Received: 20 May 2020 | Revised: 9 April 2021 | Accepted: 8 May 2021

DOI: 10.1111/rode.12800

REGULAR ARTICLE

WILEY

How climate change leads to emigration: Conditional and long-run effects

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Funding information
Leibniz-Gemeinschaft, Grant/Award Number: K36/2017

Abstract
We study the effect of climate change on migration from 121 developing and emerging countries to 20 OECD countries between 1980 and 2010. In contrast to earlier studies, we differentiate between low- and high-skilled migrants to account for the fact that not all groups are equally vulnerable and responsive to climate change. This is also the first study that uses a long-difference approach. That is, in contrast to earlier studies that investigate short-term weather changes or weather-related disasters, we also estimate the effect of climate change on migration over longer time periods. We find that both increasing temperatures and precipitation levels matter to the patterns of migration. We show that increasing temperatures only lead to low-skilled but not high-skilled migration (suggesting different migration calculi), are only influential in countries located in hotter parts of the world (consistent with the idea of different levels of vulnerability to climate change), and only materialize in the long run (pointing to the adverse impact of intensification effects due to persistent climate change). Furthermore, we provide evidence that low-skilled out-migration is also responsive to short- and long-run precipitation changes.

KEYWORDS
climate change, low- and high-skilled migration, migration

JEL CLASSIFICATION
F2; F22; Q5; Q54

1 | INTRODUCTION

Climate change will be among the most important issues of the 21st century. According to the Intergovernmental Panel on Climate Change (IPCC, 2014, p. 40), from 1880 to 2012 global temperatures already increased (on average) by approximately 0.85°C (IPCC, 2014, p. 40). Depending on the specific projection, average temperatures will be between 0.4 and 2.6°C higher in the 2046–2065 period compared to the 1986–2005 period, with further increases being likely for the remainder of the 21st century (IPCC, 2014, p. 60). Inter alia, global warming leads to a shrinking cryosphere, rising sea levels, increased erosion and desertification, shifts in plant flowering, changes in animal behavior, and more extreme weather events such as heat waves and floods (Berlemann & Steinhardt, 2017, pp. 355–359; IPCC, 2014). Consequently, climate change has and will continue to have a number of severe adverse consequences for human life, for example, jeopardizing agricultural production and food security, negatively affecting economic growth and development and contributing to political instability, especially in more vulnerable parts of the world (IPCC, 2014).

Due to these adverse effects, the IPCC (2014, p. 73) expects climate change to also affect *human migration*. Testing this proposition, in recent years a small number of empirical studies have examined the effect of climate variables on migration for large country-samples.[1] On one hand, Backhaus et al. (2015) study a panel of 142 sending countries for the 1995–2006 period, finding that increases in temperature and precipitation in these countries are associated with higher migration flows to 19 OECD countries. Similarly, Coniglio and Pesce (2015) show that temperature and precipitation shocks can contribute to migration out-flows from poor countries toward rich OECD destinations. On the other hand, Beine and Parsons (2015) use decennial migration data for the 1960–2000 period for a sample of 137 sending and 166 destination countries, showing that there is no direct effect of climatic factors on international migration. Similarly, Maurel and Tuccio (2016) find no evidence that climate instability (e.g., anomalies in temperature) directly affects international migration. Finally, Cattaneo and Peri (2016) find that higher temperatures in middle-income economies increase international migration, whereas higher temperatures reduce the probability of out-migration in poorer countries. By contrast, Beine and Parsons (2017) find that weather indicators (natural disasters as well as rainfall and temperature anomalies) tend to curtail out-migration from middle-income countries but have no effect on emigration from poorer countries.

In sum, the empirical evidence does not provide a uniform picture regarding the climate change-migration nexus. We believe that this is due to two limitations in the current literature which we aim to overcome in this article. First, existing large-*N* studies assume that the entire population of a country is equally responsive to climate change. That is, the studies discussed earlier do not consider that some groups might be more affected by climate change than others and accordingly respond differently to it.[2] For this analysis, we instead propose to study how *education* leads to different migratory responses to climate change, given that it has been shown that skill levels play an important role in understanding migration motivation (e.g., Docquier & Rapoport, 2012).[3] At the same time, skill composition of migration flows has great relevance for labor markets and immigration policies in receiving OECD countries (e.g., Cerna, 2014; Kolbe & Kayran, 2019). So far, only Drabo and Mbaye (2015) investigate how climate variables interact with emigration in a cross-country setting. They study the effect of natural disasters on out-migration, finding that such disasters especially encourage high-skilled migration. However, their study is limited to migration from only 67 developing to 6 OECD destination countries and primarily looks at short-term weather shocks (e.g., floods or droughts).

Indeed, the existing focus on the role of short-term weather changes in out-migration is a second limitation of the studies in this field that this paper aims to overcome. For instance, some studies investigate how yearly changes in temperature or precipitations affect out-migration (e.g., Backhaus et al., 2015; Coniglio & Pesce, 2015), while others examine whether weather-related disasters such as floods, droughts, or storms matter (e.g., Drabo & Mbaye, 2015). While such weather anomalies may very well be linked to climate change (e.g., Berlemann & Steinhardt, 2017), they still constitute short-run weather changes that are *mean-reverting*. Consequently, the migratory response to such short-run phenomena may be different compared to the response to climate change which is—by definition—*non-mean-reverting*. For instance, the response to sudden weather-related disasters may take the form of internal migration, with individuals eventually returning home.

By contrast, climate change in the form of persistent changes in precipitation patterns and increasing temperatures needs more time to materialize; consequently, there are distinct adaptation and intensification effects associated with it (Dell et al., 2014). These effects, in turn, have important ramifications for migratory responses. For instance, intensification effects imply that the adverse consequences of climate change accumulate over time (Dell et al., 2014): for example, in the long run arable land may permanently vanish due to desertification, which is expected to induce permanent migration away from affected areas, potentially to other destination countries less affected by climate change. Still, this long-run perspective remains unappreciated in the study of the climate change-migration nexus. By contrasting the role of short-run weather and long-run climate changes in migration, we aim at filling this gap in the literature. Indeed, to the best of our knowledge, our study is the first to contrast such effects when studying the climate change-migration nexus. Here, we use the *long-difference approach* of Dell et al. (2014) and Burke and Emerick (2016), where we estimate the effect of climate change on migration over longer time periods (contrasting two 15-year periods), so that we move closer to identifying long-run impacts that account for any adaptation and intensification effects that only materialize over longer time horizons (e.g., Dell et al., 2014, p. 778).

The remainder of this paper is organized as follows. In Section 2, we discuss the relevant literature, focusing on the potential effects of climate change on migration. Section 3 introduces our data. Section 4 presents our empirical results concerning the short-run effect of precipitation and temperature on out-migration. In Section 5, we provide long-run estimates of the effect of climate change on migration and contrast them with our short-run estimates. Section 6 concludes.

2 | LINKAGES BETWEEN CLIMATE CHANGE AND MIGRATION

2.1 | General explanations

To explain how changing climate conditions may affect migration, as a simple theoretical framework we use the economic model of migration as presented by, for example, Borjas (1989).[4] According to this model, (potential) migrants want to maximize their income. Such an income-maximizing individual—while also considering the costs of migration, for example, in the form of traveling expenses—is more likely to migrate when the (expected mean) income in their home country is relatively low (compared to the target country of migration). Indeed, migrants tend to come from relatively poor countries of origin and migrate to countries that have higher levels of economic development (e.g., Ashby, 2010; Grogger & Hanson, 2011; Meierrieks & Renner, 2017).

The income-maximizing framework can be extended to a utility-maximizing one. While the potential migrant's utility is closely linked to the income they earn, it furthermore depends on non-income factors.

For instance, there is evidence that out-migration is determined not only by differences in wages, but also by the prevalence of political violence, demographic conditions, as well as institutions that govern economic and political participation (e.g., Ashby, 2010; Cooray & Schneider, 2016; Dreher et al., 2011; Hatton & Williamson, 2003; Meierrieks & Renner, 2017). To the extent that these non-income factors reduce utility in the (potential) migrant's home country (e.g., as political violence abounds), they are consequently expected to make out-migration by a utility-maximizing individual more likely.

Considering the role of climate change in migration, in general we expect them to adversely affect conditions in the migrant's home country, leading to more out-migration. In fact, this expectation is consistent with the *mainstream view* of migration as an adaptive strategy to climate change: As "global warming continues with tremendous changes in local living conditions, one might expect populations in regions with worsening conditions to consider moving to better places, provided the costs of migration are affordable" (Berlemann & Steinhardt, 207, p. 354). Consequently, relying on the framework of a utility-maximizing migrant, a number of pathways may account for this expected relationship:

1. Climate change is anticipated to negatively affect *agricultural production* by, among others, contributing to water stress, creating damage to plants due to extreme temperatures, and exacerbating effects from pests and plant diseases (Hertel & Lobell, 2014). Indeed, many empirical studies come to the conclusion that climate change reduces agricultural output (for an overview, see Carter et al., 2018). Thus, we can expect climate change to reduce employment and wages in the agricultural sector, consequently increasing incentives for out-migration. Indeed, Backhaus et al. (2015) and Cai et al. (2016) find that migration responds especially strong to climate variability in countries that are agriculture-dependent.
2. Climate change may also negatively affect *health*, for example, due to adverse health effects from extreme weather events (cold waves, heat waves, floods, etc.), malnutrition (e.g., due to the effect of climate change on agriculture), and the increased spread of diseases (malaria, dengue fever, etc.) transmitted by vectors and rodents sensitive to climate change (e.g., Meierrieks, 2021; for an overview, see Haines et al., 2006). For a utility-maximizing migrant, this is expected to generate additional incentives (due to an increased health and life expectancy differential between origin and destination countries) for migration.
3. Through their adverse effects on agriculture and human health, climate change may also reduce *overall economic activity*. For instance, it may adversely affect the labor productivity of workers due to stronger extreme weather events (e.g., heat waves) (Dell et al., 2012). Indeed, Dell et al. (2012) show that climate change is associated with reduced economic growth. Again, for a utility-maximizing individual reduced economic activity at home reduces (expected) utility (e.g., due to a higher likelihood of unemployment), thus making it more attractive to migrate.
4. By inducing adverse economic shocks, climate change may also have *politico-institutional repercussions*. For instance, climate change may also contribute to *political violence*. Miguel et al. (2004) show that weather shocks in sub-Saharan Africa reduce economic growth, which leads to an increase in the likelihood of civil conflict.[5] The prevalence of political violence in turn has obvious negative effects on individual utility, so that it ought to facilitate out-migration (e.g., Dreher et al., 2011).

2.2 | Low- and high-skilled migration

Skill levels play an important role in understanding migration motivations (e.g., Docquier & Rapoport, 2012; Grogger & Hanson, 2011). For instance, high-skilled individuals can expect to earn higher incomes after migrating than their low-skilled counterparts, making them more responsive to (changes in) wages in sending countries (Bauer & Zimmermann, 1998). Indeed, Grogger and Hanson (2011) find that income differentials are more important determinants for high-skilled than for low-skilled individuals.

Accordingly, differences in education may induce different migratory responses to climate change. In other words, the adverse economic, health, and political consequences might be felt differently by individuals depending on their skill levels, consequently differently affecting their calculus of utility-maximization and thus migration decision. Here, it is a priori unclear whether climate change more strongly matters to the calculus of low- or high-skilled migrants. On one hand, the adverse economic effects of climate change ought to be felt especially by the low-skilled and therefore affect their migration decisions (Thiede et al., 2016). Most importantly, the low-skilled are more likely to be employed in agriculture, so that they ought to respond more strongly (by migrating) to negative effects on agricultural activity because of climate change.

On the other hand, however, climate change may also exacerbate liquidity constraints, discouraging low-skilled migration more strongly than high-skilled migration. This is because wages of the low-skilled are already lower due to their lower productivity (Mincer, 1958), making the low-skilled especially vulnerable to further negative economic shocks (affecting wages and employment in both rural and urban sectors), potentially quickly ending their migration plans. By contrast, the high-skilled are better paid and may therefore be able to withstand economic shocks without changing migration plans (e.g., Bazzi, 2017; Drabo & Mbaye, 2015).

2.3 | Short- and long-term changes

Climate change is a long-run phenomenon and, potentially, short-run weather shocks and long-run climate change have different effects on out-migration. According to Dell et al. (2014), this is because many effects due to persistent increases in temperatures and changes in precipitation patterns may need longer time horizons to materialize. They may consequentially not be very influential in shorter-run settings that primarily consider, for example, how weather-related natural disasters or deviations from mean temperatures and precipitation patterns affect migration. In detail, Dell et al. (2014) mention the influence of adaptation and intensification effects.

With respect to *adaptation effects*, the idea is that economic agents do not instantaneously adapt to changing climate conditions. Rather, we would expect adaptive behavior by economic agents to occur when temperature increases or precipitation changes are *persistent*. For instance, under persistence it may be cost-efficient for economic agents to adapt by fully taking advantage of existing technologies to counter adverse effects, for example, by switching to advanced farming machinery to reduce losses in agricultural production. By contrast, incentives for costly adaptation would be much smaller if conditions revert back to a stable long-run mean after a short-run weather shock (e.g., a particularly hot year). Similarly, government policies (e.g., with respect to providing additional health services to counter detrimental climate effects) may only adapt to changing climate conditions after some time and when such changes are not mean-reverting. When adaptation effects matter, the effect of *short-run weather shocks* on out-migration may overestimate the *long-run effect of climate change* on migration by not allowing for economic agents to (fully) adapt to changing climate conditions.

Considering *intensification effects*, the idea is that the full adverse effects of weather shocks do not materialize instantaneously. For instance, due to persistent climate change individual effects are likely to accumulate, so that in the long run arable land may permanently vanish due to desertification, salinization, or rising sea levels. Similarly, persistent climate change may allow pathogen vectors to become native in new habitats, meaning that diseases become endemic and national health suffers. Thus, the existence of intensification effects would increase the effect of climate change on out-migration compared to short-run effects by, for example, magnifying economic losses in agriculture (depressing agricultural wages and employment) that would have already incentivized out-migration. Consequently, in the presence of intensification effects, we would underestimate the long-run effect of climate change on migration when only considering shorter-run impacts.

2.4 | Initial levels of economic development and temperature

To further understand possible adaptation or intensification effects, we may also need to account for contextual conditions. These conditions are more important when we investigate long-term developments because a country's vulnerability might bear bigger consequences in the long run. At the same time, the possibilities to adapt also increase. In this contribution, we focus on the roles of *economic development* and *initial climate conditions* as moderators, following earlier research that examines similar moderating variables (e.g., Beine & Parsons, 2017; Cattaneo & Peri, 2016; Maurel & Tuccio, 2016).

Concerning the role of economic development, we expect richer countries to be less vulnerable to the ill effects of climate change, while also being able to adapt more easily to them. Consequently, richer countries ought to see less out-migration due to climate change than their poorer counterparts (Cattaneo & Peri, 2016). For instance, richer countries tend to be less reliant on agriculture, so that any detrimental effects from climate change on agricultural production are less likely to be felt (Beine & Parsons, 2017; Maurel & Tuccio, 2016). Similarly, richer countries tend to be more economically diversified (so that economic shocks in specific economic sectors due to climate change ought to be less influential) and have better access to technology to counter the ill effects of weather shocks and climate change on human health as well as agricultural and industrial productivity (via the use of irrigation, fertilizers, air conditioning, etc.).

Furthermore, concerning the role of initial climate conditions, we anticipate countries with more moderate initial temperatures to be less vulnerable to climate change, meaning that they ought to see less out-migration as a consequence of them. For instance, there is evidence that economic production and human health are nonlinearly related to increasing temperatures, with very high temperatures being especially detrimental to economic productivity and human health (e.g., in the form of heat strokes) (e.g., Burke & Emerick, 2016). Consequently, we expect a utility-maximizing potential migrant to respond more strongly to climate change in those parts of the world that are already hot to begin with.

2.5 | Hypotheses

We began our discussion of potential linkages between climate change and migration by arguing that climatic shocks affect the calculus of a utility-maximizing migrant. In line with the mainstream view of migration as a response to climate change, we expect these shocks to unfavorably affect country-specific conditions in sending countries (reducing agricultural activity and economic growth, increasing political instability, etc.), making out-migration a more attractive option:

Hypothesis 1: Climate change leads to more migration

We then argued that the effect of climate change on migration may also be conditional upon the education profile of prospective migrants. On one hand, such shocks are expected to incentivize low-skilled migration more strongly than high-skilled migration. On the other hand, they are also anticipated to more severely exacerbate the liquidity constraints of low-skilled migrants, discouraging low-skilled migration more strongly than high-skilled migration. Whether the former *incentive effect* or the latter *liquidity constraint effect* dominates is an empirical question that leads to the following hypothesis:

> *Hypothesis 2*: Climate change differently affects low- and high-skilled migration

We also discussed potential differences of short-run weather and long-run climate changes due to the countervailing impact of adaptation and intensification effects. Whether the former or latter effects dominate is, again, an empirical question we shall answer below along the following two hypotheses:

> *Hypothesis 3a*: The effect of short-run weather changes on migration is stronger than the long-run effect of climate change (dominance of adaptation effects)

> *Hypothesis 3b*: The effect of short-run weather changes on migration is weaker than the long-run effect of climate change (dominance of intensification effects)

Finally, we discussed the roles of economic development and initial climate conditions. Here, we anticipate richer or colder countries to be less vulnerable and more adaptable to the adverse effects of weather and climate changes, therefore experiencing less out-migration. This leads to our final hypotheses:

> *Hypothesis 4*: Short-run weather and long-run climate changes lead to more migration especially in less developed and hotter countries

2.6 | Climate change and barriers to migration

Our arguments that climate change ought to induce additional out-migration are consistent with the literature that considers migration as an adaptive strategy to climate change (e.g., Berlemann & Steinhardt, 2017; IPCC, 2014). Still, it is possible that climate change does not lead to more international migration, primarily as it erects additional barriers to migration. First, and according to the liquidity constraints argument mentioned earlier, climate change may induce economic downturns and thus reduce the resources available to finance out-migration, which could, in turn, adversely affect international migration. Second, health problems and the dangers of political instability may make it more difficult for potential migrants to travel.[6]

Finally, it is also possible that climate change does not only erect barriers to migration but also induces favorable political change. For instance, for a sample of sub-Saharan African countries, Brückner and Ciccone (2011) find that negative rainfall shocks are followed by improvements in political institutions (i.e., by a move toward more democracy). They argue that democratic concessions become more likely during climate-induced economic downturns as the opportunity costs of protest are relatively low (because economic participation is constrained). If climate change induces democratic change, this may make out-migration less attractive because factors that accompany democratic reform (e.g., political participation and free speech) are expected to increase utility at home. Indeed, Ashby (2010) provides evidence that more political freedom in the migrants' source country makes migration less likely.

In sum, there are reasons to expect that climate change might—contrary to the mainstream view—lead to less international migration when economic downturns, poor health, political instability, and political improvements due to climate change make it sufficiently more difficult or less attractive to leave one's country. At a minimum, it is possible that such effects could (1) reduce the overall augmenting effect of climate change on international migration or (2) counteract this augmenting impact, contributing to a *null-finding* when we study the effect of climate change on migration.

3 | DATA

To test our hypotheses, we use data on climate and migration (by different education levels) for a sample of 121 countries; a country list is provided in Table A1 in the Appendix. The choice of the sample is due to the fact that the migration data set we employ considers out-migration to 20 OECD destination countries.[7] We therefore drop these 20 countries from the analyses. We also exclude countries for which data are not available either because they are too small or because they are not independent for the whole observation period. As the migration data are available for the 1980–2010 period, our analyses consider this observation period. Furthermore, as the migration data are only available for 5-year intervals, all remaining variables are averaged over each interval accordingly. The summary statistics are presented in Table 1.

3.1 | Migration data

The migration variables are drawn from the *IAB Brain Drain Dataset* published by the *German Institute for Employment Research* and described in more detail in Brücker et al. (2013). This data set provides data on international migration by country of origin and level of education to 20 OECD destination countries. To examine whether the effect of climate change differs with the level of education of migrants, we use three different migration indicators. In detail, we extract (1) the *low-skilled migration rate*, where "migration rate" refers to the proportion of migrants from a source country over the pre-migration population (i.e., residents and migrants) with the same skill level and "low-skilled" refers to lower secondary or primary education or no schooling at all.[8] We also extract (2) the *high-skilled migration rate* (higher than high-school leaving certificate or equivalent) and (3) the *total migration rate* (combines all skill levels, including medium-skilled migration).

Figure 1 provides a graphical representation of the patterns of low- and high-skilled migration over our observation periods. First, there is a clear trend toward higher migration rates regardless of the level of education. For instance, low-skilled migration rates roughly double between 1978–1982 and 2008–2012. Second, high-skilled migration rates are always much higher than low-skilled migration,

TABLE 1 Summary statistics

Variable	*N**T	Mean	Std. dev.	Min.	Max.
Total migration rate	847	0.046	0.078	0.001	0.488
Low-skilled migration rate	847	0.034	0.067	0.001	0.427
High-skilled migration rate	847	0.193	0.205	0.001	0.996
Temperature (population-weighted)	847	21.979	5.712	−1.732	29.348
Precipitation (population-weighted)	847	12.46	7.815	0.355	35.29
Temperature (non-weighted)	847	22.055	6.086	−0.96	29.10
Precipitation (non-weighted)	847	12.253	8.337	0.314	33.607

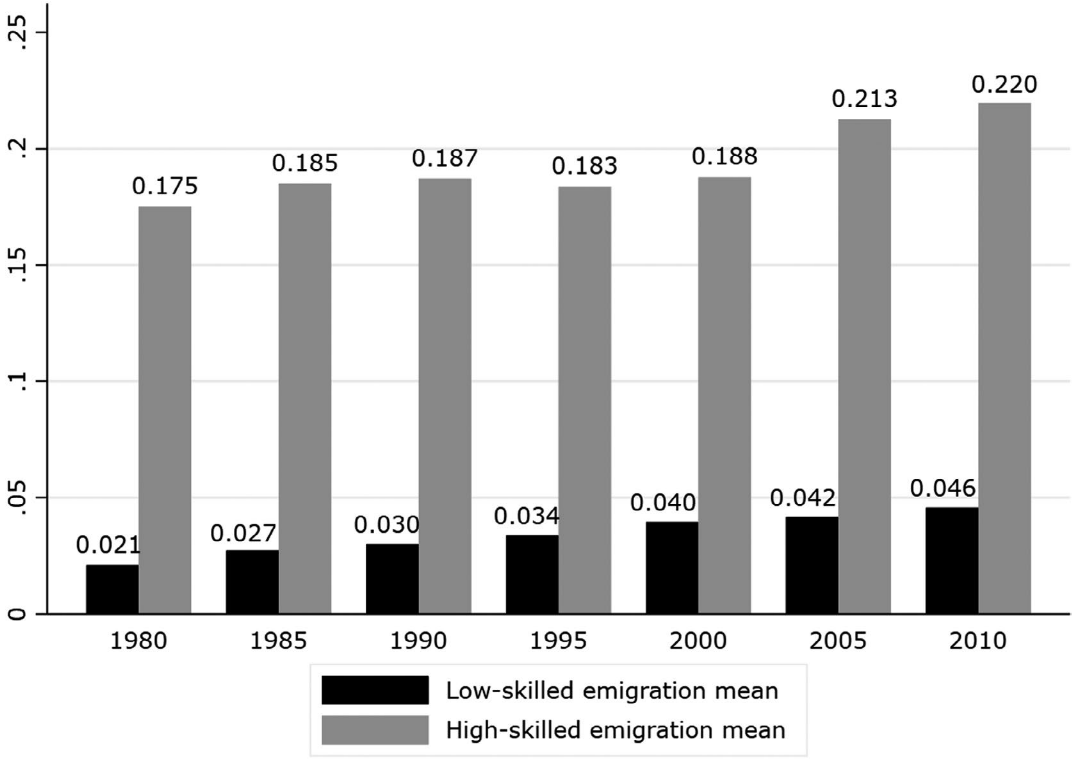

FIGURE 1 Mean migration rates in sample, 1978–2012. 1980 refers to average over 1978–1982; 1985 refers to average over 1983–1987; etc

consistent with the notion of positive selection of high-skilled labor (Grogger & Hanson, 2011). For instance, in 2008–2012 the high-skilled migration rate was approximately five times larger than the low-skilled migration rate.

3.2 | Climate data

The data on the climate variables are drawn from the *Climate Research Unit of the University of East Anglia*.[9] This research unit provides climate data collected from various weather stations. We spatially aggregate these data to correspond to the country-level; this aggregation is necessary because the weather data themselves are interpolated to a 0.5*0.5 degree grid resolution.

As a first set of climate indicators, we use *population-weighted* temperature (in °C) and precipitation (in 100 mm) data per country and 5-year period, so that climate conditions in more populated areas are more influential for the country-period-level data-point. As a robustness check, we also use *average* temperature and precipitation data. That is, we simply average all weather station data for a specific country of interest and time period.

As shown in Figure 2, average temperatures increased by approximately 0.8°C during our period of observation, consistent with the notion of global warming (e.g., IPCC, 2014). Changes in precipitation patterns are less clear-cut. While there is some variation in average precipitation levels for our observation period, there is no clear long-run trend. Again, this is consistent with the IPCC (2014), which also stresses that climate change leads to a redistribution (rather than outright loss or gain) in total precipitation, with some countries seeing decreases and others increases in precipitation levels.

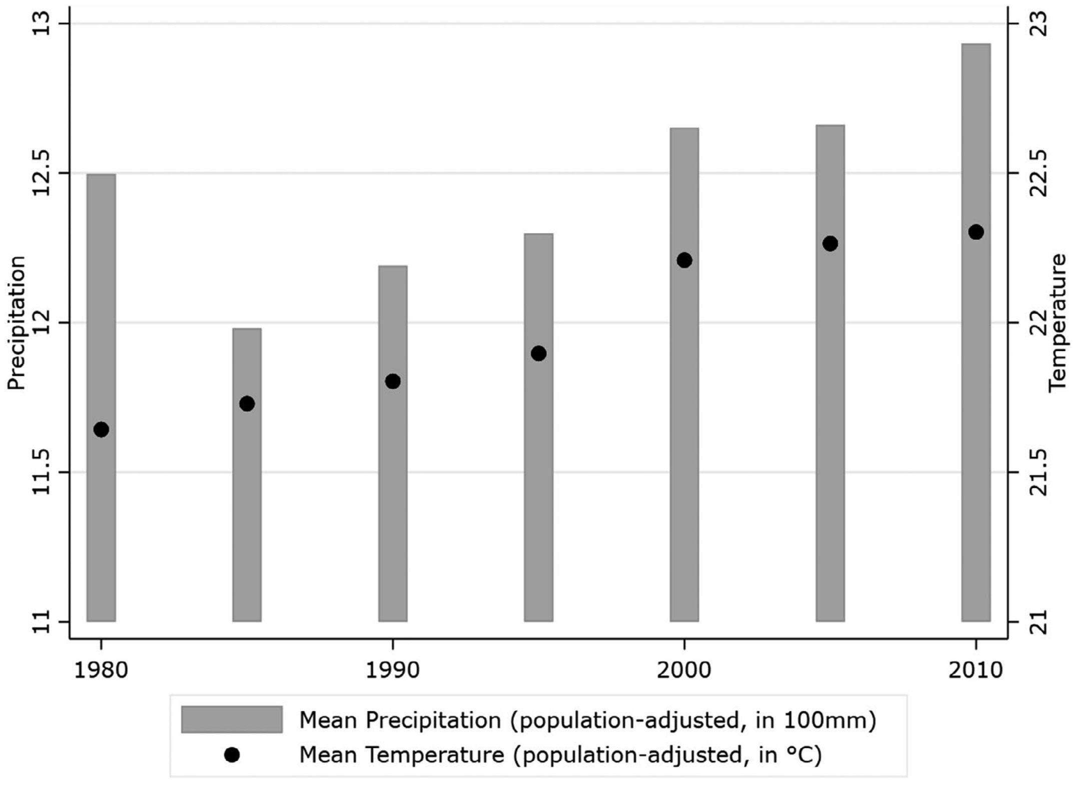

FIGURE 2 Mean temperature and precipitation in sample, 1978–2012. 1980 refers to average over 1978–1982; 1985 refers to average over 1983–1987; etc

4 | SHORT-RUN WEATHER CHANGES AND MIGRATION

4.1 | Unconditional effects

We first assess whether short-run weather changes have an unconditional effect on out-migration, as hypothesized in *H1*. We estimate a model of the following form:

$$MIG_{jit} = \theta_i + \beta_1 * T_{it} + \beta_2 * P_{it} + \tau_t Reg_r + \tau_t Poor_i + \tau_t Hot_i + \varepsilon_{it}. \quad (1)$$

MIG refers to the *j*th measure of migration from country *i* at period *t* (*t* = 1978–1982, 1983–1987, 1988–1992, etc.); it measures either the total, low-skilled, or high-skilled migration rate.[10] By accounting for different levels of migrant education, we can test *H2*. *T* and *P* refer to a country's population-adjusted or average temperature and precipitation during the same period, respectively. Following Auffhammer et al. (2013, p. 188), we control for both variables simultaneously "to obtain unbiased estimates of the effects of changes in precipitation and temperatures," given that both variables tend to be strongly correlated (for our sample the correlation is $r = 0.33$, $p < .01$ for the population-adjusted data and $r = 0.28$, $p < .01$ for the unadjusted data). The regression coefficients associated with the climate variables (β_1 and β_2) correspond to their short-run effects on out-migration. This is because the associated estimates are always conditioned on country-fixed effects (θ) and thus refer to deviations of temperature and precipitation from (long-run) country-specific temperature and precipitation means captured by the fixed effects.

Besides a well-behaved error term (ε), the model also includes period dummies (τ) to account for period-specific effects. These period dummies are interacted with region dummies (*Reg*) to control for regional trending.[11] Finally, the period dummies are also interacted with dummy variables that are equal to unity when a country is "poor" (*Poor*) or when a country is "hot" (*Hot*), respectively; this allows us to account for differences in time variation between "poor" and "non-poor" as well as "hot" and "non-hot" countries. Here, using data from the *World Development Indicators* (World Bank, 2017), countries are categorized as "poor" when their life expectancy at birth is below the median in 1975 (this median is approximately 58.4 years).[12] They are categorized as "hot" when their (population-adjusted) temperature in 1975 is above the global median (this median is approximately 23.5°C).

As advised by Berlemann and Steinhardt (2017), Equation 1 refers to a deliberately parsimonious specification designed to capture the *total effect* of the climate variables on migration. That is, we do not include covariates that may constitute potential pathways from climate change to migration (agricultural variables, indicators of political institutions and instability, etc.). For all models, we compute robust standard errors clustered at the country-level.

Our empirical results are presented in Table 2. In short, these results provide little evidence that short-run weather changes (i.e., deviations in temperature and precipitation from country-means) share a clear-cut association with immigration. First, temperature changes do not affect out-migration by any skill level. Second, positive precipitation changes tend to lead to more total emigration. On closer inspection, this result is driven by low-skilled migration, whereas we cannot draw meaningful conclusions concerning the influence of precipitation on high-skilled migration. Our results imply that a one-unit increase in precipitation (i.e., an increase in population-adjusted precipitation by 100 mm) is associated with an increase in the total and low-skilled migration rate by 0.003 points; estimated effect

TABLE 2 Short-run weather changes and migration (panel estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	Type of migration					
	Total	**Low-skilled**	**High-skilled**	**Total**	**Low-skilled**	**High-skilled**
Temperature	−0.006	−0.004	−0.018	−0.004	−0.003	−0.017
	(0.005)	(0.005)	(0.019)	(0.004)	(0.005)	(0.019)
Precipitation	0.003	0.003	−0.003	0.002	0.002	−0.004
	(0.001)***	(0.001)***	(0.003)	(0.001)**	(0.001)**	(0.003)
Climate data	POP	POP	POP	MEAN	MEAN	MEAN
Country-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Period × regional fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Period × poor fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Period × hot fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Within-R^2	0.503	0.363	0.278	0.499	0.360	0.279
No. of observations	847	847	847	847	847	847
No. of countries	121	121	121	121	121	121

Notes: POP = climate data weighted by population size. MEAN = climate data not weighted (mean over all climate station data per country). Cluster-robust standard errors in parentheses.

$^{**}p < .5$; $^{***}p < .01$.

sizes are smaller when we do not adjust the climate data for the population distribution. At the sample mean, an increase in population-adjusted precipitation by 100 mm would thus increase the total migration rate (low-skilled migration rate) by approximately 6.5% (8.8%). The finding that increases in precipitation lead to more migration may be due to two factors. First, more precipitation may indicate stronger extreme weather-related events (e.g., floods) that encourage migration. Second, increases in precipitation could also result in increased agricultural productivity and wages, consequently easing liquidity constraints and facilitating out-migration (e.g., Cattaneo & Peri, 2016).

In sum, our first hypothesis (*H1*) postulating an unconditional and positive effect of short-run weather changes on migration receives no unambiguous support from the data: changing precipitation but not temperature patterns matter to out-migration. In particular, changes in precipitation only affect low- but not high-skilled migration, while temperature changes do not affect the two types of migration. Thus, *H2* is also only partially supported by the data.

4.2 | Conditional effects

Potentially, poorer or hotter countries may see more out-migration in response to weather shocks due to their lower adaptability and higher vulnerability (*H4*). To test these propositions, we follow Dell et al. (2012) and Cattaneo and Peri (2016) and estimate a series of equations of the following form:

$$MIG_{jit} = \theta_i + \beta_1 * T_{it} + \beta_2 * P_{it} + \beta_3 * \left(T_{it} * Poor_i\right) + \beta_4 * \left(P_{it} * Poor_i\right) \\ + \beta_5 * \left(T_{it} * Hot_i\right) + \beta_6 * \left(P_{it} * Hot_i\right) + \tau_t Reg_r + \tau_t Poor_i + \tau_t Hot_i + \varepsilon_{it}. \quad (2)$$

Equation 2 amends Equation 1 by four terms that interact temperature and precipitation with the indicator variables *Poor* and *Hot*, respectively. To examine the presence of conditional effects, we can assess the effect of temperature (and precipitation) on out-migration in "poor" and "non-poor" countries by evaluating β_1+β_3 and β_1 (and β_2+β_4 and β_2 for precipitation), respectively. Correspondingly, we can investigate the effect of temperature (and precipitation) on out-migration in "hot" and "non-hot" by considering β_1+β_5 and β_1 (and β_2+β_6 and β_2 for precipitation), respectively. For all models, we again compute robust standard errors clustered at the country-level.

Our empirical results are presented in Table 3. First, we find that temperature changes (i.e., deviations from temperature country-means) are not associated with more out-migration, regardless of which type of migration we consider and whether we distinguish between poor and rich as well as hot and cold countries. Second, there is some evidence that the migration-inducing effect of positive precipitation shocks in the unconditional model (cf. Table 2) for total and low-skilled migration is driven by the effect in "hot" countries. That is, we find that a one-unit increase in precipitation (an additional 100 mm in precipitation) increases the total migration rate (the low-skilled migration rate) by 0.005 (0.006) points. At the sample mean, an increase in population-adjusted precipitation by 100 mm would thus increase the total migration rate (low-skilled migration rate) in hot countries by approximately 14.7% (17.6%). Here, a 100 mm precipitation increase is roughly equal to one-eighth of a standard deviation or equal to an increase in annual precipitation by approximately 8% at the sample mean.

In sum, these findings are not in line with *H4* when we operationalize weather shocks as temperature deviations from long-run means. Temperature shocks do not result in more emigration from relatively poor or hot countries; there is also little evidence that different educational groups might be affected to different degrees. However, focusing on precipitation deviations from long-run means, there is some evidence that low-skilled labor is especially responsive, particularly in initially hotter

TABLE 3 Moderating roles of initial temperature and level of development (short-run weather changes)

	(1)	(2)	(3)
	Type of migration		
	Total	**Low-skilled**	**High-skilled**
Temperature effect in rich and cold countries	−0.004	−0.006	−0.001
(β_1)	(0.008)	(0.008)	(0.020)
Temperature effect in poor countries	0.005	0.004	−0.022
(β_1+β_3)	(0.007)	(0.006)	(0.032)
Temperature effect in hot countries	−0.013	−0.008	0.005
(β_1+β_5)	(0.010)	(0.010)	(0.034)
Precipitation effect in rich and cold countries	0.003	0.003	−0.004
(β_2)	(0.001)**	(0.001)**	(0.004)
Precipitation effect in poor countries	−0.001	−0.002	−0.003
(β_2+β_4)	(0.002)	(0.002)	(0.007)
Precipitation effect in hot countries	0.005	0.006	−0.004
(β_2+β_6)	(0.002)**	(0.002)***	(0.005)
Country-fixed effects	Yes	Yes	Yes
Period × regional fixed effects	Yes	Yes	Yes
Period × poor fixed effects	Yes	Yes	Yes
Period × hot fixed effects	Yes	Yes	Yes
Within-R^2	0.429	0.337	0.179
No. of observations	847	847	847
No. of countries	121	121	121

Notes: Climate data weighted by population size. Cluster-robust standard errors in parentheses. β-coefficients refer to Equation 2 in main text.

**$p < .5$; ***$p < .01$.

countries. As argued earlier, this may indicate that such precipitation shocks may ameliorate liquidity constraints by improving agricultural output, where the low-skilled are expected to be especially affected by such constraints and thus be especially responsive to them (by increasing migration) when they are eased.

5 | CLIMATE CHANGE AND MIGRATION

In the previous section, we have shown that *short-run weather changes* (operationalized as deviations of temperature and precipitation from country-specific long-run means) share no statistically meaningful association with high-skilled migration. By contrast, there is some evidence that precipitation shocks encourage low-skilled migration, while temperature shocks do not matter to it. In this section, we study how *long-run climate change* is linked to out-migration. As discussed above, due to adaptation or intensification effects, long-run estimates of the effect of changes in temperature and precipitation on migration may differ from short-run estimates (*H3a* and *H3b*).

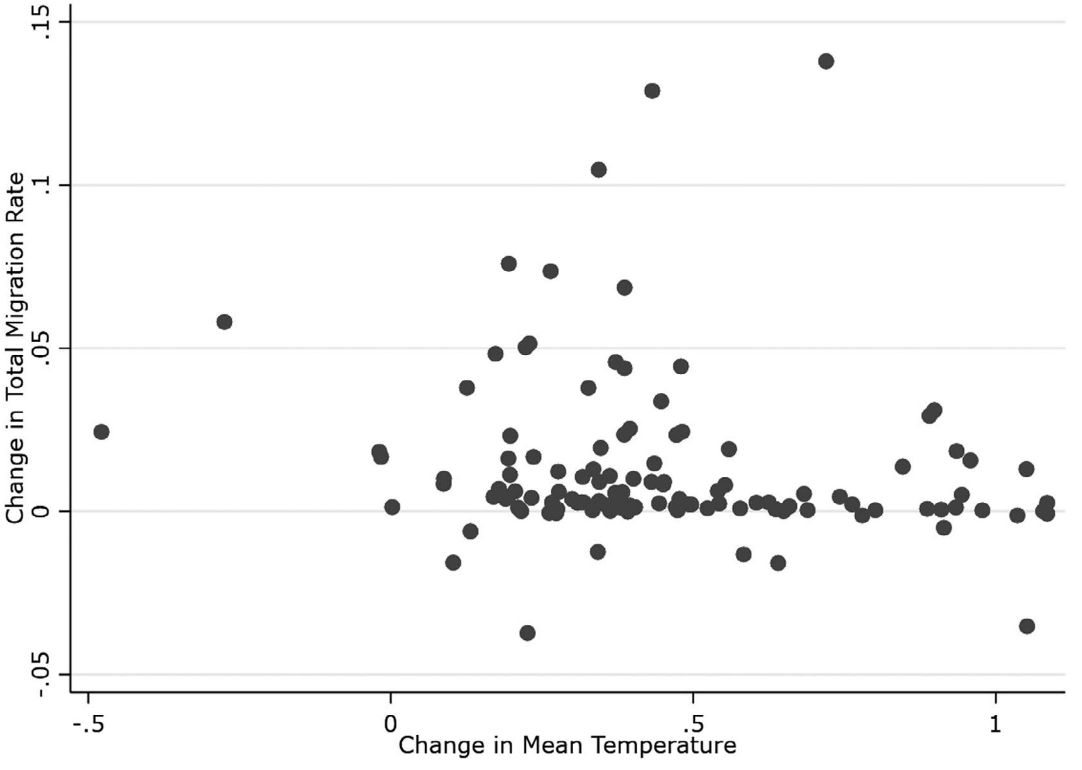

FIGURE 3 Long-run changes in migration and temperature. Change refers to the differences between the 1982–1997 and 1998–2012 averages

Figure 3 shows that many countries in our sample saw a persistent increase in temperature—consistent with the notion of global warming—between 1980 and 2010. However, this trend toward higher temperatures is not uniform across all countries, with some countries experiencing almost no or even negative changes in mean temperature (e.g., Bolivia) and others seeing an increase of over 1°C (e.g., Uganda and Jordan). Below, we exploit this variation in temperature changes (and precipitation changes) to explain the similarly diverse variation in out-migration over the same time period. Figure 3 plots the changes in total migration against changes in mean temperature and shows substantial variation in both variables. For the plotted cases, there seems to be no (significant) long-run relationship between the variables. Due to varying adaptation strategies across different migrant groups (low- versus high-skilled) and different levels of adaptability and vulnerability across countries (e.g., hot versus cold), different relationships may, however, emerge for other variable pairs.

5.1 | Unconditional effects

To estimate the long-run effect of climate change on out-migration, we use the *long-difference approach* outlined in Dell et al. (2012), Dell et al. (2014) and Burke and Emerick (2016). We first test for an unconditional effect of climate change on migration, consistent with *H1*. In detail, we compare country-specific circumstances in migration and climate change between a "late" period

(1998–2012) and an "early" period (1982–1997)[13] to identify long-run effects, using the following estimation equation:

$$\overline{MIG}_{ji2} - \overline{MIG}_{ji1} = \propto + \beta_1 * \left[\overline{T}_{i2} - \overline{T}_{i1}\right] + \beta_2 * \left[\overline{P}_{i2} - \overline{P}_{i1}\right] + Reg_r + Poor_i + Hot_i + \varepsilon_i. \quad (3)$$

Here, $\overline{MIG}_{ji2}$ is the mean migration rate (in its *j*-th form) in country *i* in the "late" period (1998–2012), from which we subtract the mean migration rate in the "early" period (1982–1997), $\overline{MIG}_{ji1}$. We create corresponding mean-differences for the population-adjusted temperature and precipitation data series. A set of regional dummies (*Reg*) as well as dummies indicating "poor" and "hot" countries (*Poor* and *Hot*) are also included. The constant (α) is equivalent to a dummy variable for the 1998–2012 period, thus accounting for trending in the dependent variable between the "early" and "late" period. After creating all first-differences, we obtain a cross-sectional data set of 121 observations. For all models, we compute heteroskedasticity-robust standard errors.

The empirical results associated with Equation 3 are presented in Table 4.[14] First, these findings suggest that climate change in the form of increasing temperatures has no statistically significant impact on out-migration, irrespective of the migrant group we consider. Second, there is evidence that increases in precipitation are positively associated with low-skilled and total migration. As before, we find that this effect is driven by the effect of precipitation on low-skilled migration. We find that a one-unit increase in population-adjusted precipitation increases the low-skilled migration rate by 0.07 points.

As argued by Dell et al. (2012, 2014), the long-difference estimate can be interpreted as capturing the influence of potential adaptation or intensification effects and therefore be directly compared with

TABLE 4 Climate change and migration (long-difference estimates)

	(1)	(2)	(3)	(4)	(5)	(6)
	Type of migration					
	Δ Total	**Δ Low-skilled**	**Δ High-skilled**	**Δ Total**	**Δ Low-skilled**	**Δ High-skilled**
Δ Temperature	0.004	0.014	−0.035	0.005	0.017	−0.051
	(0.014)	(0.016)	(0.058)	(0.013)	(0.015)	(0.060)
Δ Precipitation	0.007	0.007	−0.007	0.007	0.005	−0.010
	(0.002)***	(0.003)**	(0.009)	(0.003)**	(0.003)*	(0.009)
Climate data	POP	POP	POP	MEAN	MEAN	MEAN
1997–2012 dummy	Yes	Yes	Yes	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes
Poor country dummy	Yes	Yes	Yes	Yes	Yes	Yes
Hot country dummy	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.488	0.363	0.297	0.471	0.347	0.305
No. of observations	121	121	121	121	121	121
No. of countries	121	121	121	121	121	121

Notes: POP = climate data weighted by population size. MEAN = climate data not weighted (mean over all climate station data per country. Compares 1982–1997 and 1998–2012 periods. Δ = First-difference operator. Robust standard errors in parentheses.

*$p < .1$; **$p < .5$; ***$p < .01$.

any short-run estimates that do not reflect adaptation or intensification effects. Indeed, considering the influence of precipitation, we find that a one-unit (100 mm) increase in precipitation leads to an increase in low-skilled migration by 0.07 points (CI 95%: 0.09; 0.05) in the long-difference setting (cf. Table 4, Model 2), while it only leads to a 0.03 points increase (CI 95%: 0.04; 0.02) in the panel setting that only gauges short-run effects (cf. Table 2, Model 2). Given that the associated confidence intervals do not overlap, this suggests that the effect of positive precipitation shocks on low-skilled emigration becomes stronger in the long run. This is consistent with the notion of an intensification effect. For instance, it appears plausible that long-run gains in precipitation translate into sustainable gains in agricultural production and wages that allow low-skilled labor to build up savings to finance their eventual migration. On the flip side, the same estimates suggest that long-run losses in precipitation appear to intensify liquidity constraints (e.g., by depressing economic productivity) and thus reduce low-skilled migration more strongly in the long run.

By contrast, the results concerning temperature are less clear-cut. For instance, the long-difference estimates indicate that a 1°C increase in temperature leads to a (statistically insignificant) 0.014 point *increase* (CI 95%: −0.002; +0.030) in the low-skilled migration rate (cf. Table 4, Model 2), while in the panel setting the same increase leads to a (statistically insignificant) 0.004 point *decrease* (CI 95%: −0.009; +0.001) (cf. Table 2, Model 2). In sum, these results may suggest that adaptation and intensification effects are not overly influential in the unconditional setting. However, the long-run estimates are also less precise than their panel counterparts; this makes it less likely to obtain statistically significant findings. For one, moving from a panel to a cross-sectional setting means that we substantially reduce the variability of the data by removing its time dimension. For another, by taking differences we further amplify any measurement errors, so that precisely estimated regression coefficients become even less likely.

5.2 | Conditional effects

To further investigate the role of climate change in out-migration, we finally estimate a model that accounts for conditional effects due to initial cross-country difference in economic development and temperature, allowing us to test *H4* in the long-difference setting:

$$
\begin{aligned}
\overset{!!}{MIG}_{ji2}-\overset{!!}{MIG}_{ji1} =& \propto+\beta_1*\left[\overset{!!}{T}_{i2}-\overset{!!}{T}_{i1}\right]+\beta_2*\left[\overset{!!}{P}_{i2}-\overset{!!}{P}_{i1}\right]+\beta_3*\left(\left[\overset{!!}{T}_{i2}-\overset{!!}{T}_{i1}\right]*Poor_i\right)\\
&+\beta_4*\left(\left[\overset{!!}{P}_{i2}-\overset{!!}{P}_{i1}\right]*Poor_i\right)+\beta_5*\left(\left[\overset{!!}{T}_{i2}-\overset{!!}{T}_{i1}\right]*Hot_i\right)\\
&+\beta_6*\left(\left[\overset{!!}{P}_{i2}-\overset{!!}{P}_{i1}\right]*Hot_i\right)+Reg_r+Poor_i+Hot_i+\varepsilon_i.
\end{aligned} \tag{4}
$$

As in Equation 3, we compare the effect of changes of climate variables between the "late" and "early" period (1982–1997 and 1998–2012, respectively) on migration rates of different levels of education. We now also consider whether countries are initially "poor" and "hot" to allow for conditional effects. For all models, we compute heteroskedasticity-robust standard errors.

The estimation results associated with Equation 4 are presented in Table 5. First, the results suggest that *both* long-run temperature and precipitation increases result in long-run increase in total migration, especially in "hot" countries. Differences in initial levels of economic development, on the contrary, do not translate into different migration responses to climate change. Second, these results are driven by the effect of climate change on low-skilled migration. By contrast, we cannot precisely

TABLE 5 Moderating roles of initial temperature and level of development (climate change)

	(1)	(2)	(3)
	Type of migration		
	Δ Total	**Δ Low-skilled**	**Δ High-skilled**
Temperature effect in rich and cold countries	0.012	0.022	−0.012
(β_1)	(0.023)	(0.021)	(0.043)
Temperature effect in poor countries	0.002	0.005	−0.031
(β_1+β_3)	(0.012)	(0.011)	(0.061)
Temperature effect in hot countries	0.033	0.043	0.063
(β_1+β_5)	(0.019)*	(0.019)**	(0.055)
Precipitation effect in rich and cold countries	0.011	0.013	0.014
(β_2)	(0.005)**	(0.007)*	(0.015)
Precipitation effect in poor countries	0.003	0.001	0.017
(β_2+β_4)	(0.005)	(0.006)	(0.017)
Precipitation effect in hot countries	0.011	0.012	−0.010
(β_2+β_6)	(0.004)***	(0.004)***	(0.012)
1997–2012 dummy	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes
Poor country dummy	Yes	Yes	Yes
Hot country dummy	Yes	Yes	Yes
R^2	0.453	0.373	0.214
No. of observations	121	121	121
No. of countries	121	121	121

Notes: Climate data weighted by population size. Compares 1982–1997 and 1998–2012 periods. Δ = first-difference operator. Robust standard errors in parentheses. β-coefficients refer to Equation 4 in main text.

**p* < .1; ***p* < .5; ****p* < .01.

estimate the effect of changing climate conditions on high-skilled migration in the long run even after we account for initial economic and climate conditions. This speaks to the overall observation that estimates concerning the effects of temperature and precipitation on high-skill migration are too noisy to draw any meaningful conclusions.

The conditional model thus provides evidence in favor of a number of our hypotheses. First, we find evidence that climate change more strongly affects out-migration in more vulnerable countries, especially hotter ones, partially confirming *H4*. Second, there is evidence that for hotter countries, climate change especially matters to low-skilled migration. One reason for this differential effect on migration may be that low-skilled labor is employed in the agricultural sector which is particularly vulnerable to climate change (e.g., Burke & Emerick, 2016; Carter et al., 2018); this in turn is likely to result in especially strong migration response. The latter result also implies that the incentive effect (which encourages low-skilled migration due to climate change) trumps the liquidity constraint effect (which would make out-migration by the low-skilled less likely).

Finally, comparing the results of Table 5 and Table 3 suggests that intensification effects (*H3b*) rather than adaptation effects (*H3a*) explain differences in migration response in the short and long run, especially concerning the role of temperature in out-migration. Indeed, in the long-difference setting 1°C increase in temperature is associated with a (statistically significant) 0.043 increase in low-skilled migration (CI 95%: 0.024; 0.062) (cf. Table 5, Model 2), which needs to be compared with (statistically insignificant) 0.008 decrease in low-skilled migration (CI 95%: −0.018; +0.002) due to the same temperature increase in the short-run setting (cf. Table 3, Model 2). That is, consistent with the prevalence of intensification effects, we underestimate the effect of temperature increases on low-skilled migration in the short-run panel setting.

In fact, the long-run effect of temperature on low-skilled migration in hot countries is very pronounced. The estimated effect implies that—at the sample mean—a 1°C increase in temperature would more than double the low-skilled migration rate. Furthermore, as temperature already increased by approximately 0.85°C from 1880 to 2012 and may easily increase by 1–3°C in the coming decades (IPCC, 2014), these estimates point to potentially very strong increases in low-skilled migration induced by climate change.

6 | CONCLUSION

We study the effect of shorter-run weather shocks and longer-run climate change on migration from 121 developing and emerging countries to 20 OECD countries between 1980 and 2010. We find that both increasing temperatures and precipitation levels matter to the patterns of migration. Furthermore, our results show that especially the eventual effect of increasing temperatures on out-migration is conditional upon initial climate conditions in sending countries (which likely affect a country's vulnerability and adaptability to climate change). Importantly, increasing temperatures and precipitation levels only matter to low-skilled migration, while we cannot draw statistically meaningful conclusions concerning their impact on high-skilled migration. These findings speak to our hypothesis that different education levels are linked to different levels of vulnerability to climate change and thus different migratory responses to it. While increases in precipitation tend to encourage low-skilled migration in both conditional and unconditional as well as short- and long-run frameworks, the effect of increasing temperatures on low-skilled out-migration only materializes in the longer run, pointing to the adverse impact of intensification effects especially in already initially hotter parts of the world.

The main attribute of climate change is an increase in global temperatures (e.g., IPCC, 2014). Our study suggests that to fully gauge the impact of global warming on out-migration, a long-run perspective is necessary. Given the non-mean reverting nature of climate change, such a perspective is more likely to account for both intensification effects and adaptation strategies at both the country and individual levels that are very likely to change over time. Thus, we recommend future research to also use a long-difference approach. Such an approach is particularly promising when conditional effects are investigated. We have seen that especially initial temperature levels help us understand the effect of climate change on out-migration. We invite future research to explore such conditional effects even more thoroughly by looking at political and institutional factors, for example. Finally, our research suggests that skill levels play an important role in explaining migration decisions. It thus appeared that not all people are equally vulnerable and responsive to climate change. We recommend that future research takes a closer look at migrant characteristics to better understand migration decisions in the context of climate change. A major limitation of such an approach is the scarcity of individual-level data. It is thus important that future data collections allow such differentiations.

Our empirical analysis indicates that increasing temperatures and changing precipitation patterns lead to increased migration of low-skilled labor from less developed to OECD countries. Thus, by encouraging migration climate change is expected to have labor market consequences in both sending and destination countries. For instance, while the emigration of low-skilled workers may lead to labor shortages in sending countries, OECD countries may benefit from low-skilled migrants in certain economic sectors for which they have difficulties to find native workers. Moreover, migrants are often relatively young, which might help sustain the pension system in aging OECD societies. At the same time, however, OECD economies tend to prefer high- over low-skilled migrants. Since the 1970s, many Western states have implemented policies to attract high-skilled professionals and deter low-skilled migrants (e.g., Cerna, 2014; Kolbe & Kayran, 2019). Such policies are motivated by concerns over labor market and wage competition between immigrants and natives in low-wage sectors. These concerns are also reflected in public opinion: survey research shows that there exists a large consensus among ordinary citizens to accept high-skilled rather than low-skilled migrants (Hainmueller & Hopkins, 2014).

In sum, we expect increases in low-skilled migration that are induced by climate change—as found by our study—to also have potentially undesirable economic and political ramifications in sending and destination countries. As climate change can be expected to influence migration patterns in the future, too, our estimates may consequently prompt political action from OECD countries. In addition to a reduction in greenhouse gas emissions, policy measures by OECD countries may, for example, include adequate access to agricultural technology and expertise to reduce the vulnerability of economies in hotter parts of the world to climate change.

ACKNOWLEDGMENTS

We are very grateful to Fabien Cottier, Simon Hug, Vally Koubi, Matto Mildenberge, the anonymous referees, and the participants of presentations we gave at the WZB Berlin Social Science Center, the Berlin Institute for Integration and Migration Research (BIM) and of the annual meetings of the America Political Science Association and the European Political Science Association for their comments that helped us improve this paper. This project was financially supported by the Leibniz Association (Project IMPETUS, K36/2017).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are accessible under the following link: https://data.mendeley.com/datasets/wf75xt47km/1.

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ENDNOTES

[1] There are also a number of additional case studies examining the link between climate change and migration for specific countries. These studies are reviewed in Piguet (2010), Lilleør and van den Broeck (2011), Dell et al. (2014), Millock (2015), and Berlemann and Steinhardt (2017).

[2] There is some case study evidence concerning differences in the migratory response to weather and climate shocks between individuals who differ with respect to their levels of education, income, or other socioeconomic traits (e.g., Bazzi, 2017; Findley, 1994; Gray & Bilsborrow, 2013; Gray & Mueller, 2012a, 2012b; Thiede et al., 2016). However, while informative, findings from these studies do not allow for generalizations, for example, because they only consider individual countries or because they study the migratory response to specific types of weather disasters only (see also Piguet, 2010).

[3] Throughout this contribution and consistent with the literature, we differentiate between “low-skilled” and “high-skilled” workers. As also discussed later, “low-skilled” workers refer to individuals with lower secondary or primary

education or no schooling at all, while "high-skilled" individuals have an education higher than a high-school leaving certificate (Brücker et al., 2013).

[4] Alternative theories of international migration are discussed in, inter alia, Massey et al. (1993) and Bauer and Zimmermann (1998).

[5] For a review of the literature on climate and conflict, see Burke, Hsiang, and Miguel (2015).

[6] We thank an anonymous reviewer for raising these points.

[7] These countries are Australia, Austria, Canada, Chile, Denmark, Finland, France, Germany, Greece, Ireland, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

[8] Formally, Brücker et al. (2013, p. 6) define the emigration rate (*MIG*) for skill level e from source country i in period t as: $MIG_{ite} = \frac{M^i_{OECD20_{et}}}{R^i_{et} + M^i_{OECD20_{et}}}$, where $R^i_{s,e,t}$ denotes the total number of residents in source country i and $M^i_{OECD20_{s,e,t}}$ measures the stock of immigrants from i summed over all 20 destination countries. Only individuals born abroad and aged 25 years or older are considered.

[9] http://www.cru.uea.ac.uk/data.

[10] Other studies on the climate-migration nexus take the natural logarithm of the migration rates instead. If we follow their example as a robustness check, this does not affect our empirical results.

[11] In detail, the variable *Reg* refers to a set of seven dummy variables for the following world regions: Central Africa, Southern Africa, the Middle East and North Africa, North and Central America, South America, Europe, and Southern Asia and the Pacific Islands (with the rest of Asia excluded as the reference group).

[12] Alternatively, a country's level of economic development could be measured by its level of per capita income. However, per capita income data are not available for many countries in our sample especially before 1990. For instance, per capita income data are not reliably available for conflict-prone or data-poor countries such as Afghanistan. We therefore use life expectancy as our preferred measure of economic development; as expected, life expectancy strongly and positively correlates with per capita income ($r = 0.79$, $p < .01$). Furthermore, as a robustness check, we also use per capita income in 1990 to divide the sample into "poor" and "non-poor" economies. Dividing the sample in this manner, we arrive at findings that are very similar to those reported in the main text (see Appendix Tables A2 and A3).

[13] Note that we drop the data for the first 5-year average (1978–1982). In so doing, we can compare two (long-run) periods of equal size, which is consistent with previous descriptions of the long-difference approach (e.g., Dell et al., 2012). Here, we drop the first 5-year average because we expect climate and migration data for this period to be comparatively less accurate compared to later observation periods. However, as a robustness check we also run additional long-difference estimations where we include data for the first 5-year average in the first long-difference period, meaning that we compare the 1975–1997 with the 1998–2012 period. These additional long-difference estimations are very similar to those reported in the main text (See Appendix Tables A4 and A5).

[14] Note that the results from the first-difference model are identical to results from a two-period fixed-effects model, given the mathematical equivalence of the first-difference and fixed-effects model in the two-period case.

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How to cite this article: Helbling M, Meierrieks D. How climate change leads to emigration: Conditional and long-run effects. *Rev Dev Econ*. 2021;25:2323–2349. https://doi.org/10.1111/rode.12800

APPENDIX

TABLE A1 List of countries

Afghanistan[†]	**Cyprus**	**Kuwait**[*]	**Romania**
Albania	Djibouti[*,†]	Laos[*,†]	Rwanda[†]
Algeria[†]	Dominican Republic[*]	Lebanon	Saint Vincent and the Grenadines[*]
Angola[†]	Ecuador	Lesotho[†]	Sao Tome and Principe
Argentina	Egypt[†]	Liberia[*,†]	Saudi Arabia[*]
Bahamas[*]	El Salvador[*,†]	Libya	Senegal[*,†]
Bangladesh[*,†]	Equatorial Guinea[*,†]	Madagascar[†]	Sierra Leone[*,†]
Belgium	Ethiopia[†]	Malawi[†]	Solomon Islands[*]
Belize[*]	Fiji[*]	Malaysia[*]	Somalia[*,†]
Benin[*,†]	Gabon[*,†]	Mali[*,†]	South Africa[†]
Bhutan	Gambia[*,†]	Mauritania[*,†]	Sri Lanka[*]
Bolivia[†]	Ghana[*,†]	Mauritius	Sudan[*,†]
Botswana	Guatemala[†]	Mexico	Suriname[*]
Brazil	Guinea[*,†]	Moldova	Swaziland[†]
Brunei[*]	Guinea-Bissau[*,†]	Mongolia[†]	Syria
Bulgaria	Guyana[*]	Morocco[†]	Tanzania[†]
Burkina Faso[*,†]	Haiti[*,†]	Mozambique[*,†]	Thailand[*]
Burundi[†]	Honduras	Myanmar[*,†]	Togo[*,†]
Cambodia[*,†]	Hungary	Nepal[†]	Trinidad and Tobago[*]
Cameroon[*,†]	Iceland	Nicaragua[*,†]	Tunisia
Cape Verde	India[*,†]	Niger[*,†]	Turkey
Central African Republic[*,†]	Indonesia[*,†]	Nigeria[*,†]	Uganda[†]
Chad[*,†]	Iran[†]	Oman[*]	United Arab Emirates[*]
China	Iraq	Pakistan[†]	Uruguay
Colombia	Israel	Panama[*]	Venezuela[*]
Comoros[*,†]	Italy	Papua New Guinea[*,†]	Vietnam[*]
Congo, Dem. Rep.[†]	Jamaica[*]	Paraguay	Zambia[†]
Congo, Rep.[*,†]	Japan	Peru	Zimbabwe
Costa Rica	Jordan	Philippines[*]	
Cote d'Ivoire[*]	Kenya[†]	Poland	
Cuba[*]	Korea, South	Qatar[*]	

*Indicates "hot" country;

†Indicates "poor" country.

TABLE A2 Moderating roles of initial temperature and level of development (short-run weather changes, different definition of "poor")

	(1)	(2)	(3)
	Type of migration		
	Total	**Low-skilled**	**High-skilled**
Temperature effect in rich and cold countries	−0.005	−0.013	−0.029
(β_1)	(0.011)	(0.016)	(0.024)
Temperature effect in poor countries	0.012	0.018	0.020
(β_1+β_3)	(0.009)	(0.013)	(0.036)
Temperature effect in hot countries	−0.022	−0.021	−0.058
(β_1+β_5)	(0.013)	(0.020)	(0.040)
Precipitation effect in rich and cold countries	0.001	0.002	−0.003
(β_2)	(0.001)	(0.002)	(0.005)
Precipitation effect in poor countries	0.001	−0.001	−0.001
(β_2+β_4)	(0.002)	(0.002)	(0.007)
Precipitation effect in hot countries	0.004	0.006	−0.004
(β_2+β_6)	(0.002)*	(0.002)***	(0.005)
Country-fixed effects	Yes	Yes	Yes
Period × regional fixed effects	Yes	Yes	Yes
Period × poor fixed effects	Yes	Yes	Yes
Period × hot fixed effects	Yes	Yes	Yes
Within-R^2	0.446	0.359	0.184
No. of observations	770	770	770
No. of countries	110	110	110

Notes: Climate data weighted by population size. Cluster-robust standard errors in parentheses. β-coefficients refer to Equation 2 in main text.

*$p < .1$; ***$p < .01$.

TABLE A3 Moderating roles of initial temperature and level of development (climate change, different definition of "poor")

	(1)	(2)	(3)
	Type of migration		
	Δ Total	**Δ Low-skilled**	**Δ High-skilled**
Temperature effect in rich and cold countries	−0.014	−0.017	−0.077
(β_1)	(0.025)	(0.034)	(0.053)
Temperature effect in poor countries	0.019	0.035	0.011
(β_1+β_3)	(0.017)	(0.025)	(0.066)
Temperature effect in hot countries	0.014	0.014	0.005
(β_1+β_5)	(0.004)**	(0.004)**	(0.067)
Precipitation effect in rich and cold countries	0.007	0.007	0.008
(β_2)	(0.005)	(0.005)	(0.018)
Precipitation effect in poor countries	0.004	0.002	0.022
(β_2+β_4)	(0.005)	(0.005)	(0.019)
Precipitation effect in hot countries	0.011	0.011	−0.012
(β_2+β_6)	(0.004)***	(0.004)***	(0.014)
1997–2012 dummy	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes
Poor country dummy	Yes	Yes	Yes
Hot country dummy	Yes	Yes	Yes
R^2	0.503	0.426	0.221
No. of observations	110	110	110
No. of countries	110	110	110

Notes: Climate data weighted by population size. Compares 1982–1997 and 1998–2012 periods. Δ = first-difference operator. Robust standard errors in parentheses. β-coefficients refer to Equation 4 in main text.

**$p < .5$; ***$p < .01$.

TABLE A4 Climate change and migration (long-difference estimates, different first long-difference period)

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Type of migration					
	Δ Total	**Δ Low-skilled**	**Δ High-skilled**	**Δ Total**	**Δ Low-skilled**	**Δ High-skilled**
Δ Temperature	0.010	0.015	0.003	0.014	0.019	−0.013
	(0.016)	(0.016)	(0.057)	(0.017)	(0.016)	(0.060)
Δ Precipitation	0.009	0.008	−0.005	0.008	0.006	−0.009
	(0.003)***	(0.003)***	(0.009)	(0.003)**	(0.003)**	(0.009)
Climate data	POP	POP	POP	MEAN	MEAN	MEAN
1997–2012 dummy	Yes	Yes	Yes	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes
Poor country dummy	Yes	Yes	Yes	Yes	Yes	Yes
Hot country dummy	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.469	0.364	0.173	0.453	0.349	0.181
No. of observations	121	121	121	121	121	121
No. of countries	121	121	121	121	121	121

Notes: Climate data weighted by population size. Compares 1975–1997 and 1998–2012 periods. Δ = first-difference operator. Robust standard errors in parentheses.

**$p < .5$; ***$p < .01$.

TABLE A5 Moderating roles of initial temperature and level of development (climate change, different first long-difference period)

	(1)	(2)	(3)
	Type of migration		
	Δ Total	**Δ Low-skilled**	**Δ High-skilled**
Temperature effect in rich and cold countries	0.018	0.023	−0.006
(β_1)	(0.026)	(0.026)	(0.059)
Temperature effect in poor countries	0.005	0.007	−0.049
(β_1+β_3)	(0.017)	(0.015)	(0.081)
Temperature effect in hot countries	0.025	0.040	0.078
(β_1+β_5)	(0.016)*	(0.020)**	(0.071)
Precipitation effect in rich and cold countries	0.012	0.012	0.002
(β_2)	(0.006)**	(0.006)*	(0.013)
Precipitation effect in poor countries	0.003	−0.001	0.007
(β_2+β_4)	(0.005)	(0.005)	(0.017)
Precipitation effect in hot countries	0.013	0.013	−0.007
(β_2+β_6)	(0.004)***	(0.004)***	(0.014)
1997–2012 dummy	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes
Poor country dummy	Yes	Yes	Yes
Hot country dummy	Yes	Yes	Yes
R^2	0.488	0.390	0.192
No. of observations	121	121	121
No. of countries	121	121	121

Notes: Climate data weighted by population size. Compares 1975–1997 and 1998–2012 periods. Δ = first-difference operator. Robust standard errors in parentheses. β-coefficients refer to Equation 4 in main text.

*$p < .1$; **$p < .5$; ***$p < .01$.