origin regions are inhabited by natives. The instantaneous utility of individuals living in region r, v_{rt}, is:

$$v_{rt} = \begin{cases} c_{rt} - \gamma_r h_r I_t & if\, r \in H\, and\, individual\, is\, native \\ (1-\eta_{rt})c_{rt} & if\, r \in H\, and\, individual\, is\, an\, immigrant \\ c_{rt} & if\, r \in O \end{cases},$$

where c_{rt} is per capita consumption in region r at time t and $h_r I_t$ denotes the amount of migrants entering the host region in period t. γ represents the marginal social cost of immigration and η is a (destination) country-specific migration cost that immigrants must bear forever. I assume that only recently arrived immigrants have a direct impact on natives' utility. This aligns with empirical studies finding that hostility towards immigrants decresases with contact over time (Kaufmann 2014). Consistent with this study, one period

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[18] Despite ethically questionable, this aligns with recent electoral outcomes in Europe and the United States. Still, the baseline quantitative exercise disables this feature, assuming no social cost of immigration.

[19] The terms "region" and "country" are used interchangeably and can also refer to a group of countries.

corresponds to ten natural years.

Each region produces a final good with a Cobb-Douglas technology:

$$\overline{Y}_{rt} = A_{rt} K_{rt}^{\alpha} \left(L_{rt}^{Y}\right)^{\upsilon} E_{rt}^{1-\alpha-\upsilon}, \tag{2}$$

where $\alpha, \upsilon \in (0,1)$ and K_{rt}, L_{rt}^{Y}, E_{rt}, and A_{rt} denote capital, final output labor, energy, and total factor productivity, respectively. $\overline{Y}$ corresponds to final output before climate damages. Total factor productivity, A_{rt}, is exogenous and can vary over time. In each region, consumption must satisfy the feasibility constraint in the final good sector:

$$C_{rt} + K_{rt+1} = Y_{rt}, \tag{3}$$

where capital letters represent total values, that is, $C_{rt} \equiv c_{rt} P_{rt}$, with P_{rt} denoting regional population. K_{rt} and Y_{rt} stand for capital and final output net of climate damage, respectively. Expression (3) assumes full capital depreciation. This abstraction would be significant under shorter time periods because full depreciation requires high investment efforts, which reduce output and mechanically lead to a lower carbon price. However, I use long time periods—10 years, which substantially offsets this effect.

An intermediate sector produces a carbon-based energy input using labor, L_{rt}^{e}, subject to a specific energy production technology, G, and productivity level, A_{rt}^{e}:[20]

$$E_{rt} = G(A_{rt}^{e}, L_{rt}^{e}). \tag{4}$$

where E_{rt} is measured in terms of its carbon content; hence, energy and emissions are equivalent. In this model, E_{rt} should be interpreted as coal, which is considered the main driver of climate change (GHKT). Formally, (4) assumes there is no limit for the total cumulative use of energy. This assumption is motivated by recent estimates of coal reserves provided by the US Energy Information Administration (EIA), which are projected to last over 3.5 centuries. It is also consistent with Casey (2024), who finds a discrepancy between empirical evidence and a model that attributes increasing energy prices to scarcity rents. The author suggests that aggregate data align more closely with increasing extraction costs.

Labor is mobile across sectors and regions satisfy the labor-clearing condition:

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[20] To reduce emissions one must allocate fewer workers to energy production. In the quantitative analysis, I assume energy is produced under constant returns to labor: $E_{rt} = A_{rt}^{e} L_{rt}^{e}$.

$$L_{rt} = L^{Y}_{rt} + L^{e}_{rt}, \tag{5}$$

i.e., regional labor is either used to produce the final output or the energy input.

3.2 Migration flows and the size of the labor force

Global population, P, is constant and regional population, P_{rt}, evolves following FCM flows. Host regions cannot restrict the inflow of migrants, but this assumption is relaxed in extension 6.1. The total migrant inflow at time t, I_t, is a function of carbon concentrations' increase, Δz_{t-1}, [21] i.e., $I_t \equiv i(\Delta z_{t-1})$,where i is increasing in Δz_{t-1}. When $\Delta z_{t-1} \leq 0$, there are no migrants in period t. Note that the concentrations' increase is orthogonal to the emitting country, reflecting the global spread of local emissions. Online Appendix F extends the model to accommodate micro-founded climate migration, while diminishing theoretical tractability.

Each origin region contributes to the total migration flow based on an exogenous share o_r that depends on the region's climate vulnerability. Each host country receives a share h_r of total migrants. Hence, the law of motion of P_{rt} is:

$$P_{rt} = \begin{cases} P_{rt-1} + h_r I_t & if\, r \in H \\ P_{rt-1} - o_r I_t & if\, r \in O \end{cases}, \tag{6}$$

where $\sum\limits_{r \in H} h_r = 1$ and $\sum\limits_{r \in O} o_r = 1$. In each period, a new generation of individuals is born in the region their immediate ancestors resided. Individuals supply one unit of labor inelastically, with no labor disutility. Following the consensus in the migration literature, I assume that newly arrived immigrants have lower labor productivity. Thus, the effective labor force, L_{rt}, in a host region is:

$$L_{rt} = P_{rt-1} + \kappa h_r I_t \; if \; r \in H \tag{7}$$

where $\kappa \leq 1$ is a parameter that determines the native–immigrant wage differential. After one period, immigrants are naturalized and have the same productivity level as natives. In

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[21] I model FCM as a function of the concentration flow instead of the concentration stock to reflect the permanent nature of migration. In an extension, I assume an alternative specification of FCM based on the stock of carbon concentrations—see Online Appendix E.

origin regions, labor and population are equivalent: $L_{rt} = P_{rt} \ if \ r \in O$.

3.3 Climate module and climate damages

The climate system and climate damages are mostly characterized following GHKO, which provides an accurate representation of climate dynamics (Dietz et al. 2021). Intuitively, global carbon emissions, E_t, increase the amount of atmospheric carbon concentrations, which rise global temperature and, as a result, a fraction Ω_{rt} of output is destroyed.

Let z_t denote a function of historical global emissions (since pre-industrial times):

$$z_t = f(E_1, E_2, ..., E_t), \tag{8}$$

where E_t represent time t global emissions. z_t summarizes the level of carbon concentrations in the atmosphere and is characterized by the sum of permanent and non-permanent concentrations—z_{1t} and z_{2t}, respectively. Permanent concentrations are given by $z_{1t} = z_{1t-1} + \phi_L E_t$, that is, a share $\phi_L \in (0,1)$ of time t emissions remains in the atmosphere forever. Non-permanent concentrations will eventually decay following the law of motion: $z_{2t} = (1-\phi)z_{2t-1} + (1-\phi_L)\phi_0 E_t$. This implies that a share $(1-\phi_0)$ of time t emissions disappear within a decade while a fraction $(1-\phi_L)$ of the remaining emissions disappear later on. Accumulated emissions decay at a constant rate ϕ.

Carbon concentrations determine the extent of climate damages to output through a damage function denoted by $1 - \Omega_r(z_t)$. Following GHKT, it takes the exponential form:

$$\Omega_r(z_t) = exp\left(-\theta_r\left(z_t - \bar{z}\right)\right), \tag{9}$$

where θ scales the damage function and $\bar{z}$ denotes the pre-industrial level of carbon concentrations. Unlike GHKT, the damage function is country-specific. Final output net of climate damages, Y, is given by:

$$Y_{rt} = \Omega_{rt}(z_t)\overline{Y}_{r,t}, \tag{10}$$

where $1 - \Omega_r(z_t)$ represents the share of output lost due to climate change.

4 Unilateral Climate Action in Host Region

I first examine optimal carbon pricing in a non-cooperative setting where only host regions take unilateral climate action. For simplicity, I consider one host and one origin region.

4.1 Theoretical analysis

4.1.1 The origin region's decentralized economy

The origin region is environmentally inactive and regional emissions in the laissez-faire are proportional to population:

$$E_{ot} = \xi_t P_{ot}, \tag{11}$$

where $\xi_t \equiv \frac{1-\alpha-\upsilon}{1-\alpha} A^e_{ot}$ captures the carbon intensity of population. See Appendix A.1 for a detailed derivation of the decentralized use of energy in (11).

4.1.2 The host region's planned economy and the host planner problem

The host region is governed by a utilitarian planner maximizing natives sum of discounted well-being over time. The planner aggregates welfare following the assumptions:

Assumption 1: *The planner aggregates natives' welfare under a concave utility function, u_h, that takes the logarithmic form.*

Assumption 2: *The social planner cannot individually distinguish (treat differently) natives and migrants, but is aware of the amount of immigrants at each point in time.*

Assumption 1 is common in the literature—see, for instance, GHKO where it allows the derivation of closed-form solutions. Assumption 2 is a sensible approach in a long-term analysis and adds tractability to the model.[22] Given the initial level of K_h, L_h, and z, the planner decides consumption, savings, and energy use to maximize the discounted lifetime utility of the native population, W_{ht}:

$$\max_{K_{ht+1}, E_{ht}} W_{ht} = \sum_{t=0}^{\infty} \beta^t u_{ht}\left(P_{h0} v\left(c_{ht}, I_{ht}\right)\right),$$

subject to Assumptions 1 and 2 and equations (2)–(11). $\beta \in (0,1)$ is the discount factor.

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[22] Essentially, immigrants cannot be distinguished by labor or capital endowments, resulting in an equal consumption distribution among the regional population. While this assumption would be strong for comparing welfare across citizens and countries, it is sensible for measuring the long-term social cost of carbon.

4.1.3 The unilateral carbon price in the host region

The social cost of carbon (SCC) represents the present value of marginal damages caused by carbon emissions and, following Pigou, it should determine the price on carbon. I use the term ‘unilateral SCC’ to emphasize that the local planner accounts for the warming externalities that affect host natives’ welfare. Given the planner’s problem described above, one can analytically characterize the unilateral optimal carbon price as follows.

Let λ_t denote the Lagrange multiplier on the final production function (2). Additionally, let ω_t be the multiplier on the carbon concentrations equation (8) and μ_t^h and μ_t^o the multipliers associated with the evolution of population—equation (6)—in the host and origin region, respectively. To simplify the expressions, I assume $\kappa = 1$, hence, $L_{ht} = P_{ht}$. It can be shown that, in a setting where the origin region is environmentally inactive, the unilateral planner in the host region will increase pollution until the net marginal product of energy, $NMPE_{ht}$,[23] equals the unilateral SCC. That is, $NMPE_{ht} = SCC_t^{Uh}$, where:

$$SCC_t^{Uh} \equiv \frac{1}{\lambda_t}\Bigg(\overbrace{\sum_{j=0}^{\infty} -\omega_{t+j}\frac{\partial f_{t+j}(.)}{\partial E_{ht}}}^{Standard\,Output\,Damages} - \overbrace{\mu_{t+1}^{o}(-1)\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Emissions\,Reallocation} + \overbrace{\beta u'_{t+1}P_{h0}\gamma\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Social\,Cost\,of\,Immigration} + \overbrace{\mu_{t+1}^{h}(-1)\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Labor\,Effect} \Bigg), \tag{12}$$

which leads to the following proposition:

Proposition 1: *The unilaterally optimal use of energy in the host region can be achieved by implementing a carbon price equal to* $\tau_{ht}^{Uh} = SCC_t^{Uh}$*, with the* SCC_t^{Uh} *evaluated at the optimal allocation.*

See Appendix A.2 for a detailed derivation of (12) and Proposition 1.[24] According to (12), the unilateral SCC consists of the sum of four components.[25] While the first one is standard

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[23] More specifically, $NMPE_{ht} \equiv \frac{\partial Y_{ht}}{\partial E_{ht}} + \frac{\partial Y_{ht}}{\partial L_{ht}^{Y}}\frac{\partial L_{ht}^{Y}}{\partial E_{ht}} = (1-\alpha-\upsilon)\frac{Y_{ht}}{E_{ht}} - \upsilon\frac{Y_{ht}}{L_{ht}-L_{ht}^{d}}\frac{1}{A_{ht}^{e}}$. Note that $NMPE_{ht}$ embeds a private benefit and a private cost of using emissions. The private benefit (first element of $NMPE_{ht}$) corresponds to the marginal increase in production. The private cost (second element of $NMPE_{ht}$) accounts for the marginal reduction in labor left to produce final output.

[24] Intuitively, under the carbon price in Proposition 1, energy use is such that private and public marginal consequences of polluting are equalized. Equation (12) summarizes the public consequences (SCC), while the private ones are captured by the $NMPE_{ht}$.

[25] Each component is multiplied by $\frac{1}{\lambda_t}$, where λ_t is the shadow value of one unit of final good production.

in most IAMs, the other ones are novel and arise from considering FCM. The first component, denoted *Standard Output Damages*, corresponds to the present discounted value of climate damages to final output, measured in utils. In the optimum, the shadow value of carbon concentrations, ω_t, equals the marginal impact of concentrations on final production and is given by $\omega_t = \beta^t u_t' \frac{P_{h0}}{L_{ht}} \frac{\partial Y_{ht}}{\partial z_t}$. The term $\frac{\partial f_{t+j}(.)}{\partial E_{ht}}$ captures the impact of emissions on carbon concentrations. Note that despite being a standard component, its magnitude may differ to IAMs without FCM because it is evaluated at a different optimum.

The second component, denoted *Emissions Reallocation*, accounts for the decline in origin emissions due to migrants moving to host regions. This benefits the host population because it lowers climate damages, hence it reduces the price of carbon. In the optimum, the shadow value of the origin population, μ_t^o, equals the impact that origin emissions have on host natives' lifetime welfare. It is given by $\mu_t^o = \sum_{j=0}^{\infty} (j+1)\beta^{t+j} u_{t+j}' \frac{P_{h0}}{L_{ht+j}} \frac{\partial Y_{ht+j}}{\partial z_t} \frac{\partial f(.)}{\partial P_{ot}} \xi_{t+j}$. Intuitively, the effect of the origin population on host natives' welfare is decomposed into: i. the influence of the origin population on carbon concentrations z_t, denoted by $\frac{\partial f(.)}{\partial P_{ot}}$; and ii. the impact of carbon concentrations on climate damages to final output, denoted by $\frac{\partial Y_{ht+j}}{\partial z_t}$. The term $\frac{\partial i(\Delta z_t)}{\partial E_t}$ reflects the amount of migrants caused by a marginal increase in energy use.

The third component, denoted *Immigration Social Cost*, represents the direct disutility experienced by natives due to immigration.[26] When $\gamma > 0$, societies present opposition to immigration and the unilateral SCC increases.

Finally, the *Labor Effect* captures the future discounted sum of both a welfare cost and a welfare benefit associated with climate FCM. μ_t^h is the shadow value of the host population, and quantifies the contribution of host residents to present and future natives' welfare. In the optimum, $\mu_t^h = \sum_{j=0}^{\infty} \left(\beta^{t+j} u_{t+j}' \frac{P_{h0}}{L_{ht+j}} \left[\frac{\partial Y_{ht+j}}{\partial L_{ht+j}} - \frac{Y_{ht+j} - K_{ht+1+j}}{L_{ht+j}} \right] \right)$. Therefore, the sign and magnitude of μ_t^h depends on two opposing effects. On the one hand, FCM leads to a higher output in the host region because they increase labor. This positive externality is captured by the first element inside the square brackets—note that μ_t^h is multiplied by -1 in equation (12), and reduces the carbon price. On the other hand, FCM reduces per capita consumption in host. This negative externality is captured by the second element in the

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Hence, they are expressed in terms of the final good. In the optimum, λ_t equals the marginal utility of natives' consumption, $\lambda_t = \beta^t u_t' \frac{P_{h0}}{L_{ht}}$. λ_t is multiplied by $\frac{P_{h0}}{L_{ht}}$ to adjust for the native population.

[26] It is multiplied by the discount factor because emissions today cause migrants one period ahead.

square brackets, increases the carbon price, and is attributed to two reasons. First, migrants lower per capita final output net of climate damages because environmental resources are finite, that is, there is climate degradation. Note that this would be omitted in a migration model that did not account for climate damages. Second, capital is diluted because migrants move without capital.

Although the net impact of the *Labor Effect* on the unilateral carbon price is initially ambiguous, the next theoretical result sheds light on it.

Result 1: *Under a Cobb-Douglas production function and multiplicative climate damages, the "Labor Effect" is a negative externality that increases the unilateral SCC.*
Proof: see Appendix A.3. Intuitively, Result 1 is a consequence of the decreasing marginal returns to labor of the production function, which arises from incorporating climate damages and capital into the model. A larger population dilutes production net of climate damages and capital; thus increasing the cost of carbon. Online Appendix E considers the case where the decreasing marginal returns to labor are weaker than the benchmark.

To simplify notation, I have presented the price of carbon for the case where $\kappa = 1$, but showing the effect of a lower κ on the carbon tax is straightforward. Note that under $\kappa < 1$, newly arrived immigrants are less productive than natives and longstanding immigrants. Thus, the labor supply is lower under $\kappa < 1$, which affects the price of carbon as stated in the following remark:

Remark 1: *The social cost of carbon is decreasing in κ.*

Proof: For $\kappa < 1$ the positive externality element of the *Labor Effect*—that is, the first element of μ_t^h inside the square brackets—is multiplied by κ in period $j = 1$. Hence, the lower the κ, the lower the benefit of having additional labor. ■

Taking stock, expression (12) shows that failing to account for FCM significantly affects the analytical characterization of the SCC. The novel unilateral SCC acknowledges that population reallocation affects the labor force, reallocates emissions, and affects welfare in host regions. Additionally, this new framework can capture host natives' opposition to migration, if any.

4.2 Quantification of impacts and calibration of the model

This section presents an original empirical analysis of the impact of warming on displacement, quantifies the social cost of immigrants, and discusses the parameter selection.

4.2.1 Displacement response to climate change-induced disasters

I employ an elasticity decomposition methodology to calibrate the relationship between climate change and disasters' displacement. The percentage change of migration due to changes in carbon concentrations is decomposed into two elasticities: $\frac{\partial ln(Migrants_t)}{\partial ln(CarbonConc_t)} = \frac{\partial ln(Migrants_t)}{\partial ln(\#Disasters_t)} \frac{\partial ln(\#Disasters_t)}{\partial ln(CarbonConc_t)}$. The first one captures the change in migration due to a change in disasters' frequency. Its estimation is based on the methodology and data from the empirical analysis, after pooling countries into two regions—host and origin. The resulting estimate takes a value of 0.88. The second elasticity quantifies the change in disasters's frequency attributable to changes in carbon concentrations. It is quantified using a time-series cointegration analysis, based on Thomas and López (2015).[27] While the authors examine each disaster type individually, I adopt two distinct approaches. First, I consider climatological and hydrological events jointly, as they present a stronger relationship with migration (see Table B.5 in the Online Appendix). Second, I incorporate meteorological events. I find that the elasticity between atmospheric concentrations and the frequency of natural disasters is 13.49, and 6.74 when meteorological events are included.[28] That is, a 1% increase in carbon concentrations leads to a 13.49% increase in disasters. Hence, the overall elasticity of interest is: $\frac{\partial ln(ClimateRefugees_t)}{\partial ln(CO_2Conc_t)} = 0.88 \times 13.49 = 11.87$, or 5.93 with meteorological events.[29]

In the benchmark analysis, I assume migration is a linear function of the change in carbon concentrations: $I_t = B(z_{t-1} - z_{t-2})$, where B captures the migration response to a marginal change in concentrations. B is calibrated using the historic average increase in concentrations per decade, the elasticity of migration to concentrations, and the average decade migration flow normalized by the host population.[30] This leads to a value of $B =$

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[27] The authors explore whether there is a "significant relationship between climate change and the global increase in the frequency of intense natural disasters", admitting that the causal relationship between "climate change and natural disasters is not fully understood."

[28] Although I include five more years of data, my results remain largely consistent with those of Thomas and López (2015) when analysing disaster types individually.

[29] These estimates are within the ranges that can be derived from the estimates by Fischer, Sippel, and Knutti (2021) for extreme heat in Central North America.

[30] More specifically, in the last four decades carbon concentrations have increased by 4Gt of carbon (approximately 2 ppm) yearly on average, which represents a 0.5% increase in total concentrations (400 ppm). This corresponds to an annual 5.9% increase in immigrants (2.9% including meteorological events). Given that the yearly average number of immigrants entering OECD countries in the last years was 4,175,000 (OECD (2015)) , this implies 250,500 immigrants per year (125.250 including meteorological events) due to climate-related disasters. This magnitude is non-negligible especially if we compare it to political asylum

5.0334×10^{-5} (2.52×10^{-5} with meteorological disasters). See Online Appendix E for an alternative migration function based on concentrations' stock.

4.2.2 Social cost of immigration

The theoretical model is able to account for host natives' anti-immigration sentiment through the parameter γ. It represents natives' willingness to pay to prevent immigration. In economic terms, it corresponds to the consumption-equivalent loss of a marginal increase in immigration—see Online Appendix D for more details. While the literature has made several attempts to measure the impact of immigration on local population wages,[31] to the best of my knowledge there is no study that specifically targets the measurement of γ. Consequently, I calibrate it using different approaches:

A: "Pay-to-Go" programs. These programs involve immigration control policies that incentivize immigrants to return to their country of origin, typically by offering paid travel and financial assistance to cover resettlement expenses.[32] Oftentimes, they may have to commit to not returning to the host country for a specified time period. Using data on the European Pay-to-Go programs in 2015 (European Migration Network 2015), I derive a value for the parameter γ of 7.1×10^3.[33]

B: EU-Turkey Agreement. In 2015 the European Union (EU) experienced an inflow of nearly one million political refugees, primarily from Syria, who entered the EU through the Turkish border. In March 2016 the EU authorities approved a deal with Turkey to manage the influx of individuals into the EU (European Commission 2016), despite being strongly criticized by human-rights groups. Using data on migration flows from this refugee crisis, the associated costs of this policy, and EU consumption data, I derive a value for the parameter γ of 7.3×10^3.

These estimates are not intended to represent the fundamental social cost of migration

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applications. For instance, from 2008 to 2013, the European Union received on average 200.000 new refugee applications per year according to Eurostat. Finally, this corresponds to 2.0134×10^{-4} (1.01×10^{-4}) billions of migrants, per 4 Gt of carbon.

[31] For instance, Aydede (2014) and Card and DiNardo (2000) quantify the effect of immigration on natives' dislocation, finding contradicting results.

[32] Nearly all European countries have implemented similar programs. Germany first implemented a Pay-to-Go program in 1974 and Belgium in 1984. Canada has also implemented a mild version.

[33] This value represents the amount, evaluated in terms of the final good, that a EU native is willing to pay to reduce the inflow of migrants by one billion.

for host citizens. Instead, they provide suggestive evidence on the matter. Given the similarity between the two measures, I present the simulation results based on the Pay-to-Go calibration.

4.2.3 Technology, energy and other parameters

Each period represents a span of 10 years, with $t_0 = 2015$. The host region is calibrated to match Kyoto Annex I countries, while the origin matches the rest of the world. Table 2 summarizes the calibration of the main parameters. I follow the literature on the discount factor and set $\beta = 0.985$ (1.5% per year). In an extension, I acknowledge the Nordhaus-Stern discussion (Stern 2007) and use a lower time discount. The technology parameters (α and β) are taken from GHKO.

The GDP for the initial year is obtained from the Penn World Tables (Feenstra, Inklaar, and Timmer 2015). The initial capital stock is calibrated to achieve a net rate of return on capital of 5% as in Nordhaus' DICE model and GHKO. To obtain the capital stock for Kyoto countries, I use the GDP relationship between OECD and Kyoto countries, according to which Kyoto countries represent 95% of the OECD GDP. Initial emissions, E_0^{Host} and E_0^{Origin}, are obtained from OECD data on carbon dioxide emissions embodied in final domestic demand[34] and they are apportioned to Kyoto–non Kyoto countries using the same method as capital imputation. I calibrate the initial share of labor allocated to final output assuming that the economies are initially in laissez-faire. Initial period total factor productivities, A_{r0}, are calibrated based on the definition of the standard neoclassical growth model, $TFP = \frac{Y}{\Omega K^{\alpha}(L^{Y})^{\nu}E^{1-\upsilon-\alpha}}$. Their growth rate is taken from GHKO. Energy productivities are calibrated analogously, using the share of labor allocated to energy production and assuming a linear energy production function. The initial population for the host country is normalized to 1, and the origin population is calculated to reflect the current share relative to host regions.

Finally, the parameters and functional forms for the damage function and climate model adopt the specifications and calibration from GHKT. However, in my analysis the scale parameter is region-specific, θ^r, and I calibrate it using the estimates from Hassler et al. (2019) (HKOR). I use the GDP-weighted averages of the United States and Europe for host

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[34] OECD statistics report global CO_2 emissions of 32 Gt of CO_2-equivalent in 2015 (this corresponds to 8.7 Gt of carbon), 13 Gt of which is imputed to OECD countries.

Table 2: Calibrated Parameters

Parameter	Value	Source
***I.** Preferences and technology*		
β	0.985	Literature
α	0.3	GHKT
1-$\alpha - \upsilon$	0.04	GHKT
***II.** Initial values*		
Y_0^{Host}	52,380 Billion USD per year	Feenstra, Inklaar, and Timmer (2015)
Y_0^{Origin}	60,365 Billion USD per year	Feenstra, Inklaar, and Timmer (2015)
E_0^{Host}	3.325 GtC per year (2015)	OECD (2015) & calibrated
E_0^{Origin}	5.275 GtC per year (2015)	OECD (2015) & calibrated
K_0^{Host}	96,470 Billion USD	Calibrated
K_0^{Origin}	111,180 Billion USD	Calibrated
$\frac{L_{r0}-L_{r0}^d}{L_{r0}}$	$1-\frac{1-\alpha-\nu}{1-\alpha}=0.94$	Calibrated
$A_0^{Host}(g_{A_0^H})$	15,211 (1.3% per year)	Calibrated (GHKT)
$A_0^{Origin}(g_{A_0^O})$	5,719 (1.3% per year)	Calibrated (GHKT)
$A_0^{eHost}(g_{A_0^{eH}})$	581	Calibrated
$A_0^{eOrigin}(g_{A_0^{eO}})$	183	Calibrated
θ^{Host}	2.4×10^{-5}	HKOR
θ^{Origin}	5×10^{-5}	HKOR
L_0^{Host}	1	Normalized
L_0^{Origin}	5.02	Calibrated to match L_0^{Host}
***III.** Other parameters*		
κ	0.8	Calibrated, based on Card (2014)

countries, and the GDP-weighted averages of India, Africa, and China for origin countries.

4.3 Quantitative results

To approximate the planner's infinite-horizon problem, I simulate the economy for 300 years. I solve the problem using direct optimization. The choice variables are the savings rate and the energy labor share. The model extensions require additional choice variables, like the stringency of a border control policy. The quantitative results are presented across four scenarios:

1. "Without FCM" scenario. To establish a connection with existing studies, I first ignore FCM.

2. "Without disutility" scenario. Considers FCM but assumes there is no social cost of immigration.

3. "Pay to Go" scenario. Assumes a social cost of immigration based on the Pay to Go programs.

I also present the results under two different calibrations of the migration response to disasters, first including climatological and hydrological events (C&H disasters) and then adding meteorological events (C&H&M disasters).

Table 3 presents the near-term unilateral carbon prices—equivalently, unilateral SCC—for the host country under each scenario. The optimal price of carbon without FCM is almost 45 USD per ton of carbon (column 1), which closely aligns with existing estimates for the United States. This adds confidence that the benchmark model is of a comparable order of magnitude to existing studies. With FCM (column 2), the unilateral SCC increases by approximately 22% (11% if meteorological events are included). As expected, the social cost of immigration further raises the price of carbon (column 3), although only slightly.[35] Therefore, when a society opposes immigration and the government internalizes this sentiment even if it's ethically questionable, the stringency of the unilateral climate policy increases.

Table 3: Unilateral carbon price in the host region, SCC^{Uh}

	Without FCM	With FCM	
		Without Disutility	With Disutility
			Pay to Go
$ per ton of carbon	(1)	(2)	(3)
C&H disasters	44.72	54.73	54.99
C&H&M disasters		49.77	49.89

Notes: This table presents short-term unilateral host SCC under each scenario. "C&H disasters" calibrates the migration response to disasters including only climatological and hydrological disasters; "C&H&M disasters" includes also meteorological disasters.

Figure 1 depicts the evolution of carbon prices over the next 100 years for the "C&H

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[35] Under the alternative EU-Turkey agreement calibration, the carbon price is very similar. However, with other calibrations of γ, it would rise significantly. For example, data from a survey conducted in the UK during the Brexit period, where citizens were explicitly asked about their willingness to pay to reduce EU immigration, assigns a substantially higher value to γ, resulting in a four-fold increase in the unilateral SCC. Due to the unique circumstances of that period, this measure may not be representative.

disasters" case. The figure shows that long-term prices remain higher with FCM, and increase over time due to exogenous total factor productivity growth. Figure E.1 in the Online Appendix displays the decomposition of the carbon price into its individual components—*Standard Output Damages*, *Emissions Reallocation* and *Labor Effect*—for the scenario "without disutility" ($\gamma = 0$). As migrants are forced to move to host regions, emissions in the origin region are mechanically reduced. This generates a positive externality for the host that lowers the unilateral SCC. Hence, the "*Emissions Reallocation*" component appears negative in the graph. The *Standard Output Damages* component is lower compared to the scenario without migration because, although population in the host region is larger, per capita emissions at the optimum are lower, leading to lower total emissions.[36] Therefore, the impact of FCM on emissions reallocation and output damages is advantageous for host regions because the host planner benefits from having a larger population under its control. However, despite the advantage of controlling a larger population, the net cost associated with the *Labor Effect* dominates and accounts for almost the totality of the increase in the carbon tax compared to the no migration scenario. This holds true throughout the simulation period. More specifically, even though the *Labor Effect* includes the benefit of higher labor, this is offset by the reduction in per capita income that results from a lower energy use and capital dilution. Online Appendix E provides results under weaker decreasing marginal returns to labor.

5 Optimal Policy Under a Global Agreement (First-best) and Unilateral Policies (Nash Equilibrium)

This section solves the model under the first-best scenario and the Nash equilibrium, and provides analytical characterizations and quantitative measures of the SCCs.

5.1 Global climate policy: first-best

The first-best scenario assumes full cooperation across countries and a benevolent global planner who maximizes global welfare, accounting for the local and global impacts of

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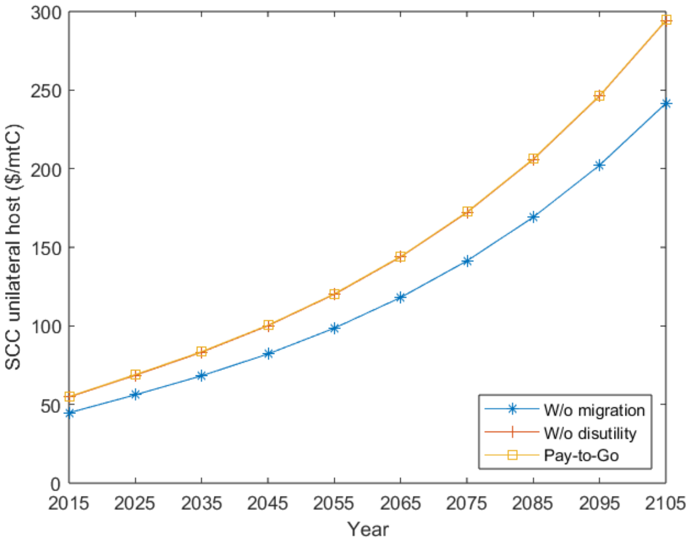
[36] Figure E.2 in the Online Appendix shows that host per capita emissions are persistently lower with migration compared to the no migration scenario, consistent with higher carbon prices.

Figure 1: Evolution of the unilateral carbon price in host region



polluting. The main functional forms and capital depreciation mimic the unilateral host setting discussed earlier.[37] The planner's problem is given by:

$$\max_{K_{rt+1},E_{rt}} W_t^{GSP} = \sum_{t=0}^{\infty} \beta^t \left[u \left(\sum_{r \in H} (P_{r0} + (P_{rt} - P_{r0})(1 - \eta_{rt}))\, c_{rt} + \sum_{r \in O} P_{rt} c_{rt} - \sum_{r \in H} P_{r0} \gamma_r h_r I_t \right) \right],$$

subject to Assumptions 1 and 2, equations (2)–(11) and the regional budget constraints $P_{rt}c_{rt} = Y_{rt} - K_{rt+1}$. To simplify notation, I define $\Theta_{rt} \equiv P_{r0} + (P_{rt} - P_{r0})(1 - \eta_{rt})$ and assume $\kappa = 1$. Note that the first element in the objective function aggregates consumption of host regions' inhabitants (natives, P_{r0}) and migrants ($P_{rt} - P_{r0}$), who must bear a migration cost, η_{rt}). The second element aggregates consumption of origin regions' inhabitants. The third element accounts for the social cost of immigration borne by host regions' natives.

To analytically derive the global SCC, SCC^{GSP}, let λ_{rt}^{GSP} denote the Lagrange multiplier on regional output (2), ω_t^{GSP} on carbon concentrations (8), and μ_{rt}^{GSPh} and μ_{rt}^{GSPo} on population evolution in host and origin regions (6), respectively. In the first-best, the global planner will increase pollution until the net marginal product of energy, $NMPE_{rt}$, equals the global SCC, that is, $NMPE_{rt} = SCC_t^{GSP}$, where

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[37] I assume the planner does not have any preference for redistribution within periods and only considers the intertemporal allocation of consumption—this is relaxed in Online Appendix E using Negishi weights.

$$SCC_t^{GSP} \equiv \frac{1}{\lambda_{rt}^{GSP}}\Bigg(\overbrace{\sum_{j=0}^{\infty} -\omega_{t+j}^{GSP}\frac{\partial f_{t+j}(.)}{\partial E_{rt}}}^{Standard\,Global\,Output\,Damages} \quad \overbrace{+\beta^{t+1}u'_{t+1}\sum_{r\in H} P_{r0}\gamma_r h_r \frac{\partial i(\Delta z_t)}{\partial E_{dt}}}^{Social\,Cost\,of\,Immigration}$$

$$\overbrace{+\sum_{r\in H}\mu_{t+1}^{GSPh}(-1)h_r\frac{\partial i(\Delta z_t)}{\partial E_t}+\sum_{r\in O}\mu_{t+1}^{GSPo}o_r\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Global\,Labor\,Effect}\Bigg). \tag{13}$$

This leads to the next proposition:

Proposition 2: *The globally optimal use of energy can be achieved by implementing a carbon price equal to $\tau_t^{GSP} = SCC_t^{GSP}$, with the SCC_t^{Uh} evaluated at the globally optimal allocation.*

See Appendix C.4 for a detailed derivation of (13) and Proposition 2. Equation (13) shows that the globally optimal carbon price is the sum of three components.[38] The first one embodies the present discounted value of climate damages to global final output, as in GHKO or Gerlagh and Liski (2018).[39]The second one captures the social cost of immigration borne by host natives. The third one, denoted *Global Labor Effec*t, captures the welfare implications of having a larger population in host regions (first summand) and a lower population in origin regions (second summand). In the optimum, $\mu_{rt}^{GSPh} = \sum_{j=0}^{\infty}\left(\beta^{t+j}u'_{t+j}\left[\frac{\Theta_{rt+j}}{P_{rt+j}}\frac{\partial Y_{rt+j}}{\partial P_{rt+j}} - \frac{P_{r0}}{P_{rt+j}}\eta_{rt+j}c_{rt+j}\right]\right)$, which implies that the first summand accounts for: i. the *Labor Effec*t that affects host regions (as detailed in the unilateral host setting); ii. the fact that migrants now consume in the host—more developed and less vulnerable—region; and iii. the fact that migrants must bear migration costs. The second summand of the *Global Labor Effect* captures the impact of population outflows on origin regions' final production.[40]

Taking stock, the key distinction between the global SCC—equation (13)—and the unilateral SCC—equation (12)—is the fact that the global planner internalizes the global externality of pollution and considers welfare of the entire population. As a result, the ben-

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[38] Each component is multiplied by $\frac{1}{\lambda_{rt}^{GSP}}$, the inverse of the shadow value of one extra unit of final good in region r, which in the optimum equals the marginal utility gain of the final good, $\lambda_{rt}^{GSP} = \beta^t u'_t \frac{\Theta_{rt}}{P_{rt}}$. Hence, the price is expressed in final good terms.

[39] In the optimum, the social value of one unit of concentrations is $\omega_t^{GSP} = \sum_r \lambda_{rt}^{GSP}\frac{\partial Y_{rt}}{\partial z_t}$.

[40] In the optimum, $\mu_{rt}^{GSPo} = \sum_{j=0}^{\infty}\beta^{t+j}u'_{t+j}\frac{\partial Y_{rt+j}}{\partial P_{rt}}$.

efits for migrants of moving to less vulnerable and more developed regions are considered. Since migration occurs due to pollution, there is a risk of prescribing policies that promote climate change to facilitate population reallocation to more developed areas. In the quantitative exercise, migration costs are used as a tool to avoid this, allowing for an accurate assessment of the impact of FCM on the global SCC.

5.2 Non-cooperative climate policy in all regions: Nash equilibrium

While standard climate-economy models typically feature a global planner, it is unreasonable to assume that our society will implement the globally optimal carbon tax anytime soon. Even if all regions agreed on implementing a carbon tax, they might disagree on its magnitude. Hence, the analysis of non-cooperative policies becomes highly relevant. In what follows, I analyse a second-best scenario where each local planner implements its own optimal policy, assuming that other countries will respond with their best course of action. Local planners internalize the emissions externality from their country's perspective, i.e., considering pollution damages that affect their natives only. Compared to the initial setting, where the origin region was environmentally inactive, each country now implements the best response to the strategies of other countries without taking other countries' decision as given.

The objective function of a host planner is: $W_t^{NE\,host} = \sum_{t=0}^{\infty} \beta^t u\left[P_{r0}c_{rt} - P_{r0}\gamma_r h_r I_t\right]$; and that of an origin planner is: $W_t^{NE\,origin} = \sum_{t=0}^{\infty} \beta^t u\left[P_{rt}c_{rt} + \sum_{l\in H}\left((1-\eta_{lt})\left(\sum_{m=0}^{t\text{-}1} h_l o_r I_{t-m}\right)c_{lt}\right)\right]$. Note that origin regions' planners care about the well-being of migrants. The Nash equilibrium solution comprises the equilibrium strategies of each country. Local planners design a policy path that is the best response to other planner's paths and fully commit to it. Given the planners problems, one can find analytical expressions of the non-cooperative carbon price for host and origin regions. Again, I assume $\kappa = 1$.

Non-cooperative climate policy in host regions

In the Nash equilibrium, a host planner increases pollution until the net marginal product of energy, $NMPE_{ht}$, equals the SCC_t from the host planner's perspective. That is, $NMPE_{ht} = SCC_t^{NEh}$, given by (14). This leads to Proposition 3.

$$SCC_t^{NEh} \equiv \frac{1}{\lambda_t^{NEh}} \left(\overbrace{\sum_{j=0}^{\infty} -\omega_{t+j}^{NEh} \frac{\partial f_{t+j}()}{\partial E_{ht}}}^{Standard\,climate\,damages} + \overbrace{\beta^{t+1} u'_{t+1} P_{h0} \gamma_r h_r \frac{\partial i(\Delta z_t)}{\partial E_{ht}}}^{Social\,Cost\,of\,Immigration} + \overbrace{\mu_{t+1}^{NEh} (-1) \frac{\partial i(\Delta z_t)}{\partial E_t}}^{Labor\,effect} \right). \tag{14}$$

Proposition 3: *The unilaterally optimal use of energy in a host region, when all the other regions are environmentally active, can be achieved by implementing a carbon price equal to* $\tau_t^{NEh} = SCC_t^{NEh}$*, where* SCC_t^{NEh} *is given by (14).*

See Appendix C.5 for a detailed derivation of (14) and Proposition 3. λ_t^{NEh}, ω_{t+j}^{NEh}, and μ_{t+1}^{NEh} denote the Lagrange multipliers on final output, (2), carbon concentrations, (8), and population evolution in the host region, (6), respectively.[41] The non-cooperative host SCC^{NEh} resembles the SCC^{Uh} from Section 4, except that it lacks the *Emissions Reallocation* component. This is because each country's strategy is the best response to the other countries' strategies. Since the other regions also implement their own optimal strategy, a host planner cannot consider the other countries' change in emissions as given.

Non-cooperative carbon price in origin regions

Let λ_{ot}^{NEo}, ω_{t+j}^{NEo}, μ_{t+1}^{NEoh}, and μ_{t+1}^{NEo} denote the Lagrange multipliers for final output, carbon concentrations, and population evolution for host and origin countries, respectively. In a Nash equilibrium setting, an origin planner will increase pollution until the net marginal product of energy $NMPE_{ot}$, equals the SCC from the origin planner's perspective. That is, $NMPE_{ot} = SCC_t^{NEo}$, given by (15). This leads to Proposition 4.

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[41] In equilibrium, the shadow values are equal to: $\lambda_t^{NEh} = \beta^t u'_t \frac{P_{h0}}{P_{ht}}$, $\omega_t^{NEh} = \lambda_t^{NEh} \frac{\partial Y_{ht}}{\partial z_t}$ and $\mu_t^{NEh} = \sum_{j=0}^{\infty} \left(\beta^{t+j} u'_{t+j} \frac{P_{h0}}{P_{ht+j}} \left[\frac{\partial Y_{ht+j}}{\partial P_{ht+j}} - \frac{Y_{ht+j} - K_{ht+1+j}}{P_{ht+j}} \right] \right)$.

$$SCC_t^{NEo} = \frac{1}{\lambda_{ot}^{NEo}} \Bigg(\overbrace{\sum_{j=0}^{\infty} -\omega_{t+j}^{NEo} \frac{\partial f_{t+j}()}{\partial E_{ot}}}^{Standard\,Climate\,Damages} + \overbrace{\mu_{t+1}^{NEoh}(-1)\frac{\partial i(\Delta z_t)}{\partial E_{ot}}}^{Labor\,Effect\,Affecting\,Migrants}$$

$$\overbrace{-\sum_{j=1}^{\infty} \beta^t u_t' \left(\sum_{l\in H} \left(c_{lt}\left(1-\eta_{rt}\right) h_l o_r \frac{\partial i(\Delta z_t)}{\partial E_{ot}} \right) \right)}^{New\,Migrants\,Consume\,in\,Host} + \overbrace{\mu_{t+1}^{NEo} \frac{\partial i(\Delta z_t)}{\partial E_{ot}}}^{Reduction\,Local\,Production} \Bigg). \quad (15)$$

Proposition 4: *The unilaterally optimal use of energy in an origin region when all the other regions are environmentally active can be achieved by implementing a carbon price equal to* $\tau_t^{NEo} = SCC_t^{NEo}$*, where* SCC_t^{NEo} *is given by (15).*

See Appendix C.6 for a detailed derivation of (15) and Proposition 4. The origin carbon price consists of the sum of four components, each one multiplied by $\frac{1}{\lambda_{ot}^{NEo}}$, which in equilibrium is given by $\beta^t u_t'$. The first one summarizes the standard climate damages. In equilibrium, $\omega_t^{NEo} = \lambda_{ot}^{NEo}\frac{\partial Y_{ot}}{\partial z_t} + \sum_{r\in H} \lambda_{rt}^{NEo}\frac{\partial Y_{rt}}{\partial z_t}$, indicating that the origin planner internalizes the climate damages affecting both host and origin regions. This is because some origin natives reside in host regions as migrants. The second component, denoted *Labor Effect Affecting Migrants*, represents the *Labor Effect* that affects migrants as a consequence of subsequent migration. In equilibrium, $\mu_t^{NEoh} = \sum_{j=0}^{\infty}\left(\beta^{t+j}u_{t+j}' \sum_{l\in H}\left[\frac{\partial Y_{ht+j}}{\partial L_{ht+j}} - \frac{Y_{lt+j}-K_{lt+1+j}}{P_{lt+j}^2}\left(1-\eta_{rt+j}\right)\sum_{m=0}^{t\text{-}1\text{+j}} h_l o_r I_{t-m}\right]\right)$. The third component, denoted *New Migrants Consume in Host*, accounts for consumption of migrants in host regions. Because they move to more developed and less vulnerable regions, their consumption is higher. Finally, the fourth component refers to the decrease in local production in the host region as a result of emigration, with $\mu_t^{NEo} = \sum_{j=0}^{\infty} \beta^{t+j}u_{t+j}'\frac{\partial Y_{rt+j}}{\partial P_{rt+j}}$.

Taking stock, since local planners only internalize the externality partially, carbon prices vary substantially for host and origin regions. While host planners consider the potential consumption dilution associated with immigration, origin planners may benefit from the reallocation of population to more developed regions.

5.3 Additional calibration

Migration costs, η_{rt}, play a crucial role in the quantification of the SCCs. The real-world disparities in per capita consumption across countries may lead the global planner (and the unilateral planners in origin regions) to strategically use pollution to reallocate population to more developed regions. This would result in unrealistic policy recommendations that would encourage pollution. To avoid it, I calibrate migration costs such that in the absence of climate change, individuals are equally well-off regardless of whether they migrate or stay.[42] This ensures that energy use balances emissions costs and benefits and is not influenced by the desire to modify the spatial distribution of population. I implement the following procedure: first, I simulate the economy under a hypothetical scenario with no climate change; then, I calculate the level of η_t in each period that equalizes consumption per capita across regions, i.e., that fulfills the equality: $c_{ht}(1-\eta_t) = c_{ot}$. Finally, the obtained path of η_t is used for the subsequent simulations with climate damages.

5.4 Calibration results

5.4.1 The global climate policy: first-best solution

Table 4 presents the near-term globally optimal carbon prices—equivalently, the global SCC. The carbon price without FCM is higher than the unilateral host price in Table 3 because the global planner considers global climate damages. We observe that the globally optimal carbon price is almost the same with and without FCM (columns 1 and 2). If anything, it is slightly larger with migration but that changes after 40 years—see the "without disutility" case in Figure E.3 of the Online Appendix. This change after four decades is primarily driven by the fact that, by then, a larger population resides where emissions are less harmful. In other words, global climate damages are lower because a greater proportion of the economic activity takes place in less vulnerable areas. Once again, the magnitude of the social cost of immigration influences whether the SCC is only slightly higher or substantially higher.

It is particularly relevant to emphasize the role of migration costs, η_t, to avoid the planner's strategic use of emissions to reallocate population. If both regions faced the same climate damages, the calibration method would completely eliminate this strategic behavior because immigrants' net consumption per capita would be exactly equal to that in the origin region. However, when the two regions have a different evolution of climate damages, small differences in net consumption per capita persist. One can observe this in Figure E.4

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[42] Hence, one can interpret the estimated migration costs as including amenities n the absence of mobility frictions.

Table 4: First-best, Globally Optimal Carbon Price, SCC^{GSP}

	Without FCM	With FCM	
		Without Disutility	With Disutility
			Pay to Go
$ per ton of carbon	(1)	(2)	(3)
C&H disasters	118.62	123.03	123.16
C&H&M disasters		120.84	120.91

Notes: This table presents short-term globally optimal SCC under each scenario. "C&H disasters" calibrates the migration response to disasters including only climatological and hydrological disasters; "C&H&M disasters" includes also meteorological disasters.

in the Online Appendix, which shows that immigrants may experience a—minimal—gain in consumption as a result of migration after a few decades.

Taking stock, despite qualitatively different, the quantitative global SCC is almost unaffected by climate FCM. This is due to the global nature of the *Labor Effect*, which considers labor implications in both regions. Importantly, as population flows from the origin to the host region, less population is exposed to severe climate damages, resulting in lower global climate damages. Migration costs play a crucial role in preventing the strategic use of emissions to reallocate population to more developed areas.

5.4.2 Non-cooperative climate policies in all regions: Nash equilibrium

The numerical algorithm is designed to find an allocation (path of emissions and savings) that maximizes the local planner's objective function, considering other regions allocations as fixed. I optimize iteratively for each region, holding allocations from other regions in the previous iteration constant, and I continue this sequence until the control variables are unchanged. Since the outcome of the quantitative analysis is invariant to initial conditions, this increases confidence in the uniqueness of the Nash equilibrium.

Table 5 shows that, without FCM, carbon prices are higher in the origin region because it experiences higher climate damages (column 1). However, with FCM, the host carbon price increases and the gap is reduced (column 2)—more so under higher values of the social cost of immigration (column 3). The origin carbon price is slightly lower with displacement because migrants experience lower climate damages when they move to the host region. Although one cannot see it in the table, host and origin carbon prices follow the

Table 5: Carbon Price Under Nash Equilibrium, SCC^{NEh} and SCC^{NEo}

		Without FCM	With FCM	
			Without Disutility	With Disutility
$ per ton of carbon				Pay to Go
	Region	(1)	(2)	(3)
C&H disasters	Host	44.72	49.89	50.02
	Origin	73.81	72.51	72.52
C&H&M disasters	Host	44.72	47.33	47.39
	Origin	73.81	73.21	73.21

Notes: This table presents short-term non-cooperative SCCs for host and origin regions under each scenario. "C&H disasters" calibrates the migration response to climatological and hydrological disasters; "C&H&M disasters" includes also meteorological disasters.

same pattern over time.

Taking stock, the Nash equilibrium setting reveals distinct pollution strategies for host and origin regions. Like in the scenario with an inactive origin region, the host carbon price is higher with FCM. However, the origin carbon price is slightly reduced because people moving to less vulnerable areas experience an adaptation benefit. Comparing these results to the first-best setting, we can conclude that while the globally optimal carbon price remains largely unchanged when accounting for FCM, the unilateral incentive to address climate change is considerably higher for host regions.

6 Extensions

See Online Appendix E for results under Stern discounting, a damage function with more catastrophic damages and an analysis using Negishi weights (Stanton 2011).

6.1 Border Control

I investigate the interaction between a carbon tax and a border control policy. The baseline model assumes no barriers to immigration.[43] I now allow host regions to use a policy that

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[43] Although this is reasonable from a long-run equilibrium perspective, and despite the fact that my measures of migration flows already factor in current border controls, in the short-run countries could modify the stringency of border control measures to restrict population inflows.

restricts the inflow of migrants. More specifically, the host planner decides the share of migrants that can enter the country every period, ψ_t. Hence, a share $1-\psi_t$ of immigrants is deported to their origin region. The deportation cost per immigrant, χ_t, is borne by the host region and is measured in terms of final consumption.

The following presents the case of a host region acting unilaterally, while the origin is in laissez-faire. The lifetime objective function of the social planner is given by $W_t^{UhBC} = \sum_{t=0}^{\infty} \beta^t \left[u\left(P_{h0}c_{ht} - P_{h0}\gamma\psi_t I_t\right)\right]$, and is subject to the regional budget constraint, $c_{ht} = \frac{Y_{ht}-K_{ht+1}}{P_{ht}} - \chi_t(1-\psi_t)I_t$, where $0 \leq \psi_t \leq 1$ $\forall t$, $P_{ht} = P_{ht-1} + \psi_t I_t$, $P_{ot} = P_{ot-1} - \psi_t I_t$ and $I_t = i(\Delta z_{t-1})$. Note that the budget constraint includes the costs of border control and ψ_t is a new choice variable. Assuming $\kappa = 1$, hence $L_{ht} = P_{ht}$, the host unilateral SCC with border control is:

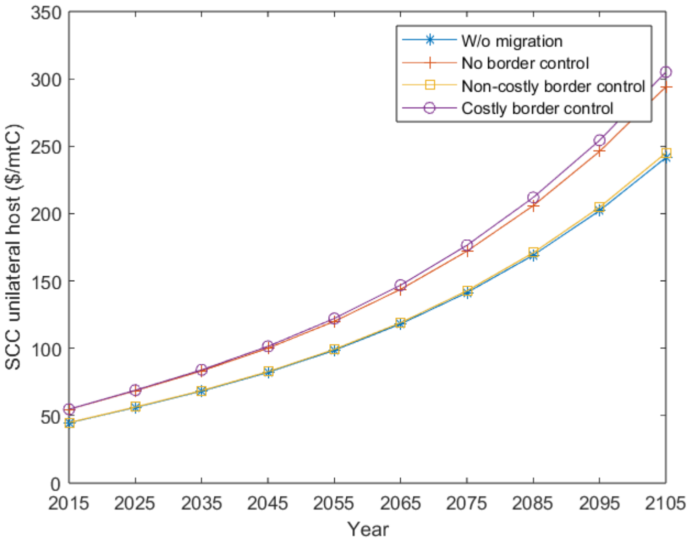
$$\begin{aligned} SCC_t^{UhBC} = \frac{1}{\lambda_t^{BC}} \Bigg(& \overbrace{\sum_{j=0}^{\infty} -\omega_{t+j}^{BC}\frac{\partial f_{t+j}(.)}{\partial E_{ht}}}^{Standard\,Output\,Damages} \overbrace{-\mu_{t+1}^{BCo}(-1)\psi_t\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Emissions\,Reallocation} \\ & + \overbrace{\beta^{t+1}u'_{t+1}P_{h0}\gamma\psi_t\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Social\,Cost\,of\,Immigration} + \overbrace{\mu_{t+1}^{BCh}(-1)\psi_t\frac{\partial i(\Delta z_t)}{\partial E_t}}^{Labor\,Effect} \Bigg), \end{aligned} \tag{16}$$

where λ_t^{BC} denotes the Lagrange multiplier on the final production function (2), ω_t^{BC} is the concentration's multiplier (8), and μ_t^{BCh} and μ_t^{BCo} are the multipliers of the evolution of population in the host and the origin region, respectively. The characterization of the shadow values in the optimum is equivalent to the benchmark case.

Equation (16) shows that when the planner implements a border control policy, i.e. when $\psi_t < 1$, the social cost of immigration and the net cost of the *Labor Effect* are lower. This reduces the carbon price. At the same time, restricting inflows reduces the benefit of emissions reallocation, which increases the carbon price. In equilibrium, $\chi_t - \gamma = \frac{\mu_t^{BCo} - \mu_t^{BCh}}{\beta^t u'_t P_{h0}}$, i.e., the level of immigration restriction will be such that it balances the costs and benefits of population inflows.

I present the quantitative results under $\gamma = 0$ and I compare them to two border control scenarios. The first scenario assumes a positive and constant border control cost ($\chi > 0$) and I calibrate it using data from the US department of Homeland Security. Specifically, I use the annual number of detentions of illegal population and border control expendi-

Figure 2: Evolution of carbon prices with border control (no social cost of immigration)



Notes: This figure shows the evolution of carbon prices without FCM ("W/o migration"); with FCM but no border control ("No Border Control"); with costless border control ("Non-costly Border Control") and with costly border control ("Costly Border Control). Throughout, the social cost of immigration is zero.

tures for 2019, which yield an estimate of $\chi = 4.6 \times 10^5$. The second scenario assumes costless border control ($\chi = 0, \forall t$). The simulation results in Figure 2 illustrate that under a US-calibrated cost of border control, the carbon tax is equal to the setting without border control and the inflow of population is equal to the benchmark case (see Figure E.5 in the Online Appendix, bottom panel). This indicates that the planner prefers to reduce emissions (through a higher carbon tax), create fewer climate migrants and allow the entrance of all of them. Therefore, the main conclusion of the unilateral SCC is still valid under reasonable measures of the cost of border control. However, when border control is costless ($\chi = 0$), the optimal strategy changes: the planner implements a much lower carbon price—its level resembles the one without FCM—and restricts the inflow of migrants (Figure E.5 in the Online Appendix, top panel).

6.2 The welfare costs of ignoring forced climate migration

Both the economic literature and policymakers have ignored the impact of FCM on optimal climate policy. Table 6 summarizes the welfare cost of such omission for the unilateral host setting. It compares natives' welfare without migration to that with migration but under the wrong policy, namely the no FCM policy. Welfare costs are measured as the percentage consumption increase that would be necessary in every period to make individuals as well off as in the case without migration. The welfare cost is positive and increasing in the social cost of immigration.

Table 6: Welfare costs of ignoring FCM

	Without Disutility (1)	Pay to Go (2)
% change	0.193	0.195

Notes: % consumption increase required to achieve the same welfare as with no FCM.

7 Conclusions

Over the recent decades, the economic analysis of climate change has made progress in providing more accurate estimates of the SCC (Nordhaus and Boyer 2000; GHKT; Van Den Bremer and Van Der Ploeg 2021; Barrage 2019, among many others). This paper contributes to this endeavor focusing on a still unaccounted for consequence of climate change: forced climate migration.[44] In particular, it analyses how FCM shapes global and unilateral optimal carbon prices, both theoretically and quantitatively.

After documenting empirically the phenomenon of climate displacement from developing to developed regions, I develop a novel multi-region climate-macroeconomic model with FCM. The inclusion of migration results in novel analytical characterizations of the global and unilateral SCCs, showing the relevance of this phenomenon in the economic analysis of global warming. This framework is rich enough to estimate the SCCs quantitatively and its estimations match with consolidated literature when the new features are switched off. Moreover, while the magnitude of the globally optimal carbon price does not change substantially after accounting for FCM, host regions' unilateral prices increase substantially.

In light of the repeated failures of reaching an international agreement to tackle climate change, the analysis of unilateral policies is of utmost relevance. In addition, the socio-political consequences of climate-induced mobility make the phenomenon of climate mi-

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[44] The existing literature either abstracts from FCM or considers general migration omitting the analysis of optimal carbon policies.

gration a first order concern worldwide. This paper analyses these two issues together and emphasizes the distinctions between global and unilateral climate action.

Compelling continuation work would be to examine the impact of within-country forced migrants on origin regions' carbon prices. In light of the results of this paper, there may be some benefits of reallocating population to less-vulnerable areas within a country, unless these areas are less economically developed or already overpopulated. Despite being outside the scope of this paper, another intriguing aspect to explore is the distributional consequences of climate migration and the role of policies in addressing inequality issues. Climate change disproportionately affects certain regions and communities, and migration could potentially exacerbate existing inequalities. While the empirical evidence is still week in guiding us along those lines, understanding these dynamics could inform the design of policies to manage not only climate change but also to mitigate the inequalities that result from displacement.

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Appendix

A Mathematical Derivations

A.1. Derivation of origin region emissions under laissez-faire, equation (11)

The origin region is in laissez-faire, i.e., energy use is determined in the decentralized equilibrium. It is subject to the same functional forms as the host region. Final good producers are assumed competitive; hence, a representative firm will use energy until its marginal product equalizes its marginal cost. Final output is given by:

$$\bar{Y_{ot}} = A_{ot}K_{ot}^{\alpha}\left(L_{ot} - \frac{E_{ot}}{A_{ot}^{e}}\right)^{\upsilon}E_{ot}^{1-\alpha-\upsilon},$$

where one has substituted in for the labor clearing constraint, $L_{ot} = L_{ot}^{Y} + L_{ot}^{e}$, and the energy production function, $E_{ot} = A_{ot}^{e}L_{ot}^{e}$. The first order condition of a maximizing firm with respect to E_{ot} yields that the optimal level of energy use is given by:

$$E_{ot} = \frac{1-\alpha-\upsilon}{1-\alpha}A_{ot}^{e}L_{ot}.$$

Since $L_{ot} \equiv P_{ot}$ in the origin region, this is equivalent to equation (11).

A.2. Derivation of equation (12) and proof of Proposition 1

The host planner problem is defined in section 4.1.2. One can substitute the resource constraint into the objective function and E_{ot} into z_t. The labor inequality is fulfilled in equality. To simplify notation, one can remove L_{ht}^{d} by solving E_{ht} for L_{ht}^{d} and plug it into the production function. The same applies for the labor clearing constraint. I take a conservative approach and assume that immigration is only a function of the first period change in concentrations, hence essentially $i(\Delta z_{t-1}) = i^{*}(E_t)$. This yields to the following Lagrangian:

$$\begin{aligned}
\mathcal{L} =& \sum_{t=0}^{\infty}\beta^{t}u\left(P_{h0}\frac{Y_{ht}-K_{ht+1}}{L_{ht}} - P_{h0}\gamma i(\Delta z_{t-1})\right)\\
&-\sum_{t=0}^{\infty}\lambda_t\left(Y_{ht} - \Omega(z_t)A_{ht}K_{ht}^{\alpha}\left(L_{ht} - \frac{E_{ht}}{A_{ht}^{e}}\right)^{\upsilon}E_{ht}^{1-\alpha-\upsilon}\right)\\
&-\sum_{t=0}^{\infty}\omega_t\left(z_t - f\left(..., E_{ht}, \xi_t P_{ot}\right)\right)\\
&-\sum_{t=0}^{\infty}\mu_t^{h}\left(L_{ht} - L_{ht-1} - i(\Delta z_{t-1})\right)\\
&-\sum_{t=0}^{\infty}\mu_t^{o}\left(P_{ot} - P_{ot-1} + i(\Delta z_{t-1})\right)
\end{aligned}$$

where λ_t is the shadow value of final output (Y_{ht}), ω_t of carbon concentrations (z_t) and μ_t^{h}, μ_t^{o} of labor in the host (L_{ht}) and in the origin region (P_{ot}), respectively. The first order conditions (FOCs) are:

$[Y_{ht}]$: $\quad \beta^t u_t' \frac{P_{h0}}{L_{ht}} - \lambda_t = 0$

That is, the shadow value of one unit of final good production (λ_t) is equal to the marginal utility of consumption.

$[K_{ht+1}]$: $\quad -\beta^t u_t' \frac{P_{h0}}{L_{ht}} + \lambda_{t+1} \alpha \frac{Y_{ht+1}}{K_{ht+1}} = 0$

Combining the FOCs for Y_{ht} and K_{ht+1} one obtains the Euler equation $\frac{u_t'}{u_{t+1}'} \frac{L_{ht+1}}{L_{ht}} = \beta\alpha \frac{Y_{ht+1}}{K_{ht+1}}$.

$[z_t]$: $\quad \lambda_t \overbrace{\frac{\partial Y_{ht}}{\partial z_t}}^{=\frac{\partial \Omega_t}{\partial z_t}\overline{Y_{ht}}} - \omega_t = 0$

Using the FOC with respect to Y_{ht}, one can rewrite the last expression as:

$$\omega_t = \beta^t u_t' \frac{P_{h0}}{L_{ht}} \frac{\partial Y_{ht}}{\partial z_t}$$

which implies that the shadow value of carbon concentrations at time t in the optimum equals the marginal utility loss generated by a lower production due to time t concentrations.

$[L_{ht}]$: $\quad -\beta^t u_t' \frac{P_{h0}(Y_{ht} - K_{ht+1})}{L_{ht}^2} + \lambda_t \overbrace{\frac{\partial Y_{ht}}{\partial L_{ht}}}^{=\upsilon \frac{Y_{ht}}{L_{ht} - \frac{E_{ht}}{A_{ht}^e}}} - \mu_t^h + \mu_{t+1}^h = 0$

Solving for μ_t and solving recursively. Then, plugging in for λ_{t+j}:

$$\mu_t^h = \sum_{j=0}^{\infty} \left(\beta^{t+j} u_{t+j}' \frac{P_{h0}}{L_{ht+j}} \left[-\frac{Y_{ht+j} - K_{ht+1+j}}{L_{ht+j}} + \frac{\partial Y_{ht+j}}{\partial L_{ht+j}} \right] \right)$$

Thus, the shadow value of labor in the host country is equal to the sum of all future wedges between marginal production and per capita consumption.

$[P_{ot}]$: $\quad \sum_{j=0}^{\infty} \omega_{t+j} \frac{\partial f_{t+j}()}{\partial P_{ot}} \xi_{t+j} - \mu_t^o + \mu_{t+1}^o = 0$

Solving for μ_t^o, solving recursively and plugging for ω_t yields:

$$\mu_t^o = \sum_{j=0}^{\infty} (j+1) \beta^{t+j} u_{t+j}' \frac{P_{h0}}{L_{ht+j}} \frac{\partial Y_{ht+j}}{\partial z_t} \frac{\partial f_{t+j}(.)}{\partial P_{ot}} \xi_{t+j}$$

So, the shadow value of population in the origin at the optimum equals the output damage associated to the pollution caused by the origin population, in utils. One has now obtained closed solutions for the shadow values λ, ω and μ's. Assuming the immigration function $i(\Delta z_{t-1}) = i^*(E_t)$, the FOC wrt E_{ht} is:

$[E_{ht}]$:

$$\begin{aligned} &- \beta^{t+1} u_{t+1}' P_{h0} \gamma \frac{\partial i(\Delta z_t)}{\partial E_t} + \lambda_t \overbrace{\frac{\partial Y_{ht}}{\partial E_{ht}}}^{=-\upsilon \frac{Y_t}{L_t - \frac{E_t}{A_{ht}^e}} \frac{1}{A_{ht}^e} + (1-\alpha-\upsilon) \frac{Y_{ht}}{E_{ht}} \equiv NMPE_{ht}} \\ &+ \sum_{j=0}^{\infty} \omega_{t+j} \frac{\partial f_{t+j}()}{\partial E_{ht}} + \mu_{t+1}^h \frac{\partial i(\Delta z_t)}{\partial E_t} - \mu_{t+1}^o \frac{\partial i(\Delta z_t)}{\partial E_t} \\ &= 0 \end{aligned}$$

Solving the last expression for the private consequences of energy use, namely $\frac{\partial Y_{ht}}{\partial E_{ht}} \equiv NMPE_{ht}$, one obtains equation (12) and Proposition 1 follows from it.

A.3. Proof of Result 1, the *Labor Effect*

To derive the net impact of the *Labor Effect*, start by recovering the expression for μ_t^h in the optimum derived in Appendix A.2: $\mu_t^h = \sum_{j=0}^{\infty} \left(\beta^{t+j} u'_{t+j} \frac{P_{h0}}{L_{ht+j}} \left[\underbrace{\frac{\partial Y_{ht+j}}{\partial L_{ht+j}} - \frac{Y_{ht+j} - K_{ht+1+j}}{L_{ht+j}}}_{\equiv \sigma} \right] \right)$. Note that the sign of μ_t^h is determined by the sign of the element defined as σ. First, let's hypothetically assume that: i. the economy is in the Laissez-faire; ii. there are no climate damages to final output; and iii. there is no capital. Hence, the production function is $Y_{ht} = A_{ht}(L_{ht} - \frac{E_{ht}}{A_{ht}^e})^{\nu} E_{ht}^{1-\nu}$. Under these assumptions, σ becomes $\frac{\partial Y_{ht+j}}{\partial L_{ht+j}} - \frac{Y_{ht}}{L_{ht}}$. The level of emissions in the Laissez-faire is proportional to total population and given by:

$$E_{ht} = (1 - \nu) A_{ht}^e L_{ht}$$

Plugging E_{ht} into the expression for σ and rearranging, we obtain $\sigma = 0$. Hence, under the Laissez-faire, without climate damages and without capital, the *Labor Effect* of migration is zero. In other words, the increase in population caused by previous pollution has no effect on future consumption per capita, thus, it doesn't affect natives welfare. Note this is a direct consequence of the Cobb-Douglas production function and the energy production, which uses labor. Essentially, these imply that that labor is the "unique" input and the production function exhibits constant returns to scale.

Let's now incorporate climate damages to final output and move away from the Laissez-faire by assuming that there is some level of climate action. It is reasonable to assume that with climate damages, the carbon tax is positive. Thus, E_{ht} will be lower than in the Laissez-faire scenario, namely $E_{ht} = (1 - \nu - \varepsilon) A_{ht}^e L_{ht}$ with $\epsilon > 0$. Back to the latest expression for σ, one can easily see that:

$$\begin{aligned} \sigma &= Y_{ht+j} \left[\nu \frac{1}{L_{ht+j} - (1 - \nu - \varepsilon) L_{ht+j}} - \frac{1}{L_{ht+j}} \right] \\ &< 0 \end{aligned}$$

Hence, once we account for climate damages the *Labor Effect* is a negative externality that positively adds to the carbon tax. The intuition behind this finding is that the use of emissions now damages final production, through Ω, hence its use will be lower. In this context, an additional unit of labor doesn't have a neutral impact on per capita output (i.e., consumption). Instead, it dilutes it.

Finally, incorporating capital into the model implies that a marginal increase in labor dilutes per capita consumption even further. This is because the production function with capital exhibits decreasing returns to the labor input. Hence, the *Labor Effect* is a negative externality.

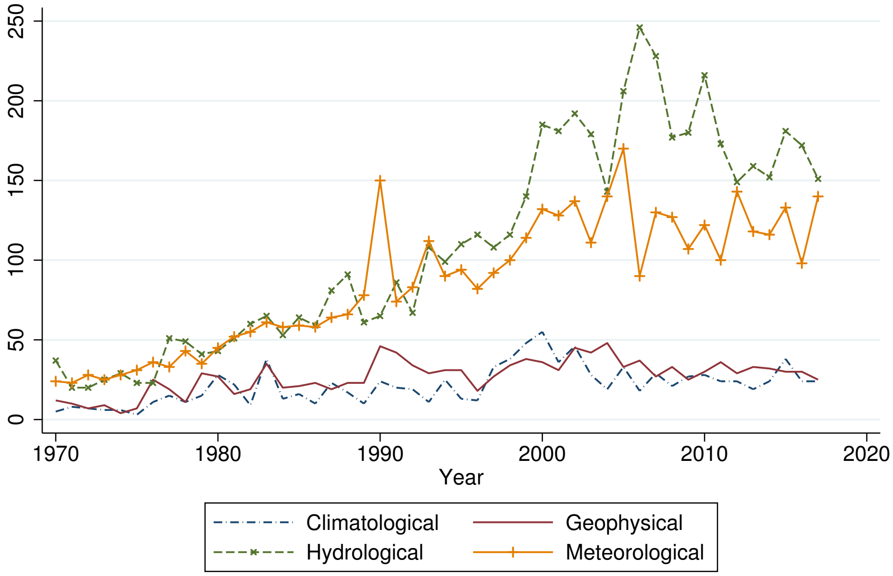
Warming with Borders: Forced Climate Migration and Carbon Pricing

Maria Alsina-Pujols

Online Appendix

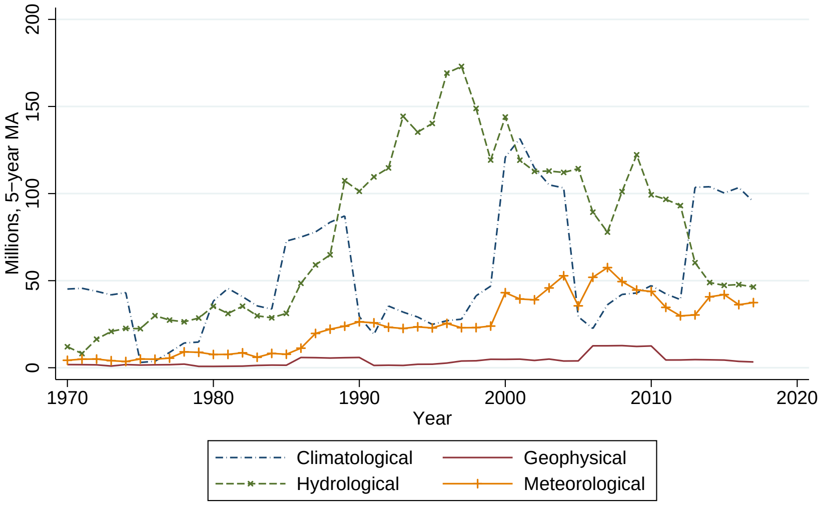
A Empirical Analysis: Figures

Figure A.1: Frequency of natural disasters by group (1970–2017)



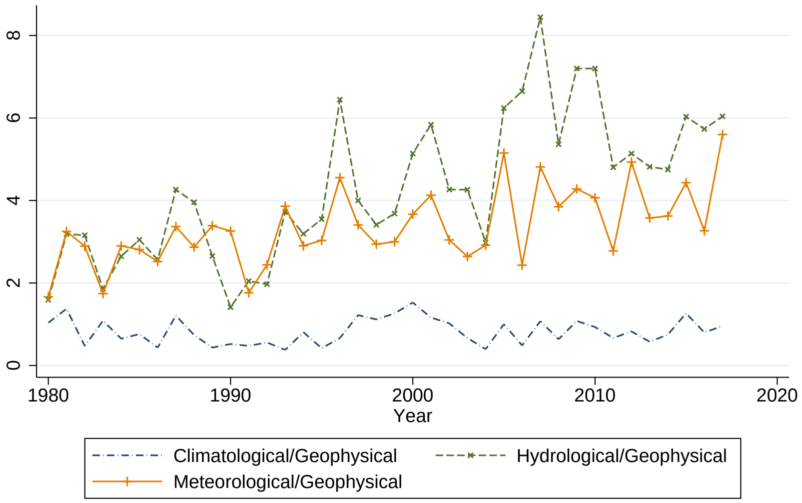
Note: This graph illustrates the evolution of natural disasters since 1970. The frequency variable in the y-axis represents the total number of shocks in a year. *Source:* Author, based on EM-DAT database.

Figure A.2: Total number of people affected by disaster group (1970–2017)



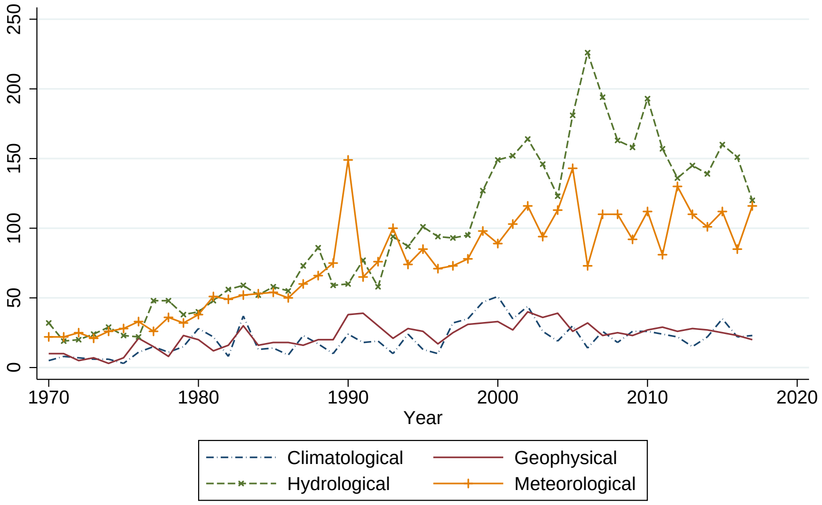
Note: This graph shows the evolution of people affected by natural disasters worldwide. Units are in millions and data points are five-year moving averages. *Source:* Author, based on EM-DAT database.

Figure A.3: Frequency of natural disasters relative to geophysical events (1980–2017)



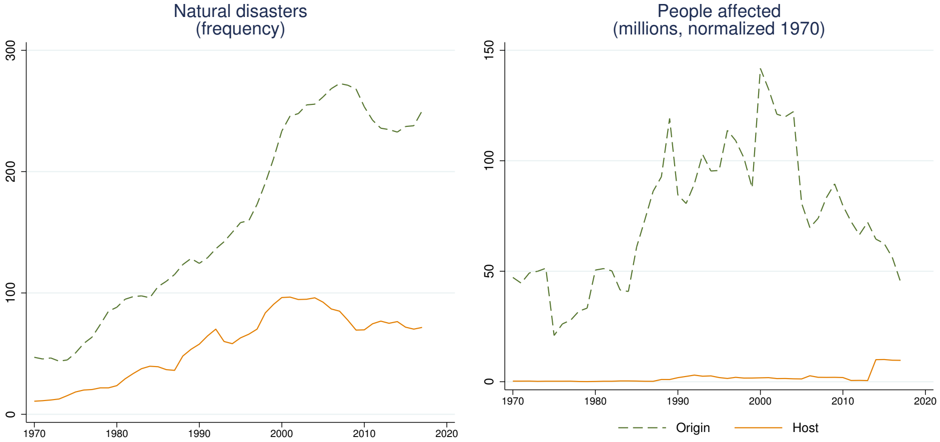
Note: This graph checks for reporting bias (unreported events) in early periods. Given that reporting bias might be orthogonal to disaster type and geophysical events are unrelated to climate change, the ratio between each disaster type and geophysical events should cancel any potential bias. The graph shows that this ratio presents the same trends as Figure A.1, indicating that the increasing pattern of disasters is not attributable to reporting bias. *Source:* Author, based on EM-DAT database.

Figure A.4: Frequency of large disasters by group (1970–2017) (Large disaster: $\geq$ 1,000 people affected or $\geq$ 100 deaths)



Note: This graph shows the evolution of large natural disasters, namely those events that have caused at least 100 deaths or directly affected at least 1,000 people. The pattern is very similar to Figure A.1, indicating that the increase is not driven by small disasters that are potentially more likely to suffer from reporting bias. *Source:* Author, based on EM-DAT database.

Figure A.5: Host–origin comparison (1970–2017)



Note: This graphs shows the evolution of disasters and the number of people affected in host and origin countries, excluding geophysical events. The number of people affected is normalized by 1970 population. Y-axes variables are five-year moving averages. *Source:* Author, based on EM-DAT database.

B Empirical Analysis: Alternative Specifications and Robustness Checks

This section presents alternative specifications and robustness checks to the empirical analysis. To address the presence of zero values in the dependent variable, column (1) in Table B.1 presents the results under a zero inflated negative binomial (ZINB) model specification.[1] The main estimate of interest remains positive and significant. Columns (2) and (3) examine bilateral migration flows, with the dependent variable defined as I_{ijt}, where i corresponds to the country of origin and j to the destination country. The main conclusions hold true under bilateral flows, both in logarithmic form and under a ZINB framework.[2] While not explicitly visible in the table, this pattern remains consistent after controlling for country time trends[3] or using net flows.

It is interesting to compare the migration response between poor and middle-income countries. Previous studies on international climate (non-forced) migration have found a greater migration response among higher income countries, suggesting that migration costs render it unaffordable for the very poor (Cattaneo and Peri 2016, among others). To investigate whether forced climate migrants respond differently than overall climate migrants, column (4) of Table B.1 introduces an interaction term between the frequency of natural disasters and a dummy variable denoting poor countries.[4] The estimate of the interaction term is positive and significant, indicating that poorer countries affected by natural disasters exhibit a stronger migration response. Hence, unlike general climate migration, the migration response to natural disasters does not seem to be driven by middle-income countries, i.e., migration costs are less relevant when the reason for migrating is a natural disaster.

Column (5) in Table B.1 reproduces column (4) from Table 1 focusing solely on the largest natural disasters (i.e., those that affected at least 1,000 people or caused at least 100 deaths). Unsurprisingly, the migration response is higher for severe disasters.

The baseline log-log specification transforms the main independent variable following log(1+#ND). This avoids losing observations as a result of the logarithmic transformation of zero values. However, given that the mean value of observations is low, this could

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[1] Still, the share of zeros in the dependent variable is low enough to be non-problematic (2%).

[2] With bilateral flows, the dependent variable exhibits a 62% share of zeros. This requires the use of a ZINB model, which accommodates the excess of zeros generating them with a different process.

[3] Accounting for the time trends of recipient countries addresses the possibility that their level of receptiveness may vary overtime.

[4] The specification follows Cattaneo and Peri (2016), which considers poor countries those in the bottom quartile of the GDP per capita distribution in 1990.

Table B.1: Alternative Specifications and Income Heterogeneity

		Bilateral flows			
	zinb (1)	log(#mig+1) (2)	zinb (3)	Income (4)	Large disasters (5)
Nat. Disasters (#)	0.245*** (0.019)		0.715*** (0.064)		
log(Nat. Disasters (#))		0.312*** (0.020)		0.096* (0.06)	0.137** (0.06)
log(Nat. Disasters (#))*Poor				0.304** (0.13)	
FE (C, T)	Y	Y	Y	Y	Y
Population$_{t-1}$, pcGDP$_{t-1}$	Y	Y	Y	N	Y
Observations	3946	144212	144208	4977	3757
Adj. R^2		0.067		0.864	0.876
Dep. var. mean	13142	1.667	405	7.364	7.674
Countries				165	156

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors, in parentheses, are clustered at the country level. Main sources: UN migration data, EM-DAT disaster data. Sample period: 1980-2013. Columns (1) and (3) use a zero inflated negative binomial (ZINB) specification, with the dependent variable in levels. Column (2) controls for origin-destination fixed effects. Column (4) adds an interaction between natural disasters and a dummy for poor countries (i.e., countries in bottom quartile of the GDP per capita distribution in 1990) and the dummy itself. Column (5) includes only large disasters in the regression ($\geq$ 1,000 people affected or $\geq$ 100 deaths).

raise a concern of creating a large bias in the estimates. To assess this, Table B.2 presents regression estimates for three-year non-overlapping windows. This reduces the number of observations with a zero value in the independent variable and it more than doubles its mean. The estimated coefficients increase more than twofold.

Table B.3 checks that results are robust to alternative variable transformations and are not driven by a few countries. Column (1) replicates the main log-log regression using the logarithm of per capita migration as the dependent variable. Column (2) weighs the occurrence of natural disasters by the share of affected population.[5] Column (3) uses the inverse hyperbolic sinus (IHS) transformation of the dependent variable, which is particularly useful to deal with zeros in the dependent variable. China and India are the largest countries in the origin group, which might display differentiated response patterns to weather shocks. To check for that, column (4) excludes China and India and rules out that results are only driven by these two countries. Note that following the Kyoto Protocol criteria, South Korea and Singapore are considered origin countries. However, one could reasonably argue that they respond differently than other origin countries due to their socioeconomic characteristics. Excluding them from the sample does not change the results (column 5), reassuring

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[5] the independent variable is defined as: $\frac{Occurrence*TotalAffected}{Population}$.

Table B.2: Regressions with 3-year periods

Dep var: log(# migrants)	(1)	(2)	(3)	(4)
log(Nat. Disasters (#))	0.328***	0.308***		
	(0.06)	(0.07)		
log(Affected (#))			0.030***	0.032***
			(0.01)	(0.01)
FE (C, T)	Y	Y	Y	Y
Population$_{t-1}$, pcGDP$_{t-1}$	N	Y	N	Y
Observations	1746	1381	1746	1381
Adj. R^2	0.857	0.872	0.856	0.871
Dep. var. mean	8.416	8.775	8.416	8.775
Countries	165	156	165	156

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors, in parentheses, are clustered at the country level. Main sources: UN migration data, EM-DAT disaster data. Sample period: 1980–2013. This table reproduces columns (2) and (3) from Table 1 for natural disasters and people affected by them, but it uses three-year observations instead of yearly observations. The sample size is smaller with controls due to missing information for some countries.

that these countries are not driving the results.

Table B.3: Additional robustness checks I

	Per capita		IHSin	w/o C, I	w/o S, SK
Dep var: log(# migrants)	(1)	(2)	(3)	(4)	(5)
log(Nat. Disasters (#))	0.125**		0.168**	0.118**	0.127**
	(0.05)		(0.07)	(0.05)	(0.05)
log(ND (#)-affected w)		0.242**			
		(0.11)			
FE (C, T)	Y	Y	Y	Y	Y
Population$_{t-1}$, pcGDP$_{t-1}$	Y	Y	Y	Y	Y
Observations	3904	3946	3949	3839	3845
Adj. R^2	0.836		0.817	0.871	0.875
Dep. var. mean	-7.440	13142.002	8.305	7.643	7.670
Countries	156	156	156	154	154

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors, in parentheses, are clustered at the country level. Main sources: UN immigration data, EM-DAT disaster data. Sample period: 1980–2013. This table presents robustness checks. Column (1) presents results for the log-log specification and migration per capita. Columns (2) weights the number of natural disasters by share of affected population. Column (3) uses the inverse hyperbolic sin transformation of the dependent variable. Column (4) reproduces the main log log regression excluding China and India. Column (5) excludes Singapore and South Korea.

Table B.4 checks that results are robust to alternative model specifications. Column (1) controls for conflict to rule out that results were driven by the relationship between climate change and conflict. I use the number of battle-related deaths from the World Bank database to proxy for conflict. Column (2) controls for the climate vulnerability index in Closset et al. (2018). Column (3) controls for the second lag of the independent variable. From the coefficient of the second lag we can see that after two years of being hit by a natural disasters, there is still a some migration response. This shows that this paper takes a conservative approach when measuring climate migration, since it deliberately accounts only for the contemporaneous effect of natural disaster. Column (4) uses a polynomial regression, including the square of the occurrence variable. Results suggest there is no acceleration, but the estimate shows some insignificant concavity. Finally, column (5) uses a Poisson model. Results are robust to all these alternative specifications.

Table B.4: Additional robustness checks II

			Contr 2lag	Polinomial	Poisson
Dep var: log(# migrants)	(1)	(2)	(3)	(4)	(5)
log(Nat. Disasters (#))	0.132**	0.101*	0.115**	0.214**	0.011***
	(0.06)	(0.06)	(0.05)	(0.10)	(0.00)
Conflict $_{t-1}$	0.044***				
	(0.02)				
Climate Vulnerability		0.057***			
		(0.00)			
log(Nat. Disasters (#))^2			0.130***		
			(0.04)		
log(Nat. Disasters (#))$_{t-2}$			0.129***		
			(0.04)		
FE (C, T)	Y	Y	Y	Y	Y
Population$_{t-1}$, pcGDP$_{t-1}$	Y	Y	Y	Y	Y
Observations	3008	3640	3571	3905	3905
Adj. R^2	0.889	0.879	0.881	0.877	
Dep. var. mean	7.930	7.824	7.740	7.704	7.704
Countries	156	144	156	156	

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors, in parentheses, are clustered at the country level. Main sources: UN immigration data, EM-DAT disaster data. Sample period: 1980–2013. This table presents additional robustness checks. Column (1) controls for conflict, defined as the number of battle-related deaths from the World Bank database. Column (2) controls for the climate vulnerability index in Closset et al (2018). Column (3) controls for the second lag of the independent variable. Column (4) uses a second-order polynomial regression. Column (5) uses a Poisson model.

Table B.5 shows the log-log specification results for each disaster group. Every group presents positive estimates, and hydrological and climatological disasters have higher and significant magnitudes.

Table B.5: Regressions by Disaster Group

	Climatological	Hydrological	Meteorological
Dep var: log(# migrants)	(1)	(2)	(3)
log(Nat. Disasters (#))	0.179*	0.233***	0.116
	(0.10)	(0.06)	(0.07)
FE (C, T)	Y	Y	Y
Observations	3208	4327	3643
Adj. R^2	0.840	0.860	0.862
ymean	6.776	7.371	7.067
Countries	165	165	165

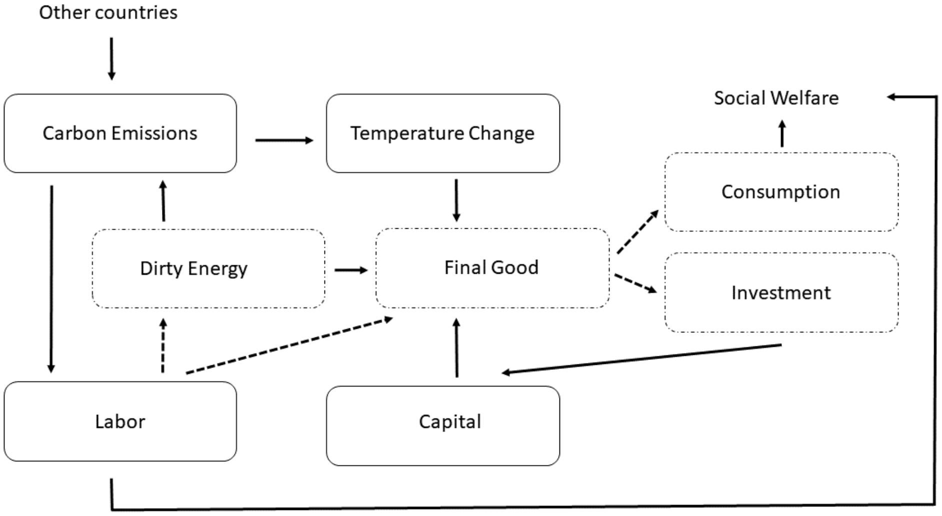
Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors, in parentheses, are clustered at the country level. Main sources: UN immigration data, EM-DAT disaster data. Sample period: 1980–2013. The table presents the relationship between disasters and migration to host regions by disaster subgroup.

C Theoretical model and mathematical derivations

C.1. Structure of the theoretical model

Figure C.1 depicts the main variables of the model and their interrelationships.

Figure C.1: Structure of the theoretical model



Note: Solid boxes characterize the state variables of the model. Dashed boxes represent flow variables. Dashed arrows represent choice variables.

C.5. The global planner solution. Proof of equation (13) and Proposition 2

The global planning problem is given by:

$$\max_{K_{rt+1},E_{rt}} \sum_{t=0}^{\infty} \beta^t \left[log \left(\sum_{r\in H} \left(P_{r0} + (P_{rt}-P_{r0})(1-\eta_{rt})\right) c_{rt} + \sum_{r\in O} P_{rt}c_{rt} - \sum_{r\in H} P_{r0}\gamma_r h_r I \right) \right]$$

subject to

$$c_{rt} = \frac{Y_{rt}-K_{rt+1}}{P_{rt}}$$

$$Y_{rt} = \Omega_r(z_t)A_{rt}K_{rt}^{\alpha}\left(L_{rt}^{Y}\right)^{\upsilon} E_{rt}^{1-\alpha-\upsilon}$$

$$z_t = f(E_1, E_2, ..., E_t)$$

$$E_t = \sum_r E_{rt}$$

$P_{rt} = P_{rt-1} + h_r i(\Delta z_{t-1})\, if\, r \in H$
$P_{rt} = P_{rt-1} - o_r i(\Delta z_{t-1})\, if\, r \in O$
$L^d_{rt} + L^Y_{rt} \leq L_{rt}$
$E_{rt} = A^e_{rt} L^d_{rt}$
$P_{rt} = L_{rt}$, since I assume $\kappa = 1$

To build the Lagrangian, let λ^{GSP}_{rt} be the shadow value of final outputs (Y_{rt}), ω^{GSP}_t of carbon concentrations (z_t) and μ^{GSPh}_{rt}, μ^{GSPo}_{rt} of population evolution in the host and in the origin regions, respectively. One can substitute the resource constraint into the objective function and E_t into z_t . The labor inequality is fulfilled in equality for every region. To simplify notation, I remove L^d_{rt} by solving E_{rt} for L^d_{rt} and plugging it into the production functions. The same applies for the labor clearing constraints. I assume $\kappa = 1$. Once again, I take a conservative approach and assume that immigration is only a function of the first period change in concentrations, hence essentially $i(\Delta z_{t-1}) = i^*(E_t)$. Let's also define $\Theta_{rt} \equiv P_{r0} + (P_{rt} - P_{r0})(1 - \eta_{rt})$.

The first order conditions (FOCs) of the planner problem are:

$[Y_{rt}]$:

$$\beta^t u'_t \frac{\Theta_{rt}}{P_{rt}} - \lambda^{GSP}_{rt} = 0\, if\, r \in H$$

$$\beta^t u'_t - \lambda^{GSP}_{rt} = 0\, if\, r \in O$$

$[K_{Rt+1}]$:

$$-\beta^t u'_t \frac{\Theta_{rt}}{P_{rt}} + \lambda^{GSP}_{rt+1} \alpha \frac{Y_{rt+1}}{K_{rt+1}} = 0\, if\, r \in H$$

$$-\beta^t u'_t + \lambda^{GSP}_{rt+1} \alpha \frac{Y_{rt+1}}{K_{rt+1}} = 0\, if\, r \in O$$

$[z_t]$:

$$\sum_r \lambda^{GSP}_{rt} \overbrace{\frac{\partial Y_{rt}}{\partial z_t}}^{= \frac{\partial \Omega_{rt}}{\partial z_t} \overline{Y_{rt}}} - \omega^{GSP}_t = 0$$

which implies that the shadow value of carbon concentrations at time t in the optimum equals the marginal utility loss generated by a lower production due to time t concentrations.

$[P_{ht}]$ for $r \in H$:

$$\beta^t u'_t \left((1-\eta_{rt}) \frac{Y_{rt} - K_{rt+1}}{P_{rt}} - \Theta_{rt} \frac{Y_{rt} - K_{rt+1}}{P_{rt}^2} \right) + \lambda_{rt}^{GSP} \overbrace{\frac{\partial Y_{rt}}{\partial P_{rt}}}^{=\upsilon \frac{Y_{ht}}{L_{rt} - \frac{E_{rt}}{A_{rt}^e}}} - \mu_{rt}^{GSPh} + \mu_{rt+1}^{GSPh} = 0$$

Solving for μ_t, solving recursively and finally plugging in for λ_{t+j}^{GSP}:

$$\mu_{rt}^{GSPh} = \sum_{j=0}^{\infty} \left(\beta^{t+j} u'_{t+j} \left[-\frac{P_{r0}}{P_{rt+j}} \eta_{rt+j} \frac{Y_{rt+j} - K_{rt+1+j}}{P_{rt+j}} + \frac{\mathit{\Theta}_{rt+j}}{P_{rt+j}} \frac{\partial Y_{rt+j}}{\partial P_{rt+j}} \right] \right)$$

$[P_{ot}]$ for $r \in O$:

$$\lambda_{rt}^{GSP} \frac{\partial Y_{rt}}{\partial P_{rt}} - \mu_{rt}^{GSPo} + \mu_{rt+1}^{GSPo} = 0$$

Plugging in for λ_{rt}, solving for μ_{rt}^o and solving recursively yields:

$$\mu_t^{GSPo} = \sum_{j=0}^{\infty} \beta^{t+j} u'_{t+j} \frac{\partial Y_{rt+j}}{\partial P_{rt}}$$

One has now obtained closed solutions for the shadow values λ, ω and μ's.

$[E_{rt}]$, under the assumption $i(\Delta z_{t-1}) = i^*(E_t)$:

$$\begin{aligned} & -\beta^{t+1} u'_{t+1} \sum_{r \in H} P_{r0} \gamma_r h_r \frac{\partial i(\Delta z_t)}{\partial E_{dt}} + \lambda_{rt}^{GSP} \overbrace{\frac{\partial Y_{rt}}{\partial E_{rt}}}^{=-\upsilon \frac{Y_{rt}}{P_{rt} - \frac{E_{rt}}{A_{rt}^e}} \frac{1}{A_{rt}^e} + (1-\alpha-\upsilon) \frac{Y_{rt}}{E_{rt}} \equiv NMPE_{rt}} \\ & + \sum_{j=0}^{\infty} \omega_{t+j}^{GSP} \frac{\partial f_{t+j}()}{\partial E_{rt}} + \sum_{r \in H} \mu_{t+1}^{GSPh} h_r \frac{\partial i(\Delta z_t)}{\partial E_t} - \sum_{r \in O} \mu_{t+1}^{GSPo} o_r \frac{\partial i(\Delta z_t)}{\partial E_t} \\ & = 0 \end{aligned}$$

This corresponds to equation (13), after solving for $\frac{\partial Y_{rt}}{\partial E_{rt}} \equiv NMPE_{rt}$. Proposition 2 follows from it.

C.6. The Nash equilibrium solution–host. Proof of equation (14) and Proposition 3

The local planning problem in a host region is:

$$\max_{K_{rt+1},E_{rt}} \sum_{t=0}^{\infty} \beta^t \left[log \left(P_{r0}c_{rt} - \sum_{r \in H} P_{r0}\gamma_r h_r I \right) \right]$$

subject to

$c_{ht} = \frac{Y_{ht}-K_{ht+1}}{P_{ht}}$

$Y_{ht} = \Omega(z_t) A K_{ht}^{\alpha} \left(L_{ht}^{Y}\right)^{\upsilon} E_{ht}^{1-\alpha-\upsilon}$

$z_t = f(E_1, E_2, ..., E_t)$

$E_t = \sum_r E_{rt}$

$P_{rt} = P_{rt-1} + h_r i(\Delta z_{t-1}) \, if \, r \in H$

$L_{ht}^{d} + L_{ht}^{Y} \leq L_{ht}$

$E_{ht} = A_{ht}^{e} L_{ht}^{d}$

$P_{ht} = L_{ht}$, since I assume $\kappa = 1$

To build the Lagrangian, let λ_t^{NEh} be the shadow value of final output (Y_{ht}), ω_t^{NEh} of carbon concentrations (z_t) and μ_t^{NEh} of labor evolution in the host (L_{ht}) and in the origin region (P_{ot}), respectively. One can substitute the resource constraint into the objective function and E_t into z_t . The labor inequality is fulfilled in equality. To simplify notation, I remove L_{ht}^{d} by solving E_{ht} for L_{ht}^{d} and plugging it into the production function. The same applies for the labor clearing constraint. I take a conservative approach and assume that immigration is only a function of the first period change in concentrations, hence essentially $i(\Delta z_{t-1}) = i^{*}(E_t)$.

The FOCs are:

$[Y_{ht}]$: $\beta^t u_t' \frac{P_{h0}}{P_{ht}} - \lambda_t^{NEh} = 0$

$[K_{ht+1}]$: $-\beta^t u_t' \frac{P_{h0}}{P_{ht}} + \lambda_{t+1}^{NEh} \alpha \frac{Y_{ht+1}}{K_{ht+1}} = 0$

$[z_t]$: $\lambda_t^{NEh} \overbrace{\frac{\partial Y_{ht}}{\partial z_t}}^{=\frac{\partial \Omega_{ht}}{\partial z_t}\overline{Y_{ht}}} - \omega_t^{NEh} = 0$

which implies that the shadow value of carbon concentrations at time t in the optimum equals the marginal utility loss generated by a lower production due to time t concentration.

$[P_{ht}]$: $-\beta^t u_t' \frac{P_{h0}(Y_{ht}-K_{ht+1})}{P_{ht}^2} + \lambda_t^{NEh} \overbrace{\frac{\partial Y_{ht}}{\partial P_{ht}}}^{=\upsilon \frac{Y_{ht}}{L_{ht}-\frac{E_{ht}}{A_{ht}^{e}}}} - \mu_t^{NEh} + \mu_{t+1}^{NEh} = 0$

Solving for μ_t^{NEh}, solving recursively and plugging in for λ_{t+j}^{NEh}:

$$\mu_t^{NEh} = \sum_{j=0}^{\infty} \left(\beta^{t+j} u'_{t+j} \frac{P_{h0}}{P_{ht+j}} \left[-\frac{Y_{ht+j} - K_{ht+1+j}}{P_{ht+j}} + \frac{\partial Y_{ht+j}}{\partial P_{ht+j}} \right] \right)$$

Thus, the shadow value of labor in the host country is equal to the sum of all future wedges between marginal production and average consumption.

Assuming $i(\Delta z_{t-1}) = i^*(E_t)$, the FOC with respect to $[E_{ht}]$ is:

$$\begin{aligned}
&- \beta^{t+1} u'_{t+1} P_{h0} \gamma_r h_r \frac{\partial i(\Delta z_t)}{\partial E_{ht}} + \beta^t u'_t \frac{P_{h0}}{P_{ht}} \overbrace{\frac{\partial Y_{ht}}{\partial E_{ht}}}^{=-\upsilon \frac{Y_t}{L_t - \frac{E_t}{A^e_{ht}}} \frac{1}{A^e_{ht}} + (1-\alpha-\upsilon) \frac{Y_{ht}}{E_{ht}} \equiv NMPE_{ht}} \\
&\sum_{j=0}^{\infty} \omega_{t+j}^{NEh} \frac{\partial f_{t+j}()}{\partial E_{ht}} + \mu_{t+1}^{NEh} \frac{\partial i(\Delta z_t)}{\partial E_t} \\
&= 0
\end{aligned}$$

As before, this corresponds to equation (14). Proposition 3 follows from it.

C.7. Nash equilibrium solution–origin. Proof of equation (15) and Proposition Proposition 4

The local planning problem in an origin region is:

$$\max_{K_{ot+1}, E_{ot}} W_{ot} = \sum_{t=0}^{\infty} \beta^t log \left[P_{ot} c_{ot} + \sum_{l \in H} \left(c_{lt} \left(1 - \eta_{rt}\right) \sum_{m=0}^{t\text{-}1} h_l o_r I_{t-m} \right) \right]$$

subject to

$c_{rt} = \frac{Y_{rt} - K_{rt+1}}{P_{rt}}$

$Y_{rt} = \Omega(z_t) A K_{rt}^{\alpha} \left(L_{rt}^Y\right)^{\upsilon} E_{rt}^{1-\alpha-\upsilon}$

$z_t = f(E_1, E_2, ..., E_t)$

$E_t = \sum_r E_{rt}$

$P_{ht} = P_{ht-1} + i(\Delta z_{t-1}) \, for \, r \in H$

$P_{ot} = P_{ot-1} - i(\Delta z_{t-1}) \, for \, r \in O$

$L_{rt}^d + L_{rt}^Y \leq L_{rt}$

$E_{ot} = A_{ot}^e L_{ot}^d$

To build the Lagrangian, let λ_t^{NEo} be the shadow value of final output, ω_t of carbon concentrations and μ_t^{NEho}, μ_t^{NEo} of labor evolution in the host (P_{ht}) and in the origin region

(P_{ot}), respectively. One can substitute the resource constraint into the objective function and E_t into z_t. The labor inequality is fulfilled in equality. To simplify notation, I remove L^d_{rt} by solving E_{rt} for L^d_{rt} and plugging it into the production function. The same applies for the labor clearing constraint. I take a conservative approach and assume that immigration is only a function of the first period change in concentrations, hence essentially $i(\Delta z_{t-1}) = i^*(E_t)$.

The FOCs are:

$[Y_{ot}]$:

$\beta^t u'_t - \lambda^{NEo}_{ot} = 0\, for\, r \in O$

$\beta^t u'_t \frac{1}{P_{rt}} (1-\eta_{rt}) \sum\limits_{m=0}^{\text{t-1}} h_l o_r I_{t-m} - \lambda^{NEo}_{rt} = 0\, for\, r \in H$

$[K_{ot+1}]: \quad -\beta^t u'_t + \lambda^{NEo}_{ot+1} \alpha \frac{Y_{ht+1}}{K_{ht+1}} = 0$

$$[z_t]: \quad \lambda^{NEo}_{ot} \overbrace{\frac{\partial Y_{ot}}{\partial z_t}}^{= \frac{\partial \Omega_{ot}}{\partial z_t} \overline{Y_{ot}}} + \sum_{r \in H} \lambda^{NEo}_{rt} \overbrace{\frac{\partial Y_{rt}}{\partial z_t}}^{= \frac{\partial \Omega_{rt}}{\partial z_t} \overline{Y_{rt}}} - \omega^{NEo}_t = 0$$

which adds up all the climate damages occurring to its own region plus the ones occurring in host regions, since origin natives have migrated there.

$$[P_{ot}]: \quad + \lambda^{NEo}_{ot} \overbrace{\frac{\partial Y_{ot}}{\partial P_{ot}}}^{= \upsilon \frac{Y_{ot}}{P_{ot} - \frac{E_{ot}}{A^e_{ot}}}} - \mu^{NEo}_t + \mu^{NEo}_{t+1} = 0$$

Solving for μ_t, solving recursively and plugging in for λ_{t+j}:

$$\mu^{NEo}_t = \sum_{j=0}^{\infty} \beta^{t+j} u'_{t+j} \frac{\partial Y_{rt+j}}{\partial P_{rt+j}}$$

$[P_{ht}]$:

$\beta^t u'_t \left[\sum\limits_{l \in H} \left(-\frac{Y_{lt} - K_{lt+1}}{P^2_{lt}} (1-\eta_{rt}) \sum\limits_{m=0}^{\text{t-1}} h_l o_r I_{t-m} \right) \right] + \sum\limits_{l \in H} \lambda^{NEo}_{l \in Ht} \frac{\partial Y_{lt}}{\partial P_{lt}} - \mu^{NEoh}_t + \mu^{NEoh}_{t+1} = 0$

Plugging in for ω_t, solving for μ^o_t and solving recursively yields:

$$\mu^{NEoh}_t = \sum_{j=0}^{\infty} \left(\beta^{t+j} u'_{t+j} \sum_{l \in H} \left[-\frac{Y_{lt+j} - K_{lt+1+j}}{P^2_{lt+j}} (1-\eta_{rt+j}) \sum_{m=0}^{\text{t-1+j}} h_l o_r I_{t-m} + \frac{\partial Y_{ht+j}}{\partial L_{ht+j}} \right] \right)$$

Assuming $i(\Delta z_{t-1}) = i^*(E_t)$, the FOC with respect to $[E_{ht}]$ is:

$$
\begin{aligned}
&\lambda^{NEo}_{r=ot} \overbrace{\frac{\partial Y_{ot}}{\partial E_{ot}}}^{=-\upsilon \frac{Y_{ot}}{P_{ot}-\frac{E_{ot}}{A^e_{ot}}} \frac{1}{A^e_{ot}} + (1-\alpha-\upsilon)\frac{Y_{ot}}{E_{ot}} \equiv NMPE_{ot}} + \sum_{j=0}^{\infty} \omega^{NEo}_{t+j} \frac{\partial f_{t+j}()}{\partial E_{ot}} + \mu^{NEoh}_{t+1} \frac{\partial i(\Delta z_t)}{\partial E_{ot}} \\
&- \mu^{NEo}_{t+1} \frac{\partial i(\Delta z_t)}{\partial E_{ot}} + \sum_{j=1}^{\infty} \beta^t u'_t \left(\sum_{l \in H} \left(c_{lt} \left(1-\eta_{rt}\right) h_l o_r \frac{\partial i(\Delta z_t)}{\partial E_{ot}} \right) \right) \\
&= 0
\end{aligned}
$$

As before, this corresponds to equation (15). Proposition 4 follows from it.

D Calibration

D.1 Social cost of immigration

I calibrate the social cost of immigration using data on different programs and policies. I complement these with World Bank data on consumption and population. To find domestic population's willingness pay to reduce immigration, I use the share of consumption per capita that, according to each different program or policy, they are willing to sacrifice to reduce the current stock of immigration. I compare this to actual consumption and calculate the hypothetical cost that would make them indifferent in both situations. In other words, I obtain the value for the social cost parameter γ solving the expression: $ln((1-\rho)c) = ln(c - \gamma * immigrants)$, where ρ denotes the share of per capita consumption that natives are willing to forgo according to each program/policy.

Details on Pay to Go Programs: The European Commission provides data on 2015 Pay to Go expenditures from individual countries[6] and the EU as an institution. For the calibration of the disutility parameter I use the expenditures for the so-called “Assisted Voluntary Return Programs".

E Additional Results

Unilateral SCC decomposition

Figure E.1 shows the decomposition of the unilateral host carbon price into the four components

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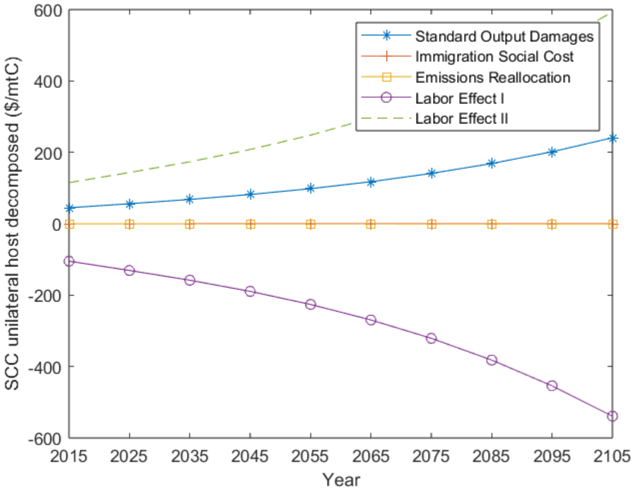
[6] Individual countries include: Austria, Belgium, Bulgaria, Cyprus, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, the Netherlands, Norway, Poland, Slovakia, Slovenia, Sweden and the United Kingdom.

presented in the main text. Note that the *Labor effect* component is disaggregated further into the positive and the negative externality originated by the increase in the population.

Figure E.1: Unilateral host SCC decomposition, without disutility



Notes: This figure shows the evolution of each component of the carbon price under the setting in which only the host country implements the carbon policy unilaterally. The disutility of immigration is zero.

Per capita emissions under the unilateral host policy scenario

Figure E.2 illustrates the evolution of per capita emissions in the host region for each scenario, relative to the scenario without forced climate migration.

Evolution of the globally optimal carbon price

Figure E.3 illustrates the evolution of the globally optimal carbon price—equivalently, the global SCC, under the three different scenarios detailed in the main text.

Consumption of forced climate migration

Figure E.4 shows that migrants experience only a minor consumption increase after a few decades.

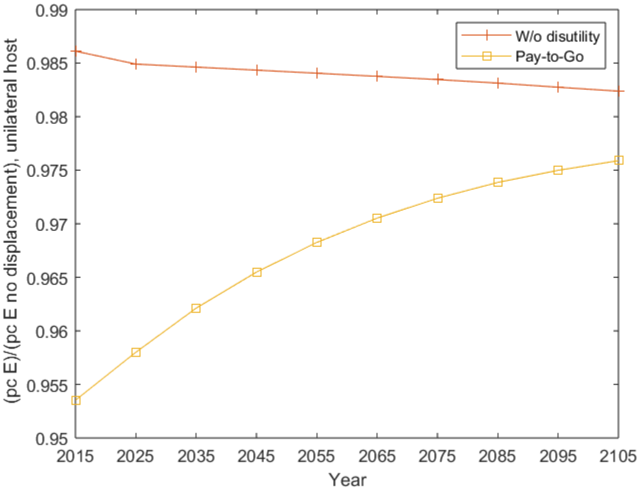
Displacement with border control

Figure E.5 shows the evolution of the number of forced migrants under a setting with border control policy, compared to the setting without border control.

Weaker decreasing marginal returns to labor

As detailed in the main text, the labor effect under the unilateral carbon policy scenario constitutes

Figure E.2: Evolution of per capita emissions in the host region under unilateral policy



a cost because: i. the inclusion of climate damages and; ii. capital depreciation. These two forces offset the benefit of having a larger labor force, hence the labor effect is a net cost.

The benchmark specification does not explicitly account for the benefits of population agglomeration (that is, doesn't present larger returns to labor). This, however, is not a concern because agglomeration forces have been found empirically meaningful when considering much smaller regions, such as cities, but not for groups of countries like in this study. Hence, the Cobb-Douglas specification is a sensible one. Still, in order to provide some intuition on how the main results would change if agglomeration forces were also present at a larger scale, Table E.1 presents the unilateral carbon taxes in the host country under a production function with weaker marginal returns to labor. More specifically, the following formulation has been used: $\tilde{Y_{ht}} = A_{ht} K_{ht}^{\alpha} \left(L_{ht}^{Y}\right)^{\upsilon} E_{ht}^{\varpi}$, where I set $\alpha = 0.3$, $\upsilon = 0.7$ and $\varpi = 0.04$, hence, $\alpha + \upsilon + \varpi > 1$.

Results, displayed in Table E.1, show that there is still an increase in the carbon tax after accounting for migration, but to a lower extent. This is consistent with the fact that the costs of a larger population in the host region still offset the benefits, but now the benefits are larger in magnitude than under the benchmark scenario.

Alternative forced climate migration function

The benchmark model employs a conservative approach on the international displacement response to climate change. It assumes that only contemporaneous changes in concentrations lead to forced migration, disregarding any delayed effect of concentrations on natural disasters and its consequent migration response. In what follows, I relax this rigidity by introducing a migration response to the accumulated amount of carbon. More specifically, migrants are now determined by the change

Figure E.3: Evolution of the first best carbon price

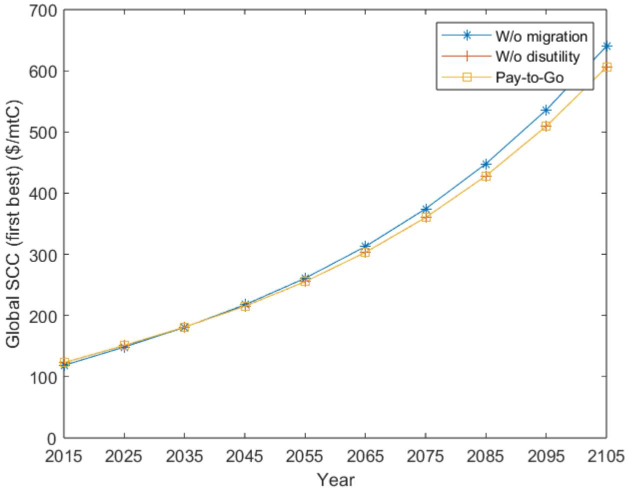


Table E.1: Unilateral carbon prices in host, weaker marginal returns to labor

	Without FCM	With FCM	
		Without Disutility	With Disutility Pay to Go
	(1)	(2)	(3)
$ per ton of carbon	44.72	48.64	48.89

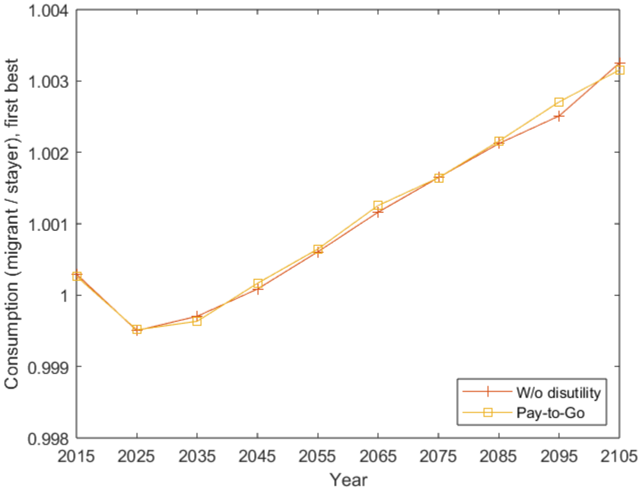
Notes: This table displays the unilateral carbon price in the Host region under weaker decreasing returns to labor. The calibration accounts for climatological and hydrological disasters.

in concentrations with respect to the initial period. This means that current emissions contribute to future periods' migration as long as they have not fully dissipated. In the analytical expression for the carbon tax, this is captured by the fact that the migration increase due to a marginal increase in emissions, $\frac{\partial I_{t+1}}{\partial E_{ht}}$, now becomes $\sum_{q=1}^{j} \frac{\partial I_{t+q}}{\partial E_{ht}}$, that is, emissions today create new migrants in the following j years. Table E.2 presents the unilateral carbon prices in the host region, with an inactive origin region. As previously mentioned, under this alternative migration function, carbon prices increase more when considering migration compared to the benchmark—and more conservative—specification.

Alternative discounting, higher climate damages, and Negishi weights

Following Nordhau's approach, I assume an annual discount factor, β, of 0.958. However,

Figure E.4: Migrants vs. stayers consumption comparison under first-best setting



Notes: This figure shows migrants' consumption relative to origin stayers under the first best.

Table E.2: Unilateral climate action in host, alternative migration function

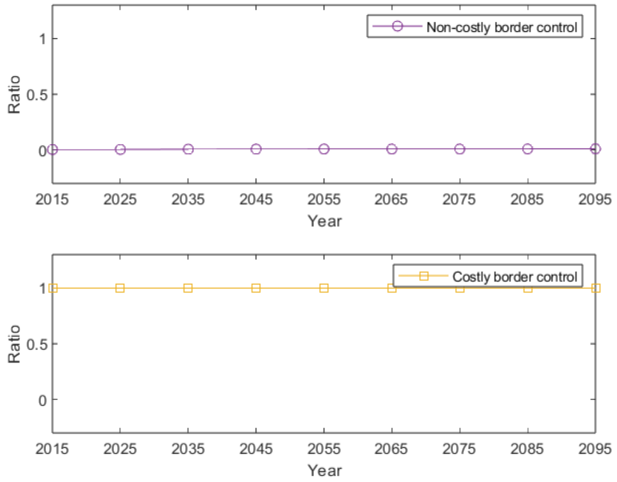
	Without FCM	With FCM	
		Without disutility	With disutility
			Pay to Go
$ per ton of carbon	(1)	(2)	(3)
	44.72	56.77	57.15

Notes: This table presents the host region unilateral carbon prices with an inactive origin region, under an alternative forced climate migration function where emissions today cause migration in the future as long as they are not fully dissipated. The migration response to climate change is calibrated using climatological and hydrological disasters.

economists have long debated the appropriate value of this factor to quantify the effects of climate change, leading to significant disagreement. Stern (2007), among others, advocates for a 0.1% discount rate arguing that future losses are as worrying as losses today, so there should be almost no discounting. Panel B of Table E.3 displays the unilateral host carbon prices under Stern discounting, and Panel A reproduces the results under the Nordhaus discounting for comparison. As expected, carbon prices under Stern discounting are higher. Still, the main message of this paper remains unchanged.

IAMs use a damage function to integrate the climate into an economic growth model. However, we are uncertain about the right characterization of this function due to our limited understanding of the true economic impacts of climate change. In this paper, I borrow the functional form and

Figure E.5: Number of migrants under border control relative to the number of migrants without border control



Notes: This figure presents the ratio between the number of migrants with border control and the number of migrants without border control for the first 100 years. The upper graph shows the case when border control is costless, while the lower graph shows the case when the cost of border control matches that in the United States.

calibration from GHKO. [7] Some scientists and economists have argued that this function leads to implausibly low damages. To account for this concern, I redo the quantitative analysis under a more severe consideration of climate damages. Panel C in Table E.3 presents carbon prices when the likelihood of "catastrophic" damages is three times higher than in GHKO's consideration. In particular, I use Nordhau's calibration for "catastrophic" damages. One can see that carbon prices increase twofold but, once again, the main message of this paper remain unchanged.

The first-best setting does not consider the distribution of consumption across countries. I now introduce the optimal global policy when the planner is concerned about consumption distribution. Specifically, the planner's objective is a weighted sum of the utilities of individuals based on their country of origin:

$$\max_{K_{rt+1},E_{rt}} W_t^{GSP^w} = \sum_{t=0}^{\infty}\beta^t \left[\sum_{r\in H}\Upsilon_r U\left(P_{r0}c_{rt} - P_{r0}\gamma_r h_r I_t\right) + \sum_{r\in O}\Upsilon_r U\left(P_{rt}c_{rt} + \sum_{l\in H}\left((1-\eta_{lt})\left(\sum_{m=0}^{t\text{-}1} h_l o_r I_{t-m}\right)c_{lt}\right)\right)\right]$$

where Υ_r is a vector of constant regional weights, with $\sum_r \Upsilon_r = 1$. Weights are determined as the

---

[7] The main parameter is θ, which scales the damage function. It is calibrated as a weighted average between a "moderate" damage and a "catastrophic" damage scenario.

Table E.3: Unilateral climate action in host region

	Without FCM	With FCM	
		Without disutility	With disutility
			Pay to Go
$ per ton of carbon	(1)	(2)	(3)
Panel A: Benchmark			
	44.72	54.73	54.99
Panel B: Stern discounting			
	147.48	159.84	159.84
Panel C: Higher climate damages			
	87.92	98.11	98.28

Notes: This table presents some sensitivity analysis of the short-term unilateral carbon prices for the host region. The migration response to climate change is calibrated using climatological and hydrological disasters. Panel A reproduces the benchmark results to facilitate the comparisons. Panel B presents the results under Stern discounting. Panel C presents the results under higher climate damages.

inverse of each region's marginal utility of consumption in the initial period.[8] Hence, individuals who originally come from poorer regions receive lower weights. This is similar to the commonly used approach based on Negishi weights (Stanton, 2011). The goal is to ensure that the initial distribution of consumption is preserved and results reflect the intention of addressing climate-related issues.[9] Table E.4 presents the first-best carbon prices using regional weights. The main message of this paper remains unchanged.

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[8] Regional weights are calculated as $\Upsilon_r = \frac{\frac{1}{U'_r}}{\sum\limits_r \frac{1}{U'_r}}$.

[9] In other words, adding weights implies that the initial level of inequality is considered to be optimal within the planner's objective function.

Table E.4: First-best carbon prices with regional weights

	Without FCM	With FCM	
		Without disutility	With disutility
			Pay to Go
$ per ton of carbon	(1)	(2)	(3)
	117.89	121.83	121.94

Notes: This table presents the globally optimal carbon prices with regional Negishi weights. Individuals' utility is weighted based on their country of origin's initial consumption. The migration response to climate change is calibrated using climatological and hydrological disasters.

F Extension with microfounded migration

The model can be extended to include microfounded migration, allowing individuals to make migration decisions based on economic factors. This reduces analytical tractability, making it impossible to derive closed-form solutions for carbon taxes. The following outlines the key modifications to the model and the main results for the setting with unilateral action in the host region only.

The economic setting remains the same, featuring one host and one more vulnerable and less economically developed origin region that does not take any climate action. However, instead of being forced to migrate due to climate change, individuals in the origin now base their migration decisions on the current per capita consumption in each region. More specifically, at the end of each period, agents decide the location of their offspring based on per capita consumption in each region and the migration cost, η_{ot}. Agents are myopic, and can only observe current total consumptions in each region, which they take as given, and current population levels. Individuals will move from the origin to the host until per capita consumption equalizes. Hence, in equilibrium, the following must hold:

$$\frac{C_{ht}(1-\eta_{ot})}{P_{ht}+MigFlow_t}=\frac{C_{ot}}{P_{ot}-MigFlow_t},$$

where $Migflow_t$ stands for the migration flow from origin to host at time t . This leads to a per period migration flow of: $MigFlow_t = \frac{C_{ht}(1-\eta_{ot})P_{ot}-C_{ot}P_{ht}}{C_{ht}(1-\eta_{ot})+C_{ot}}$.

The origin region is in the laissez faire and it is straightforward to show that will save a constant fraction of output, given by $s=\beta\alpha$. Together with the characterization of origin regional emissions in (11), this allows for determining the migration flow in each period. The migration costs are calculated such that, absent climate change, individuals in the origin region have no incentives to migrate to the origin regions. Hence, the microfounded migration flows are climate-related.

In the optimum, the host planner will allocate energy use such that the private marginal product of energy ($NMPE_h$) equals the social cost of energy use. For that reason, I estimate the carbon tax following the expression: $\tau_{ht} = NMPE_{ht}$.

Table F.1 show the main results. One can see that the carbon tax is higher with microfounded migration. This indicates that the efforts to mitigate climate change would be higher if all climate-related migration was accounted for.

Table F.1: Comparison cases: no migration, forced climate migration and microfounded climate migration only

	Without migration	Forced climate migration	Microfounded migration
$ per ton of carbon	(1)	(2)	(3)
	44.72	54.73	79.52

Notes: This table presents the host region unilateral carbon prices with an inactive origin region, without migration, with forced climate migration and with microfounded climate migration only.

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