Journal of Development Economics 122 (2016) 127–146

Contents lists available at ScienceDirect

Journal of Development Economics

journal homepage: www.elsevier.com/locate/devec

The migration response to increasing temperatures

Cristina Cattaneo[a,*], Giovanni Peri[b]

[a] Fondazione ENI Enrico Mattei and CMCC, Corso Magenta, 63, 20123 Milan, Italy
[b] Department of Economics, UC Davis, One Shields Avenue, Davis, CA 95616, USA

ARTICLE INFO

Article history:
Received 5 October 2015
Received in revised form 8 February 2016
Accepted 24 May 2016
Available online 31 May 2016

JEL classification:
F22
Q54
O13

Keywords:
Global warming
Emigration
Rural–urban migration
Agricultural productivity

ABSTRACT

Climate change, especially the warming trend experienced in recent years by several countries, could affect agricultural productivity. As a consequence the income of rural populations will change, and with it the incentives for people to remain in rural areas. Using data from 115 countries between 1960 and 2000, we analyze the effect of differential warming trends across countries on the probability of either migrating out of the country or from rural to urban areas. We find that higher temperatures in middle-income economies increased migration rates to urban areas and to other countries. In poor countries, higher temperatures reduced the probability of migration to cities and to other countries, consistently with the presence of severe liquidity constraints. In middle-income countries, migration represents an important margin of adjustment to global warming, potentially contributing to structural change and even increasing income per worker. Such a mechanism, however, does not seem to work in poor economies.
© 2016 Elsevier B.V. All rights reserved.

1. Introduction

One of the best demonstrated long-run effects of rising average surface temperature is its negative effect on productivity in agriculture. The optimal yield of agricultural products has been adjusted to local temperature for centuries and many studies (e.g. Burke et al., 2015) have shown that agricultural GDP peaks at the average yearly temperature of around 14 °C and declines for higher temperatures. Hence, as most of the world population and economic activity reside in countries with average temperatures around or above 14°, several studies find that productivity decreases as temperature increases beyond a country's historical average (Burke et al., 2015; Cline, 2007; Dell et al., 2014; IPCC, 2014). While some studies find that non-agricultural GDP may also decline for yearly temperatures above 14–15°, it also appears that the productivity decline is less steep and less precisely measured for non-agricultural sectors (see Fig. 2d and e in Burke et al., 2015). Agriculture is still a very relevant source of income and employment in poor countries, especially in rural areas. One potentially important margin of adjustment to declining agricultural productivity in poor countries is migration from rural to urban areas, either within the home country or towards another country. While some papers have begun to analyze how warming may affect income per person across countries over the long run (e.g. Dell et al., 2012), and other studies have analyzed the connection between temperature/precipitation and human migration in some specific countries (e.g. Bohra-Mishra et al., 2014; Dillon et al., 2011; Gray and Mueller, 2012a; Mueller et al., 2014), few studies look at the systematic long-run effect of temperature change on emigration and rural-to-urban migration in poor and middle-income countries in the world.[1] This paper gathers data and proposes a model and simple empirical framework to analyze the impact of temperature change on emigration rates in countries where agriculture is still an important sector and many migrants originate from rural areas.

By impoverishing the rural population of poor countries and worsening their income perspectives, long-term warming may affect migration in different ways, depending on the initial income of those rural populations. As previously suggested by studies such as

* Corresponding author.
E-mail addresses: cristina.cattaneo@feem.it (C. Cattaneo), gperi@ucdavis.edu (G. Peri).

[1] Cai et al. (2014) is probably the paper most closely related to ours. It analyzes specifically the link between temperature, crop yields and migration to OECD countries. However, they use yearly data between 1980–2000 and only migration to OECD countries, therefore capturing short-run relationships and long distance migration.

http://dx.doi.org/10.1016/j.jdeveco.2016.05.004
0304-3878/© 2016 Elsevier B.V. All rights reserved.

Mayda (2010), a decline in the income of the sending country may have a depressing effect on the share of emigrants from very poor countries. In these countries, individuals of rural communities are near subsistence, so a lower income worsens their liquidity constraint, implying that potential migrants have a reduced ability to pay migration costs. In this case, global warming may trap very poor rural workers, making them unable to leave agriculture and potentially worsening their poverty. To the contrary, in countries in which individuals are not extremely poor, a decline in agricultural income may provide incentives to migrate to cities or abroad. Decreasing agricultural productivity may encourage a mechanism that ultimately leads to shifting people out of agriculture into urban environments. The inverted U-shape of migration rates as a function of income per person in the countries of origin is usually rationalized in this type of framework. However, we are not aware of a simple formalization of this model nor of a clean analysis which tests this non-monotonic effect by exploiting variation of an exogenous determinant of productivity, such as temperature.

In this paper we are the first to extend the classical Roy–Borjas model (Borjas, 1987; Roy, 1951) and we use this framework to analyze the effects of exogenous changes in agricultural productivity (due to temperature increase) and its opposite effects on the probability of emigration for poor or middle-income countries. In particular, the model predicts that a long-run increase in temperature decreases the income of rural populations in very poor countries, generates a poverty trap and lowers the probability of emigration. To the contrary, in middle-income countries the decline in agricultural productivity pushes emigrants out of rural areas. This stimulates urbanization and may speed the country's structural transformation, ultimately increasing its income per person. In accordance with the model's predictions, we find that in very poor countries increasing temperature leads to lower emigration and urbanization rates, while in middle-income countries it leads to larger rates. We also show that long-run temperature increase speeds the transition away from agriculture in middle-income countries. Conversely, it slows this transition in poor countries – worsening the poverty trap – as poor rural workers become less likely to move to cities or abroad. We also find, for middle-income countries, emigration induced by higher temperature is local and is associated with growth in average GDP per person, while the decline in emigration and urbanization in poor countries is associated with lower average GDP per person.

The literature has emphasized the relationship between temperature and income per person is likely nonlinear. Changes in income/productivity are either relatively small or even positive for average yearly temperatures between 10 and 20 $^\circ$ C, while a decline occurs for temperatures above a threshold located around 20/25°. This implies that increases in temperature are more damaging, especially in agricultural output, above a certain value. In our analysis, we consider this type of nonlinearity by testing whether temperature increases have a nonlinear positive (or negative) effect on the migration probability of its citizens. We emphasize, however, that the behavior of migration with respect to temperature largely depends on the initial income of the country of origin. Similarly, a productivity decline will have a different effect in poor or middle-income countries due to prevailing liquidity constraints or incentive mechanisms. We find that the nonlinearity of the temperature effect is less relevant than the interaction of temperature with initial income for the migration response. Poor countries experience different temperature effects on migration relative to middle-income countries because of their lower income (likely to worsen liquidity constraints) and not because they are also hot.

The rest of the paper is organized as follows. Section 2 reviews the literature on climate and international migrations. Section 3 presents a simple variation of the Borjas–Roy model relating agricultural productivity to migration rates at different income levels. Section 4 describes the data and variables, and Section 5 presents the main empirical specifications and the main estimates of the effects of warming on migrations. Section 6 shows some robustness checks, and Section 7 checks that the climate–migration connection is consistent with the estimated effects of climate on structural change and GDP across countries. Section 8 concludes the paper.

2. Literature review

The literature analyzing the effects of weather and climate events on migration is recent and growing. Several papers have analyzed the impact of episodes of drought, high temperature, or low precipitation on rural emigration in specific countries.[2] Because of its extreme poverty and its dependence on agricultural production, Sub-Saharan Africa has received great attention. Most of the existing studies on this area analyze the year-to-year correlation between weather phenomena and migration, and mainly identify temporary displacements rather than long-term trends. In multi-country studies of Sub-Saharan Africa, Barrios et al. (2006) analyze the link between average rainfall and urbanization, and Marchiori et al. (2012) estimate how temperature and precipitation anomalies have affected migration.

A case that has also been studied in depth is the connection between weather/climate and migration out of Mexico. Looking at Mexico–US migration, Munshi (2003) is the first to show the connection between low rainfall and migration rates. More recently, Feng et al. (2010) confirm the relation between weather and migration from Mexico. However, Auffhammer and Vincent (2012) demonstrate that this effect vanishes after they control for a richer set of covariates.

Overall, the existing literature on weather change and migration focuses on within country data or uses yearly migration rates. Hence it fails to provide a general picture of the potential long-run effect of weather changes on migration within and across countries that span a range of income levels. Beine and Parsons (2015) use decade data, but they do not directly tackle the question regarding the effect of changes in average temperature on migration in the long-run. The paper produces an accurate study that focuses on bilateral migration and analyzes the impact of extreme weather events, deviations and anomalies in temperatures from the long-run averages, after one controls for many other bilateral factors. An even more recent paper by Backhaus et al. (2015) performs a similar analysis on yearly data, considering average temperature as the main explanatory variable. Both of these papers focus on partial effects of temperature and of extreme weather events as they control for productivity and income of country of origin. We think, however, the more relevant question is to identify the total effect of temperature on emigration, test interactions with the income level of the country of origin, disentangle potential nonlinearities in temperature and suggest potential channels and explanations.

Our paper does exactly this. It differs from previous work by considering all countries of the world, explicitly analyzing the effects of temperature on internal and international migration within a simple Roy–Borjas model of migration and average productivity. In so doing, we are able to identify a crucial and plausible distinction of the effect of temperature increases on migration from poor and middle-income countries and test whether such a distinction, and other

[2] Some examples follow: Dillon et al. (2011) analyzed migration in Nigeria. Mueller et al. (2014) look at the connection between temperature variation and migration in Pakistan. Gray and Mueller (2012a) consider the link between droughts and emigration in Ethiopia, while Gray and Mueller (2012b) analyze the effect of flood on mobility in Bangladesh. Gray and Bilsborrow (2013) and Gray (2009) analyze internal and international migration in Ecuador in response to rainfall. Henry et al. (2004) look at the case of annual precipitation and migration in Burkina Faso. Bohra-Mishra et al. (2014) analyze Indonesia and Kelley et al. (2015) focus on Syria.

additional implications, are supported by the data. The interaction of temperature with initial income turns out to be more crucial than the nonlinearity of the temperature effect in shaping the relation between temperature and migration. Moreover, our analysis of international migration, as well as urbanization (driven by internal migration), provides consistent results for internal and international migration. This consistency adds credibility to our results.

Differently from Beine and Parsons (2015) and Backhaus et al. (2015), we do not control for income and productivity, but consider their variation as a pathway that links temperature and migration. As income and productivity are affected by temperature (and not independent of it) our approach allows the identification of the total impact of temperature on migration, rather than isolating its partial effect, and then assesses the potential channels. A paper close to our approach, in that it estimates the total effect of temperature on migration, is Cai et al. (2014). The authors analyze how yearly bilateral migration flows depend on yearly temperatures for a panel of 163 countries of origin into 42 OECD destinations for the period 1980–2010. The structure of the analysis implies these are short-run elasticity responses (within the year) and the analysis only includes migration to OECD countries. The authors do not separate between poor and middle-income countries, nor do they look at internal migration. They use potentially noisy data on gross flows of migrants, instead of Census-based data on net migrations. Significant short-run temporary migration can be captured by that design. We are the first paper to provide long-run impacts of slow-changing temperature and precipitation on internal and international migration rates for poor and middle-income countries.

3. A simple framework

3.1. The migration decision

Consider two countries defined as "Poor", P, and "Middle-Income", M, where workers – who are potential migrants to a third country, "Rich", R– live and work. We consider a very simple two-period model, in the spirit of Roy–Borjas (Borjas, 1987; Roy, 1951), that delivers a "hump-shaped" emigration rate as a function of the country of origin's income per person (consistently with the empirical literature from Zelinsky, 1971 to Hatton and Williamson, 1994, 2003, 2011). While the Roy model is broadly used in the analysis of migrant selection, we are not aware of any paper that extends it to explain the hump-shaped relation between migration rate and income per person. Hence we find it useful to present it, compactly, in its entirety.

In the first period, individuals differ in their skills, work in their country of origin (P or M), and earn the local wage. At the beginning of the second period, individuals choose between migrating to country R or staying in their country, based on the comparison of their wage in the second period. If they stay in the country of origin they earn w_{iJ}. If they migrate to R they earn w_{iR}, but must pay up-front monetary and non-monetary migration costs. Without loss of insight we assume individuals have 0 discount rate, the wage in the country of origin for periods 1 and 2 are identical, and no uncertainty exists. The wage of individual i in country of origin J ($J = P, M$) in the first and second periods can be written as:

$$w_{iJ} = \mu_J + \beta_J \varepsilon_i \quad J = P, M \tag{1}$$

where μ_J is the basic income/wage in country J earned by a person with median skills. We can imagine that this term depends positively on agricultural productivity – among other factors – especially as the economy of country P and M depends on agriculture-related sectors. Through agricultural productivity, therefore, the median income in country J depends on its temperature T_J, expressed as: $\mu_J(T_J)$. The term β_J represents the return to skills in country J. The term ε_i is a measure of skills of individual i that we assume, for simplicity, as being normally distributed with an average of 0 and a standard deviation of 1. If the same individual were to migrate to country R he/she would earn the following wage instead:

$$w_{iR} = \mu_R + \beta_R \varepsilon_i \tag{2}$$

For simplicity we have assumed that the skills of the individual, measured by ε_i, are perfectly transferable from P or M to country R. However, the returns to skills in country R are different than in the origin country. Following strong evidence from the existing literature (Grogger and Hanson, 2011; Ortega and Peri, 2012) we assume that the rich country has higher median wage and higher skill premium than the poor and middle-income countries. Moreover, following most of the literature on climate change (Dell et al., 2014), we assume temperature changes have an effect on agricultural productivity (relevant for country $J = P, M$), but not (or much less) on non-agricultural productivity (relevant for country R). Therefore, the dependence of μ_R on T_J can be ignored. These assumptions correspond to the following restrictions on the parameters: $\mu_R > \mu_J$ and $\beta_R > \beta_J$ for $J = P, M$.[3] For simplicity, we also assume the distribution of skills, ε_i, is identical in country P and M and the cost of migrating from either of them to R, the rich country, is equal and can be expressed as $(C_{Mon} + C_{Non})$, where C_{Mon} are monetary costs of migrating – such as cost of relocating, traveling, and searching – while C_{Non} are the non-monetary (psychological) costs. Both are expressed in units of labor compensation. Following Grogger and Hanson (2011), we assume individuals have linear preferences in their net wages (i.e. wages net of migration costs) and, within this very simple framework, the decision to migrate for individual i implies a comparison between the net income when migrating and staying. Thus, the individual will migrate from country J to R if:

$$\mu_R + \beta_R \varepsilon_i - C_{Mon} - C_{Non} > \mu_J + \beta_J \varepsilon_i, \tag{3}$$

or more simply:

$$\varepsilon_i > \frac{\mu_J(T_J) - \mu_R + C_{Mon} + C_{Non}}{\beta_R - \beta_J}. \tag{4}$$

In the literature, condition (4) has been typically thought of as a "selection" equation. The parameter restriction $\beta_R > \beta_J$ implies "positive selection". Namely, only individuals with skills above a certain level have incentives to migrate. This is consistent with abundant evidence as summarized, for instance, in Docquier et al. (2011). Alternatively, we can see Eq. (4) as an incentive-compatible constraint. Namely, individuals from country J will migrate only if their gains from migration (wages at destination) exceed the opportunity cost (wage at home) plus migration costs (monetary and non-monetary). The lower the threshold in Eq. (4), the larger is the share of individuals for which the incentive constraint is satisfied.

The migration decision must also satisfy a "feasibility" constraint. If we assume that migration takes place at the beginning of the second period and individuals in country P and M cannot borrow (liquidity constraint), then they can migrate only if the monetary costs of migration do not exceed their total savings at the end of period 1, which, in our simple model, is at most equal to w_{iJ}. With

[3] Under these assumptions, and if costs of migration are equal between M and R, P and R, and P and M, we do not have to consider potential migration between P and M, as workers from either country would want to migrate to R.

labor as the only source of income and assuming that monetary costs of migration must be paid up front, the feasibility condition – or liquidity constraint – can be written simply as:

$$\mu_J(T_J) + \beta_J\varepsilon_i > C_{Mon} \tag{5}$$

or:

$$\varepsilon_i > \frac{C_{Mon} - \mu_J(T_J)}{\beta_J} \tag{6}$$

3.2. Implications on emigration rates

The fraction of people who will migrate from country J is equal to one minus the cumulative density of a normal distribution at the highest of the two thresholds defined in Eqs. (4) and (6). For each country, only one of the two thresholds can be binding. It is easy to see that the "incentive-compatible" threshold (4) is increasing in the "median" income $\mu_J(T_J)$, while the "liquidity-constraint" threshold (6) is decreasing in it. The monotonicity of the two thresholds implies that there is a value of $\mu_J^*\left(T_J^*\right)$ for which they are identical and we consider that value as marking the divide between "Poor" (P) and "Middle income" (M) countries.[4] Hence, this model provides two very clear predictions:

Proposition 1. *For middle-income countries, an increase in average temperature is associated with an increase in the emigration rate.*

Proof. For countries whose median income is higher than $\mu_J^*(T_J^*)$, defined as middle-income countries, M, only the threshold (4) is binding. Hence the share of people migrating is the one with skills above that threshold, given by:

$$\frac{Mig_M}{Pop_M} = 1 - \Phi\left(\frac{\mu_J(T_J) - \mu_R + C_{Mon} + C_{Non}}{\beta_R - \beta_J}\right) \tag{7}$$

where Φ is the CDF of a standard normal distribution. The expression on the right hand side is decreasing in μ_J (because the CDF Φ is a monotonically increasing function). If we assume that increases in temperature T decrease basic agricultural productivity μ_J, then the expression is increasing in T_J. ■

Proposition 2. *For poor countries an increase in average temperature is associated with a decrease in the emigration rate.*

Proof. For countries whose median income is lower than $\mu_J^*\left(T_J^*\right)$, defined as poor countries, P, differently than for the other group, only the liquidity threshold (6) is binding. Hence the share of people migrating is the one with skills above that threshold, given by:

$$\frac{Mig_P}{Pop_P} = 1 - \Phi\left(\frac{C_{Mon} - \mu_J(T_J)}{\beta_J}\right) \tag{8}$$

where Φ is the CDF of a standard normal distribution. The expression on the right hand side is now increasing in μ_J. If, as before, we assume that increases in temperature T decrease median productivity μ_J, then the expression above would be decreasing in T_J. ■

The intuition in both cases is straightforward. Lower agricultural productivity implies lower median income. In middle-income countries this effect increases the incentive (and hence the probability) of migrating and hence raises the emigration rate, as in those countries the liquidity constraint does not bind. In poor countries, instead, the liquidity constraint is binding. Hence, lower agricultural productivity makes people poorer, decreasing their ability to pay migration costs, hence reducing the emigration rate. For these countries the incentive to migrate is very high, but individuals are simply too poor to afford migration, which is only worsened by lower agricultural productivity.

By taking logarithms and log-linearizing both sides of each Eqs. (7) and (8) and merging them into one equation, we obtain the basic equation for our analysis. Namely, considering a generic country j that can be M (middle-income) or P (poor) we can write:

$$\ln\left(\frac{Mig_j}{Pop_j}\right) = \alpha + \gamma \ln T_j + \gamma_P \ln T_j * D(j \in P) + \beta C_j \tag{9}$$

In Eq. (9) the dependent variable is the natural logarithm of the migration rates from country j and it depends on the logarithm of the average temperatures in the country, $\ln T_j$. To capture the different dependence in poor and middle-income countries, we allow for a linear term whose coefficient γ captures the effect of temperature on emigration rates in middle-income countries. We then add an interaction with the dummy $D(j \in P)$ that is equal to 1 if country j is a poor country, for which the "liquidity threshold" is binding and 0 otherwise. With this notation, the parameter γ captures the elasticity of emigration rates to average temperature for medium-income countries and $\gamma + \gamma_P$ captures the elasticity for poor countries. The term C_j captures potential determinants of migration costs in country of origin j. Let us also notice that if we interpret "R'' as the urban areas and M and P as the rural areas in the middle-income or poor country, the model above can be interpreted as a model of rural-to-urban migration. Even in that case, it makes sense that migration is skill-intensive and the incentive condition affects migration in middle-income countries, while the liquidity constraint affects it in poor countries. Hence, the consequence of warming would be more urbanization in middle-income countries, but less urbanization in very poor countries. The prediction of the model can be summarized, within the compact format of expression (9) above, as follows:

1. As the average temperature of a middle-income country increases, reducing its agricultural productivity relative to urban productivity, we expect workers to migrate abroad and to the cities at higher rate. Therefore the model predicts $\gamma > 0$.
2. As the average temperature of a poor country increases, reducing its agricultural productivity, we expect workers whose average income is very low to have fewer resources to pay for their migration possibilities. Therefore the model predicts $\gamma + \gamma_P < 0$.

Our empirical analysis focuses on estimating the link between temperature and emigration, and will provide important evidence to evaluate the predictions of the model.

4. Data and summary statistics

In order to test the empirical predictions of the model, we merge data on the average temperature and on international migration and urbanization for all available countries in the world between

[4] That value is defined as: $\mu_J^*\left(T_J^*\right) = \frac{(\beta_R - \beta_J)C_{Mon} + \beta_J(\mu_R - C_{Mon} - C_{Non})}{\beta_R}$

1960 and 2000.[5] The data on temperatures are taken from Dell et al. (2012). In our empirical specifications we also control for a measure of annual precipitation, whose long-run behavior can affect agricultural productivity. This variable is used as a control in Dell et al. (2012) because changes in precipitation can be an important aspect of long-run climate trends affecting agricultural productivity. Moreover, given that precipitation and temperature are historically correlated, both temperature and precipitation need to be included in the empirical specification to obtain unbiased coefficients (Auffhammer et al., 2013). The (terrestrial) monthly mean temperature and precipitation data at $0.5 \times 0.5^{\circ}$ resolution, obtained from weather stations (Matsuura and Willmott, 2007), are aggregated into country-year averages using the population in 1990 at 30 arc second resolution (CIESIN et al., 2004) as weights. In an alternative approach, used as a robustness check, the weather station data are averaged using area, rather than population, weights. In some specifications, in order to analyze whether long-term warming affects countries by increasing the probability of extreme weather events, we also include the incidence of droughts, floods, storms and extreme heat as controls. Those data are taken from the International Disaster Database compiled by the Centre for Research on the Epidemiology of Disasters (Guha-Sapir et al., 2015).

The migration data are taken from Ozden et al. (2011), and include bilateral migrant stocks between 115 countries in the last five available census years spanning the period from 1960 to 2000. The advantage of these data is that they include migrations from 115 countries to 115 countries, so many more destinations than only considering OECD (as done in Cai et al., 2014). The other advantage is that the sources of these data are national Censuses, and the data are much more accurate in counting foreign-born individuals as compared to flow measures. The data are only available every ten years and hence we can capture long-run migration tendencies but not short-run temporary migration flows. Our analysis is focused on long-run relationships.

Drawing from the bilateral data, we compute net emigration flows as differences between stocks in two consecutive Censuses. We first sum all net flows for the same countries of origin and compute emigration rates as the ratio between the aggregate net flow of emigrants in the decade relative to the origin country population at the beginning of the decade.[6] The data on urbanization rates are taken from the World Urbanization Prospects (UN, 2014). They measure the share of the population of a country living in urban areas between 1950 and 2000 available over ten year intervals. Data on the value added in agriculture are from the World Development Indicators (World Bank, 2015). For GDP per capita the main sources are the Penn World Table (2009) and the World Development Indicators (World Bank, 2015).

Consistently with our model, the set of countries of origin we consider for our analysis are those that can be considered “poor” or “middle-income” according to their income per person. These are the countries for which temperature changes may have the largest productivity effect because agriculture contributes a significant share of GDP. To define poor and middle-income countries we first keep only non-OECD countries for a total of 115 countries as part of our sample.[7] We then consider poor countries those in the bottom quartile of the non-OECD income per capita distribution, PPP-adjusted and measured in 1990.[8] According to this definition, we identify a list of 30 poor countries, and 85 middle-income countries (see the Data Appendix for each list). Given that there is no clear definition of a poor country, we conduct some robustness checks to detect whether modifying the threshold implies different results. The countries near the threshold between poor and middle-income, with this definition, are those with yearly income per person around $1500 in 1990. This is a low threshold and it implies a large share of the “poor” countries are in Sub-Saharan Africa. For rural population in these countries the liquidity constraint is clearly very relevant as most of them likely live on an income of a few dollars per day. Saving the hundreds of dollars needed to emigrate can be very hard for these families. The threshold between middle-income and rich countries is instead around $15,000 per person in 1990, about the income per person of Portugal or Greece. Rich countries are important destinations for migrants from poor and middle-income countries of origin, but they are not included in our analysis as sending countries.

Table 1 provides the summary statistics of the variables of interest for the two groups of sending countries (poor and middle-income), separately. Several features of the data are worth discussing. First, the average ten-year emigration rate for middle-income countries is 4.2%, including migration to both OECD and non-OECD destinations. This average is much higher than for poor countries, whose decennial net rate is 1.8%. This is consistent with the idea that emigration rate grows with income, up to a certain level. Second, income per capita and urbanization rates are much higher in middle-income countries than in poor countries. In particular, the share of urban population is 42% in middle-income countries and only 19% in poor countries. Both are far from the level of urbanization in rich countries (around 75%). Additionally, a substantial share of value-added production in poor countries comes from agriculture, around 35%, and agriculture is a non-negligible source of GDP (accounting for about 16%) in medium-income countries, as well.

The differences in emigration rates and temperature trends are depicted in Figs. 1 and 2. The graphs show the evolution of emigration rates and temperature for ten selected poor and middle-income countries, chosen to be each at a decile of the overall distribution for the total change on four decades. In each figure we standardize the average emigration rate and average temperature of each country in the first decade to zero, making even small variations apparent.

Panel 1 of Fig. 1 shows that emigration rates are relatively stable during the period in middle-income countries, with most countries experiencing changes of only a few percentage points. Exceptions are Albania, whose emigration rate increased 28 percentage points, and Algeria, whose emigration rate decreased, especially between the first and second decades, by 9 percentage points. For poor countries, in Panel 2 of Fig. 1, we observe a larger proportion of emigration rates that increase over time, relative to those decreasing. We also observe a significant amount of variation.

As for average temperature, Fig. 2 shows that over the considered period, temperature increased in the large majority of middle-income and poor countries. As one can see from Panels 1 and 2 of the figure, the last decade was generally warmer for all countries relative to the first. The temperature changes over the period are in fact positive with the exception of countries in the bottom decile of the distribution of temperature changes. We also observe significant variation in the amount of warming experienced over three decades,

[5] Further details on the data and the full list of countries classified as either “poor” or “middle-income” can be found in the Data Appendix.

[6] Bilateral net flows that are negative (usually very small numbers) are set to 0 as they may be due to mortality of the stock of emigrants abroad.

[7] The Organization for Economic Cooperation and Development (OECD) is usually considered a “club” for developed countries. It includes most countries in the world with high GDP per person.

[8] Ideally, one would want to use GDP per capita in the initial year (1970) to partition countries between poor and middle-income. However, this choice would drastically reduce the sample of countries as not all countries have available GDP data for 1970. Given the relative stability of country ranking, we are confident that our choice, based on 1990 GDP per capita ranking, would mostly overlap with one based on the 1970 definition of GDP per person.

Table 1
Summary statistics.

Countries included in the sample	Non-OECD sample middle-income countries			Non-OECD sample poor countries		
Variable	Obs	Mean	Std. dev.	Obs	Mean	Std. dev.
Emigration rate (emigration flows/population)	338	0.042	0.084	120	0.018	0.020
Temperature, °C (pop weight)	338	22.118	4.925	120	23.499	4.172
Precipitation, 100s mm/year (pop weight)	338	13.406	8.818	120	11.407	5.157
Temperature,°C (area weight)	330	22.251	5.064	120	23.894	3.968
Precipitation, 100s mm/year (area weight)	330	13.255	9.175	120	10.894	5.742
Share of urban population	420	0.422	0.222	145	0.194	0.112
Emigration rate (to non-OECD destinations)	338	0.014	0.034	120	0.014	0.018
Emigration rate (to OECD destinations)	338	0.028	0.073	120	0.004	0.007
Emigration rate (to close destinations)	289	0.009	0.037	104	0.010	0.018
Emigration rate (to distant destinations)	338	0.033	0.065	120	0.009	0.011
Agriculture, value added (% of GDP) (WDI source)	242	16.298	11.147	83	34.787	11.992

Note: The first three columns of the table show the summary statistics including as country of origin of immigrants non-OECD countries, excluding those in the bottom quartile of the GDP per capita distribution. The remaining three columns show the summary statistics for the sample of non-OECD countries in the bottom quartile of the per-capita GDP distribution. The sample is supposed to include countries of the world that are "Poor" or "Middle-Income".

with a range of about 1 ° C separating the top 10% from the bottom 10%, both in the middle-income and poor country samples.

Fig. 3 shows the most interesting stylized fact. It plots long-term changes in temperature against long-term changes in emigration rates for poor and middle-income countries separately, along with a fitted regression line. In particular, we take the difference between the (natural log of) average temperature and emigration rates in the first two decades (1960–80) and in the last two decade (1981–2000) of our data and plot one against the other. The difference in the relationship between the two groups of countries is clear.

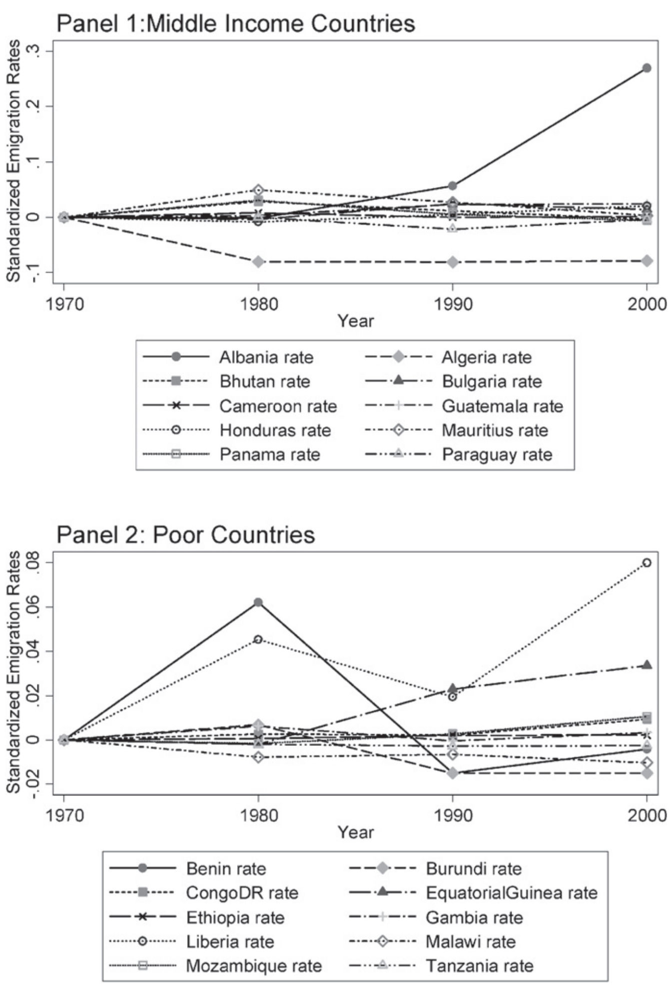

Fig. 1. Cumulated changes in emigration rates. Selected countries at each decile of the distribution, 1970–2010.

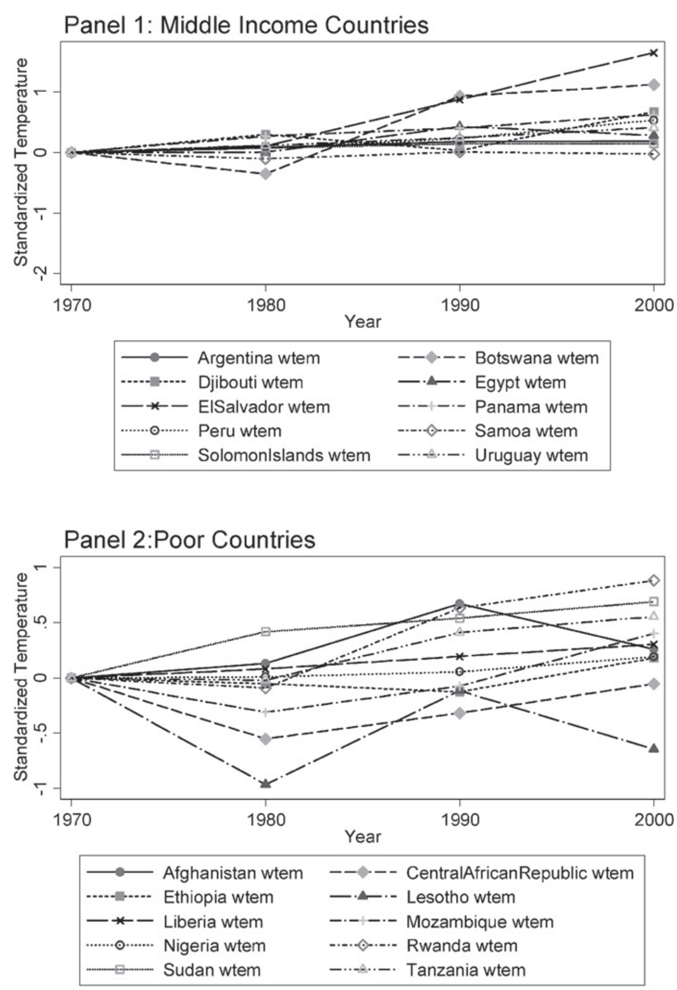

Fig. 2. Cumulated changes in average temperatures. Selected countries at each decile of the distribution, 1970–2000.

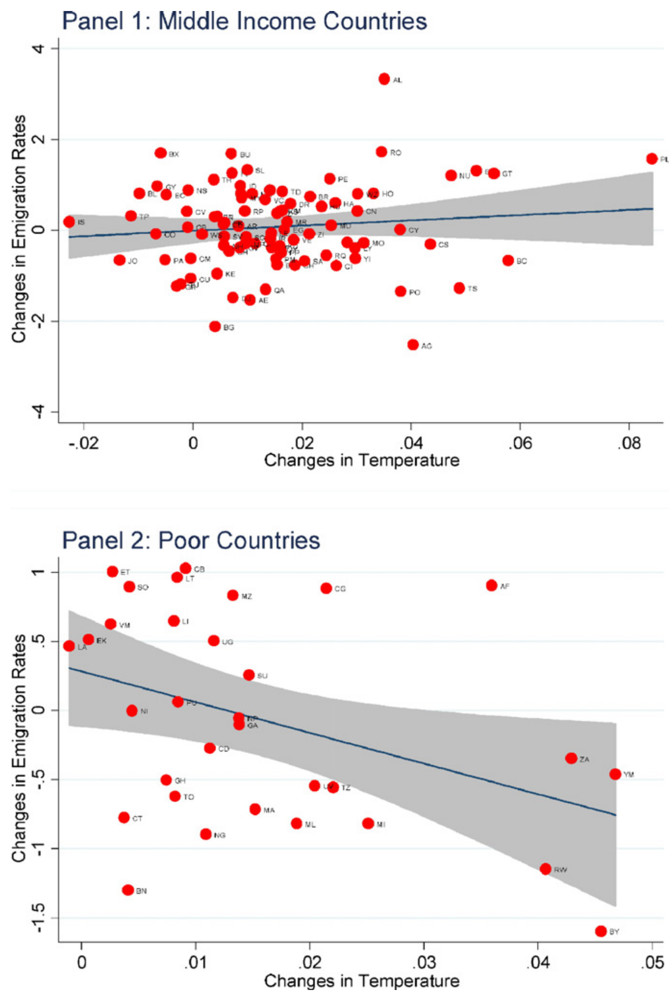

Fig. 3. Change in emigration rates and in average temperature. Note: The graphs plot on the horizontal axis the natural logarithm of the average temperatures between 2000 and 1981 minus the natural logarithm of the average temperatures between 1960 and 1980. On the vertical axis the natural logarithm of the average emigration rates between 1990 and 2000 minus the average emigration rates between 1970 and 1980.

Middle-income countries show a positive (albeit not strong) correlation while poor countries show a negative and significant correlation between temperature changes (expressed in logs) and emigration. Qualitatively these are the types of correlations predicted by our model. We will test the robustness of these correlations more systematically in the next section.

5. Empirical specification and results

Following specification (9) suggested by the model, we estimate the following empirical specification:

$$Y_{j,t} = \alpha + \gamma \ln(T_{j,t}) + \gamma_P \ln(T_{j,t}) * D_j + \delta \ln(P_{j,t}) + \delta_P \ln(P_{j,t}) * D_j + \phi_j + \phi_{r,t} + \phi_{p,t} + \epsilon_{j,t} \tag{10}$$

The variable $Y_{j,t}$ captures the outcome of interest in country j and in the decade beginning with year t (= 1960, 1970, 1980, 1990). It will be alternatively the natural logarithm of the emigration rates (described in the previous section) or the average urbanization rate, computed as the urban population over the total population of country j during the decade beginning in t.[9] $T_{j,t}$ represents the average temperature of country j during each decade beginning with year t and $P_{j,t}$ captures the ten year average precipitation. The inclusion of both temperature and precipitation in the estimated specification follows the literature that studies the effect of climate change on any outcome. Both the natural logarithm of the temperature and of the precipitation are entered linearly, as well as interacted with the dummy D_j,that equals one if country j is categorized as "Poor". This allows different elasticity estimates for poor and middle-income countries, a point emphasized in the model. We also include country fixed effects, ϕ_j, capturing fixed country characteristics such as their geography and institutions. The term $\phi_{r,t}$ captures region-decade dummies in order to absorb regional factors of variation in economic conditions over time and $\phi_{p,t}$ are decade fixed effects interacted with a poor country dummy, to capture differential time variation in the group of countries considered as "poor" relative to those considered as "middle-income". $\epsilon_{j,t}$ is a random error term that can have a correlation within country, hence our choice to cluster at the country level when estimating.

As emphasized in the previous section, we only consider a sample of middle-income and poor countries of origin. In the main specifications we include only non-OECD countries of origin equating OECD to rich countries. The dummy for "poor" countries is defined as equal to one for countries in the bottom quartile of the sample income distribution in the non-OECD sample. In robustness checks, we try different definitions of "rich" and "poor" countries by varying the threshold for the definition of rich countries. Results are robust to these alterations.

Specification (10) is based on the model presented in Section 3. It also represents a simple reduced-form linear relationship between temperature and migration allowing such a relation to vary depending on the initial income per person in the country of origin. While it is clear that average temperature is an exogenous variable, the real question is: through what channels does temperature operate on migration? In our model and analysis we focus on specific implications of a model in which the main channel operates through a decrease in agricultural productivity and rural income, both of which are not easily observable variables for our panel of countries. One option would be to include several controls such as population size, socio-political environment, probability of conflicts and others in the regression to reduce the scope of omitted channels. However, as those variables may themselves be affected by agricultural productivity, including them may produce a bias in the estimation by introducing an over-controlling problem. The estimation of an equation that controls for both temperature and other variables that are influenced by the temperature or agricultural productivity would not capture the total net effect of temperature on migration (Dell et al., 2014). The paper by Beine and Parsons (2015), for instance, introduces a very large number of controls and does not find a correlation between temperature and bilateral migration. By absorbing many potential variables correlated with agricultural productivity in the regression, that paper may obscure some of the effects we are considering. Therefore, we decided to remain parsimonious in our models (as done in Couttenier and Soubeyran, 2014; Dell et al., 2012; Jones and Olken, 2010) by including only fixed effects as controls. We then directly analyze the potential channels of the effects by assessing the impact of temperature on income per person and agricultural value-added as outcomes to see whether the estimated effects on those variables are consistent with the working of our model.

[9] For urbanization rates, our first decade starts in the year 1950 as we have data going back to that date.

Table 2
Temperature effects for different income quartiles. Poor and middle-income countries of origin included, years 1970–2000.

	(1)	(2)	(3)	(4)
	Ln(Emigration rates)		Urbanization rates	
	Population weights	Area weights	Population weights	Area weights
Ln(T)×Q1	−16.476***	−15.233**	−0.711**	−0.754**
	(6.250)	(6.289)	(0.322)	(0.359)
Ln(T)×Q2	7.474	0.442***	0.433	0.641*
	(6.824)	(0.103)	(0.481)	(0.380)
Ln(T)×Q3	8.614*	4.603	0.463	0.642
	(5.143)	(5.291)	(0.538)	(0.623)
Ln(T)×Q4	2.840**	−4.186	0.980	1.474*
	(1.391)	(9.084)	(0.776)	(0.827)
Ln(P)×Q1	−1.643	0.407	−0.160**	−0.172**
	(1.902)	(1.854)	(0.079)	(0.071)
Ln(P)×Q2	−1.684**	−2.416***	−0.021	−0.060
	(0.658)	(0.888)	(0.045)	(0.049)
Ln(P)×Q3	0.097	−0.174	−0.015	−0.035
	(0.404)	(0.397)	(0.074)	(0.080)
Ln(P)×Q4	0.434	0.833	0.027	0.042
	(0.642)	(0.657)	(0.074)	(0.077)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes
Decade×Quartile effects	Yes	Yes	Yes	Yes
Observations	458	450	565	558
R-squared	0.249	0.252	0.784	0.789
Number of countries	115	114	114	113

Note: The dependent variable is the natural logarithm of emigration rates in Columns (1) and (2) and the urbanization rates in Columns (3) and (4). Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. In Columns (1) and (3) the weather station data are averaged using population weights. Columns (2) and (4) use area as weight. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

5.1. *Effects on international migration*

Estimation of specification (9) requires correct identification of poor countries. To avoid setting an arbitrary threshold that separates poor from middle-income countries, whose responses differ in sign according to our model, we first let the data guide this choice. Columns (1) and (2) of Table 2 present the estimated effects of (the logarithm of) the temperature and precipitation on emigration rates interacted with dummies for different quartiles in the distribution of PPP-adjusted per capita GDP in 1990. The difference between the two columns is the weight we use to aggregate individual temperature observation based on population or area. The method of estimation is Least squares with fixed effects with standard errors clustered at the country-of-origin level. The estimated coefficients indicate large differences in the impact of temperature on migration along the income distribution, with a sign reversal between the first and second quartiles. The elasticities are negative for the first quartile, turn positive and large for the second and third quartiles and remain positive, though of a lower magnitude, for the top quartile. Columns (3) and (4) of Table 2 show the same estimates when the dependent variable is the rate of urbanization of a country (share of urban population). Changes in this rate are due to rural-to-urban migration and differential evolution of the population. Even in this case, we observe a significant and clear sign reversal of the effect between the first and second quartiles of the distribution. Hence, these results provide support towards the use of the first quartile of the income distribution as a reasonable definition of a poor country. Those countries are at the bottom of the GDP per capita distribution and their migration response to temperature is different from that of other countries and in line with the prediction of our model. We apply this definition throughout the paper and conduct robustness checks, modifying the value of the cut-off point around the 25th percentile.

In a robustness check, presented in Table A1 in the Table Appendix, we conduct a similar exercise on a larger sample of countries by also including rich OECD countries as potential emigration countries.[10] Results are similar to those presented in Table 2 and they show, in addition, that in rich (OECD) countries, the effect of temperature on emigration and urbanization rates is small and usually not significantly different from zero. The null elasticity of migration to temperature in rich countries is consistent with the estimated effect working through agricultural income, which is important in poor and middle-income countries, and not through other omitted channels which may be important in rich countries. As in rich countries, agriculture represents only a small source of income and the rural population is a small percentage of the total, the impact of temperature on these countries can be seen as a further test on the validity of our assumption. The results presented are consistent with our assumption.

Table 3 presents the main estimated coefficients obtained from specification (9). Columns (1) to (4) show estimates in which we use population weights for the aggregation of weather station temperature and precipitation data, while Columns (5) and (6) aggregate temperature data using area weights. The estimated specifications in Columns (2) and (6) are exactly as shown in Eq. (10). In Columns (1) and (5) we omit the interaction of temperature with the "poor country" dummy to obtain the average effect of temperature on emigration, averaging all countries. In Columns (3) and (4) we also

[10] Table A1 provides the same list of 30 poor countries as Table 2. The list of countries in the bottom income quintile of a distribution with OECD countries corresponds to the list of countries in the bottom income quartile of a distribution without OECD countries.

Table 3
Temperature and emigration. Poor and middle-income countries of origin included, years 1970–2000.

	Ln(Emigration rates)					
	Population weights				Area weights	
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(T)	1.931	3.755**	2.695	3.836**	0.589***	0.609***
	(1.892)	(1.661)	(1.904)	(1.790)	(0.076)	(0.070)
Ln(T)×Poor		−19.967***		−17.546***		−15.134**
		(6.607)		(5.068)		(6.275)
Ln(T)×Agri			−23.996***	−15.939*		
			(8.457)	(8.285)		
Ln(P)	−0.309	−0.223	−0.032	−0.113	0.032	−0.152
	(0.352)	(0.325)	(0.396)	(0.395)	(0.344)	(0.343)
Ln(P)×Poor		−1.399		−0.373		0.641
		(1.912)		(2.623)		(1.886)
Ln(P)×Agri			−2.246	−1.674		
			(1.423)	(1.577)		
Country of origin fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	458	458	414	414	450	450
R-squared	0.179	0.201	0.202	0.216	0.182	0.199
Number of countries	115	115	104	104	114	114
T effect in poor countries		−16.212**		−13.711*		− 14.525**
T effect in agri countries			−21.301**	−12.103		

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. In Columns (1)–(4) the weather station data are averaged using population weights. Columns (5)–(6) use area as weight. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

include a dummy called "prevalently agricultural" to denote countries in the top quartile of the distribution of agricultural value-added as a share of GDP. This dummy and its interaction with the logarithm of temperature is used in place of (Column (3)) or together with (Column (4)) the interaction of temperature with the "poor country" dummy. Agricultural prevalence should be an alternative to GDP per person to identify poor countries, and to single out those on which temperature may have a strong impact on productivity via its effect on agriculture. This is an important check, as we presume that agricultural productivity is the channel through which temperature affects migration. The number of observations is 115 over four decades, except when we include an interaction using the share of value-added in agriculture (Columns (3) and (4)), which reduces the number of observations significantly.

Two results emerge from Table 3 that are consistent with our model predictions and robust across different specifications. First, not including the interaction with the "poor country" dummy, Column (1) displays a non-significant effect of the average temperature on emigration rates for the full sample of poor and middle-income countries. Similarly, no significant effect is found on the precipitation variable. The second result, however, is when we allow the coefficient of the temperature variable to vary between middle-income and poor countries (as we do in Column 2 and beyond) by adding an interaction with the "Poor country" dummy. The coefficient on temperature in middle-income countries (γ) turns positive and statistically significant at the 5% confidence level, while the coefficient of the interaction between the "poor country" dummy and the temperature (γ_P) becomes negative, quite large in absolute value, and significant at the 1% level. The net effect of temperature on emigration in poor countries, obtained by adding γ and γ_P and reported in the second-to-last row of Table 3, is also negative and statistically significant.[11]

The estimated coefficients in Column (2) indicate that a one percent increase in temperature increases international migration rates by 4% in middle-income countries, whereas it decreases emigration rates in poor countries by 16%, *ceteris paribus*. This implies a middle-income country with an average yearly temperature of 22 ° C(the average of our sample) would experience a 20% increase in the rate of emigration if its average yearly temperature increased by 1° (roughly a 5% increase). Hence, at the average, this will imply an increase of the emigration rate from 0.042 to 0.05, with a 0.8 percentage point higher emigration rate. The same one degree Celsius warming in a poor country, however, would generate an 80% decrease in the rate of emigration (from 0.018 to 0.004). This seems a significant but reasonable impact. The only previous study that allows a comparison of magnitude for this effect is Cai et al. (2014). In that study the basic specification (in their Table 2 Column (2)) finds that an increase in temperature equal to one degree centigrade produces an increase in emigration rates to the average destination (and hence overall) by about 0.047 log points (i.e. 4.7%). This is an elasticity of the effect within one year. Our ten year elasticity for middle-income countries is four time larger (20%), while for low income countries we obtain a negative elasticity. As emphasized above, Cai et al. (2014) use gross rates and do not differentiate a response between poor countries and middle-income ones, although the countries with large agricultural shares that they include are likely relatively poor.

The coefficients on the variable "Precipitation" (δ) and Precipitation interacted with the "poor country" dummy (δ_P) are not statistically significant in most cases. We do not detect a comparable effect of precipitation on migration. Several other studies find small or non-significant effect of rainfall or flooding on the probability of migrating (e.g. Auffhammer and Vincent, 2012; Bohra-Mishra et al., 2014; Mueller et al., 2014) . We inquire further into this relationship by including only the precipitation variable in the regression, as warming can be related to increased probability of drought and act as a confounding factor. The estimates, reported in Table A2 of the Table Appendix, show no significant correlation between precipitation and migration even when the variable "temperature" is omitted. Using

[11] As described earlier, the "poor country" dummy identifies countries in the bottom of the country-of-origin income per capita distribution. This includes countries with income per person below $1500 in 1990 as "poor".

Table 4
Temperature and emigration with different threshold levels for poor countries. Poor and middle-income countries of origin included, years 1970–2000.

	Ln(Emigration rates)							
	Population weights				Area weights			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	10% plus	20% plus	10% minus	20% minus	10% plus	20% plus	10% minus	20% minus
Ln(T)	3.637**	3.607**	2.753	2.623	0.606***	0.607***	0.592***	0.587***
	(1.640)	(1.648)	(1.735)	(1.731)	(0.065)	(0.066)	(0.070)	(0.070)
Ln(T)×Poor	−16.897***	−15.773***	−14.207*	−7.626	−14.324***	−13.241***	−8.364	−6.579
	(5.133)	(4.997)	(7.645)	(7.750)	(4.895)	(4.526)	(7.005)	(7.500)
Ln(P)	−0.139	−0.193	−0.200	−0.359	−0.006	−0.021	−0.052	−0.106
	(0.335)	(0.340)	(0.339)	(0.352)	(0.346)	(0.347)	(0.355)	(0.353)
Ln(P)×Poor	−1.155	−0.573	−1.195	1.124	−0.246	−0.123	0.402	1.147
	(1.494)	(1.339)	(1.615)	(1.564)	(1.675)	(1.429)	(1.482)	(1.490)
Country of origin fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	458	458	458	458	450	450	450	450
R-squared	0.193	0.190	0.183	0.187	0.197	0.196	0.189	0.191
Number of countries	115	115	115	115	114	114	114	114
T effect in poor countries	−13.260***	−12.166**	−11.454	−5.002	−13.718***	−12.635***	−7.772	−5.992

Note: The dependent variable is natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. In Columns (1)–(4) the weather station data are averaged using population weights. Columns (5)-(8) use area as weight. The number of poor countries in Columns (1) and (5) is 34, in Columns (2) and (6) is 36, in Columns (3) and (7) is 24 and in Columns (4) and (8) is 18. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

specifications similar to those of Table 3, in fact, we observe that the estimated coefficient on the precipitation variable is never significant. According to these results, agriculture-related emigration seems mainly due to changes in temperature, rather than changes in precipitations.

If the negative effect on migration in poor countries proceeds from lower agricultural productivity and liquidity constraints, as assumed by our simple model, then it should be particularly strong for countries heavily depending on agriculture. The share of agriculture in GDP and the income per person generally display a strong negative correlation, so that poor countries have, in general, a larger share of agricultural value-added in GDP. For this reason we explicitly include a dummy in Column (3) capturing those countries with a large agricultural sector. Their productivity and income are likely to be more affected by warming temperatures. We compute a dummy for a country being "prevalently agricultural", which is equal to one if a country belongs to the top quartile in the world distribution of agriculture as a share of GDP.[12] Columns (3) and (4) add interactions between temperature/precipitation and the agricultural dummy to specification (10). The coefficients of the temperature-agricultural interaction are negative and statistically significant when included instead of the interactions with "poor" (Column (3)) and even when included in addition to those variables (in Column (4)). In particular, conditional on a country being poor, an increase in average temperature by 1% (about 0.2 ° C at the sample average) decreases the rate of emigration by an additional 12% if the country is also highly agricultural-dependent. When included together, the "poor country" and "prevalently agricultural" dummies interacted with the temperature have similar coefficients. Finally, notice that different weighting of the temperature data do not make much of a difference in the estimates (Columns (5) and (6)).

[12] As in the case of GDP per capita, the choice of the year for drawing the distribution was determined by the availability of data. For the agricultural share the year 2000 was chosen.

In a robustness check we use a different sample of poor and middle-income countries (Table A3). Rather than excluding OECD countries, we drop from the sample those countries in the top quintile of the income per person distribution. The dummy for "poor" countries is equal to one for countries in the bottom quintile of the income distribution determined before excluding rich countries. The empirical estimates indicate that the main findings are robust not only to a different weighting but also to a different definition of our sample (non-OECD versus countries below the top quintile of GDP per person). Hence, we will mostly use the non-OECD definition of poor and middle-income countries and the population weights.

In Table 4 we present robustness checks around the cut-off income between poor and middle-income countries. Using the bottom quartile as a benchmark, as done in Table 3, resulted in 30 countries being counted as poor. In Table 4 we increase(decrease) the number of poor countries by increasing (decreasing) by 10 and 20% the income threshold. In both cases the significant change in magnitude and sign of the effect of temperature on migration is confirmed. The change in the impact is not linked to the behavior of few countries near the threshold.

In Table 5 we present some robustness checks on possible nonlinearity in the effect of temperature on migration. The existing literature (Burke et al., 2015; IPCC, 2014; Mendelsohn et al., 1994) argues that the relationship between temperature and productivity is non-linear. Increases in temperature are more damaging for agricultural output above a certain value, which can be set around 20/25°. Therefore, the change in the marginal effect between poor and middle-income countries, that we find, could be an artifact of this non-linearity rather than a differential response of migration to changes in productivity that affects both poor and middle-income countries. If poor countries start with higher temperature than middle-income countries, then differing impacts of temperature on migration could be simply explained by this non-linear productivity effect, even without any liquidity constraint effect. To test this hypothesis we add squared terms of temperature and precipitation in the sample of non-OECD countries, without interaction for poor countries. Column (1) of Table 5 presents the estimated coefficients.

Table 5
Temperature and emigration separating poor and middle income countries. Poor and middle-income countries of origin included, years 1970–2000.

	Ln(Emigration rates)				
	All non-OECD countries	Non-OECD middle income countries		Poor countries: bottom quartile of GDP per person in Non-OECD sample	
	(1)	(2)	(3)	(4)	(5)
Ln(T)	9.280	3.801**		−21.531***	
	(5.889)	(1.742)		(6.831)	
Ln(T) squared	−1.737				
	(1.455)				
Ln(P)	−0.182	−0.253		−1.617	
	(0.380)	(0.326)		(2.371)	
Ln(P) squared	−0.030				
	(0.109)				
Ln(T)×TQ1			3.788**		−24.287***
			(1.749)		(8.450)
Ln(T)×TQ2			3.261		−38.493
			(5.653)		(23.743)
Ln(T)×TQ3			4.433		53.624**
			(8.424)		(24.152)
Ln(T)×TQ4			2.927		−6.047
			(15.758)		(18.802)
Ln(P)×PQ1			−0.709		3.794
			(0.520)		(3.071)
Ln(P)×PQ2			1.492		1.721
			(1.509)		(2.603)
Ln(P)×PQ3			−2.614**		1.053
			(1.043)		(2.758)
Ln(P)×PQ4			−0.339		−5.215**
			(0.497)		(2.488)
Country of origin fixed effects	Yes	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes	Yes
Observations	458	338	336	120	120
R-squared	0.175	0.225	0.306	0.250	0.423
Number of countries	115	85	84	30	30

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for Column (1) is all non-OECD countries. Columns (2)–(3) are non-OECD countries, excluding those in the bottom quartile of GDP per capita distribution. Columns (4)–(5) use non-OECD countries in the bottom quartile of the per-capita GDP distribution. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

The coefficients of the squared terms are not statistically significant suggesting that a simple non-linearity in temperature would not capture the change in marginal impacts on migration.

Then, in Columns (2) to (5) we split the sample and analyze the effects of temperature and precipitation on emigration for middle-income and poor countries separately. We therefore allow all the coefficients in our model (not only those on average temperature) to differ between these two groups of countries. The stratification of our sample implies Columns (2) and (3) estimate the effect on middle-income countries, while Columns (4) and (5) estimate the effect on poor countries. The point estimates in Columns (2) and (4) are in line with the corresponding coefficients presented in Table 3. An increase in temperature by 1% in middle-income countries increases emigration rates by about 4%. The same average temperature increase in poor countries decreases emigration rates by about 22%. The precipitation variable does not appear to have any significant effect on either group. The opposite effects of temperature on the emigration rate in poor and middle-income countries are consistent with the model presented in Section 3 and with a standard economic logic that emphasizes the presence of both incentives and constraints. If secular heating damages agricultural productivity, countries with a large dependence on agriculture and a very low income experience a substantial worsening of their liquidity and hence their ability to pay for emigration. On the other hand, middle-income countries experience a worsening of potential earnings, increasing people's willingness to emigrate as long as they can afford to do so. The finding is clearly related to the widespread regularity (summarized, for instance, in Clemens, 2014) that emigration rates have a hump-shaped relation with income per person in the country-of-origin. An income increase in very poor countries allows them to pay the cost of emigration, increasing the rate of emigration. Past a certain level, however, higher income reduces the incentives to migrate. Most studies find the inversion of this relation takes place between \$3000 and \$5000 per person, a level in the low range of the middle-income countries in our sample. Hence, consistently with that literature, the negative effect we find on poor countries could be fully due to the worsening of income and liquidity constraints.

As an additional robustness check, in Columns (3) and (5) we present the estimated effects of temperature and precipitation on emigration rates for different quartiles of the temperature and precipitation distributions, measured in year 1970. In this way we analyzed if being in higher temperature quartiles strengthens the impact within income group. If our liquidity-incentive story is correct, we should find a positive impact of temperature on migration in most middle-income countries, and possibly stronger (positive) effects for those in the hottest (top quartile) part of the temperature distribution. Conversely, we should find a negative effect in all poor countries, and potentially larger (in absolute value) in the hottest countries. The results confirm these expectations, with the exception of a positive coefficient in the third temperature quartile for poor countries, likely driven by a few outliers. We find positive effects of temperature on migration in middle-income countries, and

Table 6
Temperature and emigration with control for extreme temperatures. Poor and middle-income countries of origin included, 1970–2000.

	Ln(Emigration rates)					
	Both hotter and colder extremes included			Only hotter extremes included		
	(1)	(2)	(3)	(4)	(5)	(6)
ln(T)	1.390	3.101*	3.099*	1.477	3.240**	2.884*
	(1.998)	(1.578)	(1.601)	(1.967)	(1.590)	(1.604)
ln(P)	−0.265	−0.321	−0.321	−0.335	−0.382	−0.385
	(0.375)	(0.369)	(0.370)	(0.363)	(0.356)	(0.357)
Extreme T	0.106	0.102	0.103	0.026	0.020	0.065
	(0.068)	(0.068)	(0.074)	(0.085)	(0.084)	(0.093)
ln(T)×Poor		−18.34***	−18.34***		−18.57***	−17.475***
		(6.570)	(6.559)		(6.510)	(6.609)
Ln(P)×Poor		0.004	0.001		−0.067	−0.191
		(1.871)	(1.881)		(1.887)	(1.888)
Extreme T×poor			−0.002			−0.278
			(0.176)			(0.236)
Country of origin fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	448	448	448	448	448	448
R-squared	0.183	0.203	0.203	0.177	0.198	0.201
Number of countries	112	112	112	112	112	112
T effect in poor countries		−15.237**	−15.237**		−15.326**	−14.591**

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample for columns is all non-OECD countries. In Columns (1) to (3) the "Extreme temperature" variable is defined as the number of years in a decade in which the temperature was above or below two standard deviations of the 1960–2000 period mean for the country. In Columns (4) to (6) only the episodes of temperature above the average plus two standard deviations are included in the definition of "Extreme temperature". The weather station data are averaged using population weights. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

most significant (but not larger in point estimates) for hot countries, and mainly negative effects for poor countries, stronger for the hottest.[13]

The nonlinear effect of temperature can be further scrutinized by adding a variable that captures the realization of extreme temperatures during a decade in a country. We computed a variable that measures the number of years of a decade in which the temperature was above or below two standard deviations from the 1960–2000 period mean for the country. According to the variable, temperature anomalies, both above and below the mean, have been more likely in the most recent decades. The occurrence of one extreme episode in the decade was registered 117 times. Out of these, 58 cases happened between 1990 and 2000, 21 between 1990 and 1980, 23 between 1970 and 1980 and 15 between 1960 and 1970. For some countries, these temperature anomalies have occurred twice and three times within a single decade, but these occurrences were rather rare. We added to the basic specification the count of the extreme temperature events per decade, as well as its interaction with the "poor country" dummy variable. Columns (1) and (3) of Table 6 show that emigration rates in middle-income countries are not influenced by the occurrence of temperature anomalies, nor do they matter for migration in poor countries, regardless of the specification of countries we use. Columns (4) to (6) focus specifically on extremely high temperature years (only anomalies in the high temperature range), yet we do not find significant effects of those episodes while we still find the negative and significant effect on Poor countries of the increase in average temperature.

In Tables A4 and A5 of the Table Appendix we explore two further robustness checks. In Table A4 we consider decade differences in emigration rates and temperature (rather than their level) and we omit the country fixed effects in the panel. The estimated effects of temperature and its interaction with the "poor" dummy are somewhat attenuated relative to the estimates in levels, as it happens when differencing increases the noise-to-signal ratio. However, the positive impact on middle-income countries is still significant and the estimated coefficient on "poor countries" is still negative and large (although not significant). Table A5, instead, shows the results of a "long-difference" estimation. In this case we take differences (between temperature and emigration rates) over thirty years – between the seventies and nineties – and we estimate a cross-sectional regression for these long (thirty years) differences. Comparing the long-run estimates of Table A5 and the corresponding medium-run coefficients of Table 3 we see that elasticities are even larger in the first case. This suggests that persistent episodes of temperature increase have even stronger effects on the very long-run propensity to migrate, especially in poor countries. This may imply that, by worsening income perspectives in rural areas, an increase in average temperature may have damaging effects on income that amplify with time as the possibility of emigration becomes ever more remote. Overall, the pattern emerging consistently across specifications is that increased temperature encourages emigration in middle-income countries, but reduces it in poor countries. This effect is significant and for poor countries it may imply, especially in the long-run, a reduced ability of people to emigrate and escape poverty.

5.2. Effects on urbanization

International migration is certainly a way to take advantage of economic opportunities and is also a way to escape local rural

[13] This result confirms in part of Bohra-Mishra et al. (2014), who find a positive effect of temperature on emigration rates in Indonesian villages (Indonesia is a middle-income country) only for values above the median of 25 ° C. Our breakdown shows a more precisely estimated effect of increased migration for hotter countries.

poverty. However, most of the population does not migrate internationally because of high costs, lack of information and limited opportunities (e.g. Pritchett, 2006). Internal migration, especially from rural areas to urban areas is a very important alternative for most of the population. While the economic returns to internal migration are lower, such a move is less costly than emigration. The same ideas, developed in the model of Section 3, can be applied to rural–urban migrants. Increased temperature will affect agriculture productivity more than urban activities and, thus, will mainly affect the income of rural populations. Moreover, the returns to skills are likely to be larger in the city than in the countryside (as the model postulates). In very poor countries, the rural population may be so poor that it lacks the income to overcome the information and cost barriers for migrating to the city. This may actually be the main obstacle preventing migration in poor countries. Hence, a decrease in current income would make the transition to cities even less likely. In middle-income countries, instead, liquidity constraints may be less severe for rural workers, and so a worsening of the income perspectives in agriculture may increase inflows into cities. Thus, we can use a measure of "urbanization" as the outcome of interest, namely the share of a country's total population living in cities.

The change in this variable combines the effect of rural–urban migration with the effect of differential population changes due to mortality and nativity in cities and rural areas. Recent research emphasizes that during the most recent decades the largest part (around two-thirds) of the change in urbanization rates in developing countries is driven by rural–urban migration, while the rest may be due to differential population growth. Jedwab et al. (2014) find that, despite a nontrivial contribution by natural population change, the largest part of increased urbanization in middle-income and poor countries is linked to rural–urban migration. Drawing on this literature, in this analysis we take the measure of urbanization rates and their changes as proxies for the net rural-to-urban migration inside each country. We analyze the effects of increasing average temperature and precipitation on urbanization, just as we did for international migration rates.

The structure of Table 7 follows exactly that of Table 3, except that the outcome variable is the share of population living in urban areas relative to total population in the country (also called the urbanization rate). Columns (1) and (4) use the average country temperature calculated by using population weights, while Columns (5) and (6) use area weights. The results in Columns (1) and (2) suggest a response of rural–urban migration to temperature similar to that of international migration. Namely, an increase in the average temperature increases the degree of urbanization, speeding up the rural–urban transition in middle-income countries, but slows such migration down in poor countries. A 5% increase in temperature at the average (22 $^\circ$C), which is equal to about 1 $^\circ$C, increases urbanization rates by 4 percentage points in middle-income countries, while it decreases it by the same amount in poor countries. Considering that poor countries have an average urbanization rate of around 19% in this period, and the increase in urbanization was about 20 percentage points per decade over the considered period, an increase in temperature by 1 $^\circ$C may slow the urbanization process very significantly. As in the case of international migration, precipitation does not appear to have a significant effect on urbanization. To the contrary, the interaction between precipitation and the "poor country" dummy has a marginally significant effect. This effect, however, is not robust and only significant at the 10% level, so we do not think it is evidence of an additional productivity effect. In Column (3) we confirm that the negative effect of temperature on rural–urban migration exists on "prevalently agricultural" countries (as much as on "poor" countries), but Column (4) shows that when we include both interactions, only the one with "poor" remains significant.

The use of area weights (Columns (5) and (6) of Table 7) or the use of a different sample of poor and middle-income countries, which comprise countries in the bottom and fourth quintiles of GDP per person rather than non-OECD countries (Columns (3) and (4) of Table A3 of the Table Appendix) leaves the findings unchanged. As already shown in Table 2, it seems reasonable to consider the "cut-off" between poor and middle-income countries at the twenty-fifth percentile of the GDP per capita distribution. The impact of

Table 7
Temperature and urbanization. Poor and middle-income countries of origin included, years 1960–2000.

	Urbanization rates					
	Population weights				Area weights	
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(T)	0.376	0.863*	0.663	0.911*	0.531	1.048**
	(0.342)	(0.461)	(0.423)	(0.495)	(0.383)	(0.474)
Ln(T)×Poor		−1.661***		−1.349**		−1.952***
		(0.566)		(0.634)		(0.593)
Ln(P)	−0.017	0.003	−0.033	−0.033	−0.029	−0.016
	(0.037)	(0.039)	(0.043)	(0.044)	(0.043)	(0.048)
Ln(P)×Poor		−0.156*		−0.127		−0.148*
		(0.087)		(0.099)		(0.084)
Ln(T)×Agri			−1.624***	−0.872		
			(0.525)	(0.579)		
Ln(P)×Agri			0.004	0.095		
			(0.072)	(0.084)		
Country of origin fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	565	565	510	510	558	558
R-squared	0.723	0.733	0.724	0.727	0.724	0.736
Number of countries	114	114	103	103	113	113
T effect in poor countries		−0.798**		−0.437		−0.905**

Note: The dependent variable is the urban population as a share of the total population. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. In Columns (1)–(4) the weather station data are averaged using population weights. Columns (5)–(6) use area as weight. The standard errors are cluster by country of origin.

* Indicates significance at the 10% confidence level.

** Indicates significance at the 5% confidence level.

*** Indicates significance at the 1% confidence level.

Table 8
Temperature and emigration by destinations. Poor and middle-income countries of origin included, years 1970–2000.

	Ln(Emigration rates)							
	Non-OECD destinations		OECD destinations		Close destinations (<1000 km)		Distant destinations (>1000 km)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ln(T)	3.381	4.975***	−1.668	−0.486	8.953**	10.452***	−0.247	1.442
	(2.380)	(1.823)	(1.890)	(1.828)	(3.505)	(3.242)	(2.057)	(1.530)
Ln(T)×Poor		−17.172***		−12.923***		−20.439		−18.398**
		(6.499)		(4.822)		(13.260)		(7.080)
Ln(T)	0.091	0.126	−0.320	−0.226	−0.668	−0.409	−0.396	−0.296
	(0.360)	(0.369)	(0.411)	(0.423)	(0.705)	(0.718)	(0.379)	(0.376)
Ln(P)×Poor		−0.774		−1.337		−4.050		−1.540
		(1.703)		(1.385)		(3.250)		(1.566)
Country of origin fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	458	458	458	458	393	393	458	458
R-squared	0.115	0.129	0.407	0.413	0.106	0.115	0.201	0.219
Number of countries	115	115	115	115	106	106	115	115
T effect in poor countries		−12.197*		−13.410***		−9.987		−16.956**

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. In Columns (1)–(2) we include emigration to non-OECD destinations. In Columns (3)–(4) we include emigrants to OECD destinations. In Columns (5)–(6) we include emigration to close destinations (<1000km). In Columns (7)–(8) we include emigrants to distant destinations (>1000km). The sample of origin countries is all non-OECD countries. The weather station data are averaged using population weights. The standard errors are cluster by country of origin.

* Indicates significance at the 10% confidence level.

** Indicates significance at the 5% confidence level.

*** Indicates significance at the 1% confidence level.

temperature on migration appears to change sign between the group above and the group below this percentile. Such a cut-off also works well for rural-to-urban migration, as shown in Columns (3) and (4) of Table 2. The different behavior of the poor countries in terms of migration response to temperature is also shown in Table A1 of the Table Appendix, in which all countries of origin are included (not just poor and middle-income). That table shows that the effect of warming temperature on rich countries' migration (now the top quintile) is still small, while poor countries – the bottom quintile of the distribution – still exhibit a negative response.

Some studies (e.g. Marchiori et al., 2012) postulate a direct connection between rural–urban migration and international migration. Namely, they consider rural populations affected by weather shocks as first moving into cities, increasing urbanization rates and crowding urban centers. International migration proceeds as a consequence of this crowding, which produces a decrease in income and/or of amenities in cities. This is a reasonable possibility and our results are consistent with it. However, rural populations may directly migrate abroad. Moreover, the crowding of cities may decrease income, through crowding, or increase it, through agglomeration, so that international migration may not be a direct consequence of urbanization. In our framework, we consider urbanization and international migration as two possible outcomes driven by a decline in rural income, but not necessarily sequentially or linked. Individuals in rural areas are more affected by temperature and, hence, their migration behavior to cities or abroad could be affected. The results from Table 7, overall, suggest increases in temperature have similar effects on rural–urban migration as on international emigration, strengthening the plausibility of our interpretation.

5.3. Where do people migrate in response to warming?

Are rich and far away countries the main destination for people who move out of middle-income countries as a consequence of warming and lower agricultural productivity? Or are these individuals prevalently moving to nearby countries that are experiencing better economic opportunities? Does warming produce a large scale movement of individuals from middle-income countries in Africa, Asia and Latin America to rich countries in Europe and North America? Or does it produce a more local reallocation across middle-income countries within a region? In order to analyze this question, we compute the net emigration rates for each country of our sample, separating emigrants to OECD and non-OECD countries. Columns (1) to (4) of Table 8 present the findings using this split. We then separate emigration between destinations within 1000 km from the origin and farther destinations and we calculate separate rates for short-distance and long-distance emigrations. Columns (5) to (8) of Table 8 show the estimates in this case.

The estimates show a very interesting pattern for the temperature-induced emigration. Columns (1) and (2) show the effect on emigration rates towards non-OECD destinations. Columns (3) and (4) show the impact on emigration rates to OECD destinations. Inclusion of the interaction between temperature and the poor-country dummy varies by column. Two findings are worth discussing. First, a warming climate increases emigration rates from middle-income countries only to non-OECD destinations. It has no significant effect on emigration to OECD countries. This result is consistent with our proposed channel, as emigration is driven by a worsening of local opportunities and not by an increase in opportunities in rich countries. Hence, migrants move to where they have better chances of finding a job given their current constraints. This "push" factor (decreased rural income) increases migration to similar economies rather than to OECD economies. On the other hand, the immigration-reducing effect for poor countries (due to worsening opportunities) affects both types of destinations, as potential emigrants become less likely to leave the country.

Similarly and consistently, higher temperatures increase emigration rates to close destinations (<1000 km) for middle-income countries (Column (6)), while poor countries experience a decrease of emigration rates to any other country (Columns (6) and (8)). The standard error on the estimated effects in Column (6) are rather large, however. Combining the effect on poor and middle-income countries, it appears that increases in average temperature may actually decrease overall emigration to OECD countries. Middle-income countries are not more likely to experience emigration towards those destinations, while poor countries experience a reduction in emigration rates. This is bad news for the potential income of individuals from non-OECD countries, for which emigration to rich countries constitutes one of the best options for increasing household income and economic well-being.[14]

6. Robustness checks

We conducted a variety of robustness checks and present the results in the Table Appendix. However, we will summarize them here. First, we have focused our attention on countries in Sub-Saharan Africa (SSA). This specific group includes most of the poor countries in our sample as well as those whose productivity is likely to be strongly affected by temperature increases. Moreover, several of the previous studies (e.g. Barrios et al., 2006 and Marchiori et al., 2012) have considered only Sub-Saharan African Countries in their analysis of extreme weather events and migration. In Column (1) of Table A6 we have included a dummy, "SSA", in the place of "poor" and an interaction term between temperature (and precipitation) and the "SSA" dummy. In Column (2) we have included both the SSA and the "poor country" dummy, as well as their interactions. Columns (1) and (2) analyze the effect on emigration rates, while Columns (3) and (4) look at the impact on urbanization rates. A variety of interesting results emerge, mostly confirming the previous ones. First, temperature has a negative impact on emigration out of SSA countries and is mainly due to them being poor and primarily rural countries. In Column (1) the interaction is negative and significant, while in Column (2) we find no difference for Sub-Saharan Africa once we allow for a different coefficient on poor countries. Hence, our analysis shows that SSA countries' migration response to temperature increase looks in line with the response for other poor countries. A hotter climate reduces the ability of rural populations to migrate.

A second effect, however, is now estimated as significant and is consistent with the temperature effect. That is the effect of precipitation. Drier climates are associated with higher emigration rates for non-SSA countries and lower emigration-rates for SSA countries. These effects are significant and are robust to the inclusion of the "poor" dummy interactions, revealing a role for precipitation as a driver of agricultural productivity in SSA. This may be due to the fact that SSA countries are more affected by drier climate because of their rural nature, or that investments in irrigation are rare among farm households in this area of the world. Moreover, this finding indicates that some regions of frequent droughts (e.g., East Africa) are extremely dependent on seasonal water. A decline in precipitation and an increase in temperature (both of which would be associated with lower agricultural productivity in this region) will drive lower emigration, leaving people in a worsening condition of poverty. Once we allow for this effect in SSA countries, higher temperature and lower precipitation push emigration from the other countries that are not as poor. So, in line with their extreme poverty and dependence on agriculture, as well as consistent with the fact that emigration rates out of SSA countries are rather low, worsening agricultural productivity due to warmer and drier weather reduces rural-urban migration and emigration from Sub-Saharan Africa.

We conducted an additional robustness check. Given that climate change is expected to bring an intensification of natural disasters, such as droughts; floods; storms; and extreme heat, we count the total number of natural disasters in each specific decade computed from the International Disaster Database (Guha-Sapir et al., 2015). In Table A7 we added this variable along with its interaction with the "poor country" dummy variable. We find that emigration rates are not influenced by the occurrence of natural disasters. In further specifications (not reported, but available upon request) we have included each type of natural disaster; namely droughts, floods, storms, and extreme heat individually in the regression as the count of their occurrences in the decade. We do not find any impact. It is likely that natural disasters and rare weather events drive different types of migration, more akin to local mobility and potentially reversed in years of good weather. Natural disasters may be responsible for the displacement of people in near areas, generating non-permanent transitions, but in the long run they may not significantly affect rural–urban and international migration when looking at all countries as they are rare and only occur in some countries. This finding is consistent with the analysis of Beine and Parsons (2015), who do not find a direct impact for the same type of events on bilateral migration, and with the analysis of Bohra-Mishra et al. (2014) for the migration behavior in Indonesian villages. This last paper finds a permanent migration response in Indonesia (a middle-income country) to long-run increases in temperature, but not to episodic disasters. Mueller et al. (2014) report that heat stress, but not flooding, has a significant effect on migration in Pakistan.

Finally, Table A8 specifies temperature in levels rather than logarithms. The estimated values are comparable to those obtained using the log specification. An increase in 1 $^\circ$ C would increase emigration rates by 27% in middle-income countries (using Column (2) coefficients) and decrease emigration rates by 86% in poor countries. This is similar to the main results reported in Table 3.

7. Effects on structural change and GDP

In the previous sections we have estimated a reduced-form relationship between temperature (and precipitation) and emigration/urbanization rates across countries. We have shown these correlations to be consistent with the following interpretation: increased temperatures decrease agricultural productivity and exacerbate the liquidity constraint for rural populations in poor countries, reducing their ability to emigrate. Instead, they increase incentives for rural populations in middle-income countries, increasing the probability to emigrate from these countries. Several checks confirmed this interpretation and the "exogenous" nature of temperature, and its variation across countries relative to local economic and social conditions ensure that reverse causality problems are limited.

We postulated that agricultural productivity is the pathway that links temperature and migration. However, one could argue that higher temperatures have other disruptive effects in poor countries besides their impact on agriculture (increased conflict, wars, effects on health and fertility) that also reduce emigration rates. Admitting it is hard to identify those channels fully and precisely, we want to emphasize the agricultural productivity channel. Hence, we will test several other plausible implications derived from our model in which migration response (or lack of it) is prevalently linked to rural income (agricultural productivity).

Higher temperature influences emigration rates by lowering agricultural productivity both in poor and middle-income countries. While in middle-income countries lower agricultural productivity translates into higher emigration rates, and hence a further reduction in agricultural value-added, the existence of liquidity constraints in poor countries implies that lower agricultural productivity prevents people from leaving and, hence, this second channel of potential decline in agriculture value-added as a share of GDP is muted. This implies higher temperature should have a negative impact on value-added in agriculture as a share of GDP, and this effect should be particularly strong in middle-income countries in which emigration also causes a decline in the number of agricultural workers. To test this hypothesis, we regress a reduced-form relationship between temperature and agricultural value-added as a percent of GDP and

[14] In an alternative (unreported) way of testing the effect of warming on the destination distance, we have calculated the "average distance" of emigrants, where the weighted distance variable is given by: $\sum_j dist_{ji} * \frac{flows_{ji}}{\sum_j flows_{ji}}$,where $dist_{ji}$ is the geographical distance between origin j and destination i. Increases in temperature significantly decrease the average distance of emigration from middle-income countries.

show the coefficient estimates in Table 9. As before, we consider only middle-income and poor countries and obtain the data on value-added in agriculture as a share of GDP from the World Development Indicators (World Bank, 2015). In line with expectations, increases in temperature significantly decrease the agricultural share of GDP for middle-income countries (Column (2)). However, for poor countries the effect is more imprecisely estimated and is not significantly different from zero (although positive in point estimate; see the last row of the table). This is consistent with the idea that in middle-income countries the direct effect of warming (producing a decrease in agricultural productivity) and the indirect effect (inducing migration of rural population to cities or abroad) both contribute to reduced value-added in agriculture. In poor countries, to the contrary, only the direct effect is present and in aggregate may be less significant. Therefore, lower agricultural productivity because of higher temperatures, combined with the possibility of migrating (to cities or abroad) may simply speed up the structural transformation of some middle-income countries away from rural economies towards more urban and productive economies. Though, in very poor countries where migration mechanisms do not work, the loss in agricultural productivity does not trigger a structural change from rural to urban economies.

The previous channel, operating through a structural transformation, encouraged or slowed by warming, suggests another implication of our theory. Warming could be associated with an increase in GDP per capita in middle-income countries where rural workers move to more productive cities. Instead, it should be associated with a decrease of GDP per capita in poor countries where rural workers are stuck in an impoverished agricultural sector. We test this implication in Table A9 of the Table Appendix in which the dependent variable is the logarithm of GDP per capita, obtained from the Penn World Table (2009) in Columns (1) and (2) or from the World Development Indicators (World Bank, 2015) in Columns (3) and (4). Consistently with these predictions, middle-income countries experience growth in GDP per person (Columns (2) and (4)). The mobility of workers into cities (with higher productivity potential) and the out-migration of poor rural workers result in a positive effect, significant at the 5% level, of between 1.9 and 2.2. To the contrary, poor countries experience a negative impact of higher temperature on income per person, with an interaction term that is negative and significant.

Overall, warming temperature increases GDP per capita in middle-income countries while negatively affecting GDP per capita in poor countries. This result confirms what was already found by Burke et al. (2015) and Dell et al. (2012) and hence is not new. Our framework, however, provides an additional explanation, linked crucially to the role of mobility/migration as a margin of adjustment to these weather shocks. In countries in which agricultural productivity is not so low as to be at subsistence level, a worsening of economic opportunities in agriculture pushes individuals to migrate to cities and to other countries, opening them up to better opportunities and eventually helping to raise the average income of a country. Urbanization and moving out of agriculture are crucial mechanisms to the increase of GDP, and in countries at middle-income levels, warming can be an additional push to realize the gains from urbanization. However, in places in which agricultural productivity is so low as to leave rural populations liquidity constrained and stuck to agriculture, a warming climate and lower agricultural productivity may slow economic transformation and growth. These effects ultimately contribute to a poverty trap.

Table 9
Temperature and agriculture share in GDP. Poor and middle-income countries of origin included, years 1970–2000.

	(1)	(2)
	Value added in agriculture as a share of GDP	
Temperature	−1.435	−2.205*
	(1.341)	(1.256)
Temperature×Poor		3.846
		(3.857)
Precipitations	−0.598**	−0.672**
	(0.277)	(0.295)
Precipitation×Poor		0.895
		(1.052)
Country of origin fixed effects	Yes	Yes
Decade×Region effects	Yes	Yes
Decade×Poor effects	Yes	Yes
Observations	325	325
R-squared	0.328	0.334
Number of countries of origin	94	94
Temperature effect in poor countries		1.641

Note: The dependent variable is the value added in agriculture as a share of GDP. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. The weather station data are averaged using population weights. Data on the share of agriculture in GDP are from a World Development Indicator database. The standard errors are cluster by country of origin.

* Indicates significance at the 10% confidence level.

** Indicates significance at the 5% confidence level.

*** Indicates significance at the 1% confidence level.

8. Discussion and conclusions

In this paper we have focused on the potential impact that the increase in average temperature, experienced in many countries during the last few decades, may have on internal and international migration. We have assumed the main impact of temperature increase is through an effect on agricultural productivity and, hence, countries experiencing larger increases may have suffered declining agricultural productivity. This channel, which should mainly affect rural populations, has differential consequences on emigration rates depending on the income level of potential migrants. In very poor countries, where the main obstacle to migration is that people are so poor they cannot afford the cost of emigration, warming and lower rural income may imply less emigration. That is, rural populations go even deeper into poverty and subsistence mode as a consequence of low agricultural productivity. In countries where income is not as low, however, lower agricultural productivity will enhance the incentives to migrate either to cities or abroad. Consistent with these predictions, we find climatic warming associated with significantly higher emigration rates in middle-income countries and significantly lower rates in poor countries (income per capita lower than 1500 $ per person, which includes many countries in Sub-Saharan Africa). We also show that, as a consequence of the migration out of rural poverty encouraged by warming, middle-income countries are better off in terms of their GDP per capita. Poor countries, to the contrary, are made worse off and may be further trapped in poverty as a consequence of climatic warming.

Acknowledgments

We thank one anonymous referee for her/his constructive comments. Participants to the 4th Convention of FEEM and CMCC on Climate Change and Sustainable Development Economics and to the 4th Annual Conference of the Italian Association of Environmental and Resource Economists (IAERE) also provided useful suggestions. The research leading to these results has received funding from the Italian Ministry of Education, University and Research and the Italian Ministry of Environment, Land and Sea under the GEMINA project.

Appendix A. Table Appendix

Table A1
Temperature effects for different income quartiles. All countries of origin included.

	(1)	(2)	(3)	(4)
	Ln(Emigration rates)		Urbanization rates	
	Population weights	Area weights	Population weights	Area weights
Ln(T)×Q1	−16.178**	−17.546***	−0.663**	−0.687*
	(6.530)	(6.239)	(0.321)	(0.360)
Ln(T)×Q2	6.419	0.488***	0.461	0.617*
	(6.499)	(0.072)	(0.473)	(0.357)
Ln(T)×Q3	7.999	5.049	0.442	0.591
	(4.897)	(4.955)	(0.537)	(0.632)
Ln(T)×Q4	3.851**	−3.576	0.352	0.152
	(1.491)	(5.030)	(0.551)	(0.489)
Ln(T)×Q5	0.897	0.683	0.225*	0.081
	(2.210)	(0.704)	(0.118)	(0.051)
Ln(P)×Q1	−1.732	−0.771	−0.153*	−0.161**
	(1.893)	(1.962)	(0.080)	(0.071)
Ln(P)×Q2	−1.721***	−1.932**	−0.029	−0.063
	(0.649)	(0.740)	(0.044)	(0.048)
Ln(P)×Q3	0.011	−0.144	−0.009	−0.031
	(0.403)	(0.381)	(0.077)	(0.081)
Ln(P)×Q4	1.285	1.709	0.045	0.020
	(1.432)	(1.144)	(0.087)	(0.084)
Ln(P)×Q5	0.065	0.256	0.031	0.043
	(0.342)	(0.363)	(0.067)	(0.082)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes
Decade×Quartile effects	Yes	Yes	Yes	Yes
Observations	578	566	715	708
R-squared	0.242	0.249	0.770	0.772
Number of countries	145	143	144	143

Note: The dependent variable is the natural logarithm of emigration rates in columns 1 and 2 and the urbanization rates in columns 3 and 4. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all (OECD and non-OECD) countries. In columns 1 and 3 the weather station data are averaged using population weights. Columns 2 and 4 use area as weight. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A2
Precipitations and emigration. Poor and middle-income countries of origin included, years 1970–2000.

	Ln(Emigration rates)			
	Population weights		Area weights	
	(1)	(2)	(3)	(4)
Ln(P)	−0.399	−0.364	−0.089	−0.283
	(0.364)	(0.342)	(0.355)	(0.360)
Ln(P)×Poor		−0.363		1.995
		(2.067)		(1.531)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes
Observations	462	462	456	456
R-squared	0.162	0.162	0.150	0.155
Number of countries	116	116	115	115
P effect in poor countries		−0.727		1.712

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. In columns 1–2 the weather station data are averaged using population weights. Columns 3–4 use area as weight. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence levels.

Table A3
Temperature and emigration/urbanization. Poor and middle-income countries of origin included, years 1970–2000.

	(1)	(2)	(3)	(4)
	Ln(Emigration rates)		Urbanization rates	
Ln(T)	2.689	4.398***	0.172	0.466
	(1.746)	(1.224)	(0.274)	(0.354)
Ln(T)×Poor		−20.134***		−1.196**
		(7.118)		(0.480)
Ln(P)	−0.369	−0.276	−0.002	0.022
	(0.422)	(0.393)	(0.039)	(0.043)
Ln(P)×Poor		−1.313		−0.167*
		(1.921)		(0.089)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes
Observations	462	462	570	570
R-squared	0.195	0.218	0.752	0.759
Number of countries of origin	116	116	115	115
Temperature effect in poor countries		−15.736**		−0.730**

Note: The dependent variable is the natural logarithm of emigration rates in columns 1 and 2 and the urbanization rates in columns 3 and 4. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is poor and middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. The weather station data are averaged using population weights. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A4
Temperature and emigration, decade differences. Poor and middle-income countries of origin included, years 1970–2000.

	(1)	(2)
	Δln(Emigration rates)	
ΔLn(T)	2.291*	2.911**
	(1.281)	(1.368)
Δ Ln(P)	−0.416	
	(0.376)	
Δ Ln(T)×Poor		−6.302
		(5.070)
Δ Ln(P)×Poor		−0.648
		(2.156)
Year×Area	Yes	Yes
Year×Poor	Yes	Yes
Observations	343	343
R-squared	0.156	0.159
Number of countries of origin	343	343
Country fixed effects	No	No
Δ ln(Temp) effect on poor countries		−3.391

Note: The dependent variable is the ten year difference of the natural logarithm of emigration rates. Each column corresponds to a different estimated regression. The sample is all non-OECD countries. The units of observations are decade-differences for each country. Method of estimation is ordinary least squares. The weather station data are averaged using population weights. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A5
Temperature and emigration. Long differences. Poor and middle-income countries of origin included, 1970–2000.

	(1)	(2)
	Δln(Emigration rates)	
ΔLn(T)	2.904	4.277*
	(2.792)	(2.481)
Δ Ln(T)×Poor		−35.339***
		(8.906)
Δ Ln(P)	−0.269	−0.197
	(0.424)	(0.444)
Δ Ln(P)×Poor		−3.649**
		(1.808)
Area dummies	Yes	Yes
Poor dummy	Yes	Yes
Observations	114	114
R-squared	0.211	0.271
Tem effect on poor countries		−31.062***

Note: The dependent variable is the thirty year difference of the natural logarithm of emigration rates. Each column corresponds to a different estimated regression. The sample is all non-OECD countries. The units of observations are the difference between the average temperatures in the last decade of our sample (1990–2000) and the average temperatures in the first decade (1970–1980). The weather station data are averaged using population weights. Method of estimation is ordinary least squares.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A6
Temperature and emigration/urbanization. Additional interactions with SSA. Poor and middle-income countries of origin included, 1970–2000.

	(1)	(2)	(3)	(4)
	Ln(Emigration rates)		Urbanization rates	
Ln(T)	3.274*	3.778**	0.848**	0.972**
	(1.666)	(1.715)	(0.398)	(0.430)
Ln(T)×Poor		−19.966**		−1.237
		(8.721)		(0.964)
Ln(T)×SSA	−11.139**	−0.249	−1.325*	−0.649
	(5.438)	(6.663)	(0.744)	(1.077)
Ln(P)	−0.680*	−0.583*	0.017***	0.017
	(0.348)	(0.313)	(0.042)	(0.042)
Ln(P)×Poor		−2.683		−0.085
		(1.742)		(0.090)
Ln(P)×SSA	2.237*	3.114**	−0.149*	−0.104
	(1.274)	(1.391)	(0.076)	(0.079)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes	Yes
Observations	458	458	565	565
R-squared	0.203	0.221	0.731	0.734
Number of countries of origin	115	115	114	114
Tem effect on poor countries		−16.188*		−0.265

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample includes non-OECD countries. Columns 1–2 use the natural logarithm of emigration rates as dependent variable. Columns 3–4 use urbanization rates as dependent variable. The weather station data are averaged using population weights. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A7
Temperature and emigration. Control for natural Disasters. Poor and middle-income countries of origin included, 1970–2000.

	(1)	(2)	(3)
	Ln(Emigration rates)		
Ln(T)	1.561	3.414**	3.382*
	(1.787)	(1.695)	(1.709)
Ln(P)	−0.264	−0.196	−0.196
	(0.354)	(0.329)	(0.330)
Natural disasters	−0.007*	−0.005	−0.005
	(0.004)	(0.004)	(0.004)
Ln(T)×Poor		−19.310***	−19.368***
		(6.628)	(6.641)
Ln(P)×Poor		−1.314	−1.446
		(1.901)	(1.826)
Natural disasters×Poor			0.010
			(0.031)
Country of origin fixed effects	Yes	Yes	Yes
Decade×Region effects	Yes	Yes	Yes
Decade×Poor effects	Yes	Yes	Yes
Observations	458	458	458
R-squared	0.183	0.203	0.204
Number of countries of origin	115	115	115
Temperature effect on poor countries		−15.896**	−15.986**

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample for columns 1–3 is all non-OECD countries. The “Natural disasters” variable is defined as the number of times in a decade that a natural disaster occurred. The weather station data are averaged using population weights. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A8
Temperature and emigration. Temperature in levels. Poor and middle-income countries of origin included, 1970–2000.

	Ln(Emigration rates)			
	Population weights		Area weights	
	(1)	(2)	(3)	(4)
Temperature	0.036	0.267*	−0.142	0.076
	(0.161)	(0.155)	(0.148)	(0.164)
Precipitations	−0.030	−0.013	−0.025	−0.020
	(0.028)	(0.024)	(0.031)	(0.030)
Temperature × poor		−1.127***		−0.844**
		(0.336)		(0.334)
Precipitations × poor		−0.159		−0.033
		(0.116)		(0.160)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade × Region effects	Yes	Yes	Yes	Yes
Decade × Poor effects	Yes	Yes	Yes	Yes
Observations	458	458	452	452
R-squared	0.057	0.178	0.162	0.176
Number of countries of origin	115	115	114	114
Tem effect on poor countries		−0.860***		−0.768**

Note: The dependent variable is the natural logarithm of emigration rates. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries is all non-OECD countries. In columns 1–2 the weather station data are averaged using population weights. Columns 3–4 use area as weight. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Table A9
Temperature and GDP per capita. Poor and middle-income countries of origin included, years 1970–2000.

	Ln (GDP per capita)			
	Penn World Table source		WDI source	
	(1)	(2)	(3)	(4)
Ln(T)	1.545*	2.173**	1.396*	1.908**
	(0.872)	(1.096)	(0.762)	(0.772)
Ln(T) × Poor		−6.806**		−5.816**
		(2.907)		(2.692)
Ln(P)	0.428**	0.457***	0.356**	0.382**
	(0.168)	(0.172)	(0.148)	(0.157)
Ln(P) × Poor		−0.382		−0.523
		(0.532)		(0.484)
Country of origin fixed effects	Yes	Yes	Yes	Yes
Decade × Region effects	Yes	Yes	Yes	Yes
Decade × Poor effects	Yes	Yes	Yes	Yes
Observations	452	452	390	390
R-squared	0.277	0.290	0.288	0.298
Number of countries	115	115	108	108
T effect in poor countries		−4.633*		−3.909

Note: The dependent variable is the natural logarithm of GDP per capita. Each column corresponds to a different Least Square estimated regression with fixed effects. The sample is all non-OECD countries. The weather station data are averaged using population weights. Columns 1–2 use data on GDP from Penn World Table. Columns 3–4 instead use data on GDP from a World Development Indicator database. The standard errors are cluster by country of origin.
* Indicates significance at the 10% confidence level.
** Indicates significance at the 5% confidence level.
*** Indicates significance at the 1% confidence level.

Appendix B. Data Appendix

The migration data used in this paper are taken from Ozden et al. (2011) and include matrices of bilateral migrant stocks in five available census years spanning 1960–2000, for 226 countries of origin and 226 countries of destination. To compute the emigration rates used in the estimations, first we compute bilateral emigration net flows as differences between bilateral stocks in two consecutive censuses. Then we sum all bilateral flows for the same countries of origin j, setting negative values to 0, as they are likely be due to mortality of the stock of emigrants abroad. The emigration rate from country of origin j is the ratio between the aggregated net flows from origin country j and the origin country population at the beginning of the decade. The computed emigration rates span the period from 1970 to 2000. The temperature and precipitation data are taken from Dell et al. (2012). The (terrestrial) monthly mean temperature and precipitation data at 0.5×0.5 degree resolution obtained from weather stations (Matsuura and Willmott, 2007) are aggregated into country-year averages using the population in 1990 at 30 arc second resolution as weights or alternatively using area weights. By merging the two datasets and considering only "Poor and Middle-income" countries, we were able to compile final datasets with 114 and 115 countries. The exact number depends on the weights used to aggregate the weather station data (population or area). Given that the emigration rates were only available at decade level, temperature and precipitation have been averaged over the 10 years of the decade. For almost all countries the data were available for four decades. Only for Namibia, the first decade available is 1990.

B.1. List of poor countries

Afghanistan, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Democratic Republic of Congo, the Equatorial Guinea, Ethiopia, Gambia, Ghana, Guinea-Bissau, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Nepal, Niger, Nigeria, Rwanda, Somalia, Sudan, United Republic of Tanzania, Togo, Uganda, Yemen and Zambia

B.2. List of middle-income countries (population weights)

Albania, Algeria, Angola, Argentina, Bahamas, Bangladesh, Belize, Bhutan, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cameroon, Cape Verde, Chad, China, Colombia, Comoros, Congo, Costa Rica, Cote d'Ivoire, Cuba, Cyprus, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, Gabon, Guatemala, Guinea, Guyana, Haiti, Honduras, India, Indonesia, Iran, Iraq, Jamaica, Jordan, Kenya, Kuwait, Lebanon, Libya, Malaysia, Mauritania, Mauritius, Morocco, Namibia, Nicaragua, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Puerto Rico, Qatar, Romania, Russia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia and Montenegro, Sierra Leone, Solomon Islands, South Africa, Sri Lanka, Suriname, Swaziland, Syrian Arab Republic, Thailand, Trinidad and Tobago, Tunisia, United Arab Emirates, Uruguay, Vanuatu, Venezuela, Viet Nam, Zimbabwe

Appendix C. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jdeveco.2016.05.004.

References

Auffhammer, M., Hsiang, S.M., Schlenker, W., Sobelz, A., 2013. Using weather data and climate model output in economic analyses of climate change. Rev. Environ. Econ. Policy 7 (2), 181–198.

Auffhammer, M., Vincent, J.R., 2012. Unobserved time effects confound the identification of climate change impacts. Proceedings of the National Academy of Science 109 (30), 11973–11974.

Backhaus, A., Martinez-Zarzoso, I., Muris, C., 2015. Do climate variations explain bilateral migration? a gravity model analysis. IZA J. Migr. 4, 3.

Barrios, S., Bertinelli, L., Strobl, E., 2006. Climatic change and rural–urban migration: the case of Sub-Saharan Africa. J. Urban Econ. 60 (3), 357–371.

Beine, M., Parsons, C., 2015. Climatic factors as determinants of international migration. Scand. J. Econ. 117 (2), 723–767.

Bohra-Mishra, P., Oppenheimer, M., Hsiang, S.M., 2014. Nonlinear permanent migration response to climatic variations but minimal response to disasters. Proc. Natl. Acad. Sci. 111 (27), 9780–9785.
Borjas, G.J., 1987. Self-selection and the earnings of immigrants. Am. Econ. Rev. 77 (4), 531–553.
Burke, M., Hsiang, S., Miguel, E., 2015. Global non-linear effect of temperature on economic production. Nature 527, 235–239.
Cai, R., Feng, S., Pytliková, M., Oppenheimer, M., 2014. Climate Variability and International Migration: The Importance of the Agricultural Linkage. CReAM Discussion Paper Series 1418, Centre for Research and Analysis of Migration (CReAM). Department of Economics, University College London.
Clemens, M., 2014. Does Development Reduce Migration? IZA Discussion Papers 8592. Institute for the Study of Labor (IZA).
Centro Internacional de Agricultura Tropical - CIAT, 2004. Gridded Population of the World, Version 3 (GPWv3): Population Count Grid Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC).
Cline, W.R., 2007. Global Warming and Agriculture: Impact Estimates by Country. Center for Global Development and Peterson Institute for International Economics, Washington.
Couttenier, M., Soubeyran, R., 2014. Drought and civil war in Sub-Saharan Africa. Econ. J. 124 (575), 201–244.
Dell, M., Jones, B., Olkien, B., 2012. Temperature shocks and economic growth: evidence from the last half century. Am. Econ. J. Macroecon. 4 (3), 66–95.
Dell, M., Jones, B., Olkien, B., 2014. What do we learn from the weather? The new Climate-Economy literature. J. Econ. Lit. 52 (3), 740–798.
Dillon, A., Mueller, V., Salau, S., 2011. Migratory responses to agricultural risk in Northern Nigeria. Am. J. Agric. Econ. 93 (4), 1048–1061.
Docquier, F., Marfouk, A., Özden, C., Parsons, C., 2011. Geographic, Gender and Skill Structure of International Migration. MPRA Paper 47917. University Library of Munich, Germany.
Feng, S., Krueger, A.B., Oppenheimer, M., 2010. Linkages among climate change, crop yields and Mexico–US cross-border migration. Proc. Natl. Acad. Sci. 107 (32), 14257–14262.
Gray, C.L., 2009. Environment, land, and rural out-migration in the Southern Ecuadorian Andes. World Dev. 37 (2), 457–468.
Gray, C.L., Bilsborrow, R., 2013. Environmental influences on human migration in rural Ecuador. Demography 50 (4), 1217–1241.
Gray, C.L., Mueller, V., 2012. Drought and population mobility in rural Ethiopia. World Dev. 40 (1), 134–145.
Gray, C.L., Mueller, V., 2012. Natural disasters and population mobility in Bangladesh. Proc. Natl. Acad. Sci. 109 (16), 6000–6005.
Grogger, J., Hanson, G., 2011. Income maximization and the selection and sorting of international migrants. J. Dev. Econ. 95 (1), 42–57.
Hoyois-EM-DAT, Ph, Guha-Sapir, D., Below, R., 2015. International Disaster Database -Www.Emdat.Be-. Université Catholique de Louvain, Brussels - Belgium.
Hatton, T.J., Williamson, J.G., 1994. What drove the mass migrations from Europe in the late nineteenth century? Popul. Dev. Rev. 20 (3), 533–559.
Hatton, T.J., Williamson, J.G., 2003. Demographic and economic pressure of emigration out of africa. Scand. J. Econ. 105 (3), 465–486.
Hatton, T.J., Williamson, J.G., 2011. Are third world emigration forces abating? World Dev. 39 (1), 20–32.
Henry, S., Schoumaker, B., Beauchemin, C., 2004. The impact of rainfall on the first out-migration: a multilevel event-history analysis in Burkina Faso. Popul. Environ. 25 (5), 423–460.
IPCC, 2014. Fifth Assessment Report: Impacts, Adaptation, and Vulnerability. UNEP, Washington DC.
Jones, B., Olken, B.A., 2010. Climate shocks and exports. Am. Econ. Rev. 100 (2), 454–459.
Jedwab, R., Christiaensen, L., Gindelsky, M., 2014. Rural Push, Urban Pull And Urban Push? New Historical Evidence From Developing Countries. Working Papers 2014-04. The George Washington University, Institute for International Economic Policy.
Kelley, C.o.P., Shahrzad, M., Cane, M.A., Seager, R., Kushnir, Y., 2015. Climate change in the Fertile Crescent and implications of the recent Syrian drought. Proc. Natl. Acad. Sci. 112 (11), 3241–3246.
Marchiori, L., Maystadt, J., Schumacher, I., 2012. The impact of weather anomalies on migration in Sub-Saharan Africa. J. Environ. Econ. Manag. 63, 355–374.
Matsuura, K., Willmott, C.J., 2007. Terrestrial Air Temperature and Precipitation: 1900–2006 Gridded Monthly Time Series, Version 1.01. http://climate.geog.udel.edu/climate/.
Mayda, A.M., 2010. International migration: a panel data analysis of the determinants of bilateral flow. J. Popul. Econ. 23 (4), 1249–1274.
Mendelsohn, R., Nordhaus, W.D., Shaw, D., 1994. The impact of global warming on agriculture: a Ricardian analysis. Am. Econ. Rev. 84 (4), 753–771.
Mueller, V.A., Gray, C.L., Kosec, K., 2014. Heat stress increases long-term human migration in rural Pakistan. Nat. Clim. Change 4, 182–185.
Munshi, K., 2003. Networks in the modern economy. Mexican migrants in the US labor market. Q. J. Econ. 118 (2), 549–599.
Ortega, F., Peri, G., 2012. The effect of income and immigration policies on international migration. Migr. Stud. 1, 1–28.
Ozden, C., Parsons, C.R., Schiff, M., Walmsley, T.L., 2011. Where on earth is everybody? The evolution of global bilateral migration 1960–2000. World Bank Econ. Rev. 25 (1), 12–56.
Penn World Table, 2009. Version 6.3. http://datacentre.chass.utoronto.ca/pwt/.
Pritchett, L., 2006. Let Their People Come: Breaking the Gridlock on International Labor Mobility. Center for Global Development, Washington DC.
Roy, A.D., 1951. Some thoughts on the distribution of earnings. Oxf. Econ. Pap. 3 (2), 35–46.
UN, 2014. World Urbanization Prospects: The 2014 Revision. Department of Economic and Social Affairs, Population Division, United Nations publication.
World Bank, 2015. World Development Indicators. http://data.worldbank.org/data-catalog/world-development-indicators.
Zelinsky, W., 1971. The hypothesis of the mobility transition. Geogr. Rev. 61 (2), 219–249.