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ABSTRACT

Climate change, especially the warming trend experienced by several countries, could affect agricultural productivity. As a consequence the income of rural populations will change, and with them the incentives for people to remain in rural areas. Using data from 116 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 increased emigration rates to urban areas and to other countries in middle income economies. In poor countries, higher temperatures reduced the probability of emigration to cities or 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.

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1 Introduction

One of the long-run effects of rising average surface temperatures is the disruption of productivity in agriculture. The optimal yield of agricultural products has been adjusted to local temperature for centuries. Hence, productivity decreases as temperatures increase beyond a country's historical average (IPCC, 2014; Dell et al., 2014; Cline, 2007). Agriculture is still a 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 migrations in some specific countries (e.g. Bohra-Mishra et al., 2014; Dillon et al., 2011; Mueller et al., 2014; Gray and Mueller, 2012a), only very 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 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 are near subsistence, so a lower income worsens their liquidity constraint, implying potential migrants have a reduced ability to pay migration costs. In this case, global warming may trap very poor rural workers who become unable to leave agriculture, 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 economic success for migrants, benefiting their country of origin and 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

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

effect by exploiting variation of an exogenous determinant of income per person, such as temperature.

In this paper we use a simple framework that extends the classical Roy-Borjas (Roy, 1951; Borjas 1987) model and uses it 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 that decreases the income of rural populations in very poor countries generates a poverty trap and lowers the probability of emigration. To the contrary, for 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 temperatures decrease emigration and urbanization, while in middle-income countries they increase those measures. We then show how long-run warming speeds the transition from agriculture to non-agriculture in middle-income countries. Conversely, it slows this transition in poor countries – worsening the poverty trap – as poor rural workers become less able to move to cities or abroad. We also find that emigration in middle-income countries, induced by higher temperatures, is local and is associated with a growth in GDP per person, while the decline in emigration and urbanization in poor countries is associated with lower average GDP per person.

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 connection climate-migration 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 fast. Several papers have analyzed the impact of episodes of drought, high temperature, or low precipitation on rural emigration in some specific countries. Dillon et al. (2011) analyze 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 draughts 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 precipitations and migration in Burkina Faso. Bohra-Mishra et al. (2014) analyze Indonesia and Kelley et al. (2015) focus on Syria. Because of its extreme poverty and dependence on agricultural production and employment, Sub-Saharan Africa has been a main area of attention. Most of these studies, however analyze the yearly correlation between weather phenomena and migration and may pick up 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 in sub-Saharan Africa.

Another case that has been studied in depth is the connection between climate and migration out of Mexico. Looking at Mexico-US migrations Munshi (2003) was the first to show the connection between low rainfall and migration rates from Mexico to the US. More recently, Feng et al. (2010) confirm the relation between weather and migration from Mexico. However, Auffhammer and Vincent (2012) demonstrate this effect vanishes after they control for a richer set of covariates. Overall, the existing literature on weather/climate change and migration focuses on within country data and usually on gross yearly migration rates. Hence it fails to provide a general picture on the potential long-run effect of weather changes on migration across countries. Some econometric analyses at the macro level exist, but they mainly focus on the consequences of natural disasters, such as droughts, earthquakes, floods, storms, and volcanic eruptions. They do not directly tackle the question regarding the effect of changes in average temperatures on migrations in the long-run. Beine and Parsons (2015) produced 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. The narrow focus on partial effects and on some extreme events makes that paper different from ours. Our paper differs from all the previous ones by considering all countries of the world and explicitly analyzing the effects of temperature on migration within a simple Roy-Borjas model of migration and average productivity. In so doing, it identifies a crucial distinction of temperature increases on poor and middle-income countries and tests whether such distinctions and other additional implications are supported by the data. Finally the paper closer to our approach is Cai et al (2014). In this paper the authors analyze how yearly bilateral migration flows depend on yearly temperatures at origin for a panel of 163 countries of origin into 42 OECD destinations for the period 1980-2010. The structure of the analysis implies that these are short-run elasticity responses (within the year) and only includes migration to OECD countries. The authors do not separate between poor and middle income countries and use quite 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 more interested in the long-run impact of slow changing temperature and precipitation on migration rates.

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 (Roy, 1951; Borjas, 1987), 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 and 2011)). 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 during 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. For simplicity (and without loss of insight) we assume individuals have 0 discount rate, the wage in the country of origin for period 1 and 2 are identical, and no uncertainty exists. The wage of individual i when residing in country of origin J ($= P, M$) in the first and second period 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 this term depends positively on agricultural productivity – among other factors – especially as the economy of country P and M depend on agriculture and 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 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 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) and Ortega and Peri (2012)) we assume 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) so that 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 $J = P, M$.[2] 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 (2012) we assume individual's 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:

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

Condition (4) has been typically thought of in the literature as a "selection" equation. The parameter restriction $\beta_R > \beta_J$ implies "positive selection". Namely, as shown in equation (4), 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 equation (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 (4), the larger is the share of individuals for

[2] 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.

which the incentive constraint is satisfied. The migration decision, however, should also satisfy a "feasibility" constraint . If we assume 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 does not exceed their total savings at the end of period 1, which, in our simple model, is at most equal to w_{iJ}. With labor as the only source of income and assuming monetary costs of migrations must be paid up front, the necessary condition for feasibility – which can be called a 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

Using the fact that individual skills ε_i are distributed in the population of country J as a normal with 0 mean and unitary variance, the two conditions (4) and (6) above imply 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 (4) and (6). For each country only one of the two thresholds can be binding. It is easy to see that the "incentive" threshold (4) is increasing in the "median" income $\mu_J(T_J)$, while the "liquidity" threshold (6) is decreasing in it. The monotonicity of the two thresholds implies that there is a value of $\mu_J^*(T_J^*)$ for which they are identical and we consider that value as marking the divide between "Poor" (P) and "Middle income" (M) countries[3]. 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:

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

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

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. ■

The intuition is straightforward. As lower agricultural productivity implies lower median income, in middle-income countries this effect increases the incentive (and hence probability) of migrating and hence raises the emigration rate. For those countries the liquidity constraint does not bind.

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 $\mu_J^*(T_J^*)$, 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 is also straightforward. In poor countries, 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.

Figure 1 illustrates these two cases in Panels 1 and 2, respectively. Panel 1 represents the skill distribution in the middle-income country. We see the migrating population is the one in the shaded area with skills above ε_I (T_I), the skill-threshold determined by the incentive-constraint. On the contrary, the skill-threshold driven by the liquidity constraint, ε_L (T_L), is not binding and, hence, irrelevant. The arrows in the graph represent the shift of the thresholds implied by an increase in temperature, T. As a consequence of increases in temperature, the upper (incentive) threshold moves to the left, while the lower (liquidity) threshold – irrelevant for middle- income countries – moves to the right. This implies the area below the skill density distribution and to the right of the threshold increases. Panel 2 shows the picture for poor countries. We assume the same relative distribution of skills, but in this case the ordering of the thresholds is switched. The liquidity threshold that moves to the right as T increases is now binding. This implies a smaller mass of people migrating as a consequence of higher temperatures.

By taking logarithms and log-linearizing both sides of each equation (7) and (8) and merging them into one equation, we obtain the basic equation and prediction for our empirical test and 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 (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 1960 and 2000.[4] 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 0.5×0.5 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 (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 116 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 116 countries to 116 countries, so many more destinations than only considering OECD (as done in Cai et al 2014). The other advantage is that the source of these data are national censuses, much more accurate in counting foreign-born than yearly flow measures. The disadvantage is that data are only available every ten years and hence can capture long-run migration tendencies but not short-run temporary migration flows. In our current analysis, focussed on long-run relationships this is not an issue.

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.[5] The

[4] 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 A.

[5] Bilateral net flows that are negative (usually very small numbers) are set to 0 as they may be due to

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 1960 and 2000 available over ten year intervals. For GDP per capita the main sources are the Penn World Table (2009) and the World Development Indicators (World Bank, 2015). Data on the value added in agriculture are from 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. In practice we define poor and middle-income countries in two ways. In a first definition, we consider all non-OECD countries,[6] for a total of 115 countries, as part of our sample. In a second definition we rank countries by PPP-adjusted per capita GDP in 1990, taken from the Penn World Table, and we choose those below the top quintile, which leaves us with 116 countries in the sample of countries of origin. In the first definition we consider poor countries those in the bottom quartile of the non-OECD sample income distribution, measured as PPP-adjusted per capita GDP in 1990. In the second definition, poor countries are those in the bottom quintile of the sample income distribution, computed before excluding rich countries. Under both definitions we end up with the same list of 30 poor countries, while the list of 85 (or 86) middle-income countries is somewhat different between the two definitions (see the Data Appendix for each list). Ideally, one would want to use 1970 as the reference year to partition countries between poor and middle income, but 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 in per capita GDP 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. The countries near the threshold between poor and middle income are those with yearly income per person around $1,500 in 1990. This is clearly a low threshold, implying a large share of the "poor" countries are in sub-Saharan Africa. For rural population in these countries, which tends to be the poorest portion within the country, the liquidity constraints is clearly very relevant as they likely live on an income of a few dollars per day. Saving some hundreds of dollars needed to move out of the country can be very hard for these families. The threshold between middle-income and rich countries was instead around $15,000 per person in 1990 which was about the income per person of Portugal or

mortality of the stock of emigrants abroad.

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

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 countries (poor and middle income) separately when we include all non-OECD economies. 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 Figures 2 and 3. The graphs show the evolution of emigration rates and temperatures for ten selected poor and middle-income countries, chosen to be each at a decile of the overall distribution for the total four decade change. 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. The left-hand panel of Figure 2 shows that emigration rates are relatively stable during the period in middle-income countries, with most countries experiencing changes of only 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 decade, by 9 percentage points. For poor countries, we can observe a larger proportion of increasing emigration rate than decreasing it, with a significant amount of variation.

As for temperature, Figure 3 shows that over the considered period temperatures increased in the large majority of middle-income and poor countries. As one can see from the figure, the last decade was generally warmer for all countries than 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, with a range of about 1 degree Celsius separating the top two deciles for both middle-income and poor countries.

Figure 4 shows our 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 temperatures 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. Middle-income countries show a positive (albeit not strong) correlation while poor countries show a negative 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:

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

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.[7] $T_{j,t}$ 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

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

sample of middle-income and poor countries of origin. In the main specification we apply the first definition of poor and middle-income countries and include only non-OECD countries of origin equating OECD to rich countries. Alternatively, in robustness checks we apply the second definition and consider as "rich" (and drop from the country of origin sample) those countries in the top quintile of the income per person distribution. 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. It is equal to one for countries in the bottom quintile of the income distribution (determined before excluding rich countries) in the sample that excludes top income countries.

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, sociopolitical 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 that we are considering. Therefore, we decided to remain parsimonious in our models (as done in Jones and Olken, 2010 or Dell et al., 2012) 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.

5.1 Effects on International Migration

The main estimated coefficients capturing the effects of average temperature on international migrations are presented in Table 2. Columns (1) to (4) and (7)-(8) show estimates in which we use the population weights for the aggregation of weather station temperature and precipitation data, while Columns (5) and (6) aggregate temperature data using area weights. In Columns (1) to (6) OECD countries are excluded from the origin countries, so the sample of poor and middle-income countries is defined as non-OECD ones. In Columns (7) and (8) countries in the top quintile of income per capita distribution are dropped in identifying poor and middle-income countries. The estimated specifications in Columns (2), (6) and (8) are exactly as shown in equation (10). In Columns (1), (5) and (7) we omit the interaction of temperature with the "poor country" dummy to obtain the average effect of temperature on emigration, averaging all countries. In Specifications (3) and (4) we also 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 agricultural productivity is the channel through which temperature affects migration. The number of observations varies between 114 and 116 countries 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 2. These results are consistent and robust across different specifications. The first is, when 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 that when we allow the coefficient on 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, is reported in the second-to-last row of Table 2: it is also negative and statistically significant.[8] The estimated coefficients in Column (2) indicate that a one percent increase in temperature increases international migration rates by four percent in middle-income countries, whereas it decreases emigration rates in poor countries by 16 percent, *ceteris paribus*. This implies a middle-income country with an average yearly temperature of 22 degree Celsius (the average of our sample) would experience a 20% increase in the rate of emigration if its average yearly temperature increased by one degree (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; 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. Aufhammer 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 draught and act as a confounding factor. The estimates, reported in Table A1 of the appendix, show no significant correlation between precipitation and migration even when the variable "temperature" is omitted. Using specifications similar to those of Table 2, in fact, we observe that the estimated coefficient on the precipitation variable is never significant. According to these results, agriculture-related emigration is mainly due to changes in temperature, rather than changes in precipitations.

If the negative effect on migration in poor countries proceeds from lower agricultural

[8] 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 $1,500 in 1990 as "poor". In a robustness check (not reported), we use a less stringent definition of "poor" by including countries in the lowest tercile of the income distribution. This includes all countries with GDP per person below 2,000$ as poor. The results, available upon request, are very similar to those reported in Table 2.

productivity and liquidity constraints, as assumed by our simple model, then it should be particularly strong for countries heavily depending on agriculture. Granted that there is a strong negative correlation between the share of agriculture in GDP and income per person, so that poor countries have, in general, a larger share of agriculture value added in GDP, we explicitly include a dummy in Column (3) capturing those countries with a large agricultural sector. Their productivity and incomes 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.[9] 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 degree Celsius at the sample average) decreases the rate of emigration by an additional 12 percent 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 definitions of our sample (non-OECD versus countries below the top quintile of GDP per person) and a different weighting of the temperature data do not make much of a difference in the estimates. Hence, we will mostly use the non-OECD definition of poor and middle-income countries and population weights.

In Table 3 we present some robustness checks that confirm the results in Table 2. In this case, we divide the sample and analyze the effects of temperature and precipitation on emigration for middle-income countries (Columns 1-4) and poor countries (Columns 5-6) separately. This implies that we allow all the coefficients in our model (not only those on average temperature) to differ between these two groups of countries. The point estimates in Table 3 are in line with the corresponding coefficients in Table 2. 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 21%. The precipitation variable does not appear to have any significant effect on either group.

Another simple implication that the effects we are estimating proceed through the impact of climate on agricultural income and not from other omitted channels is that average temperature should not have any impact on the emigration rates from rich countries. Agriculture is not an important source of income for those countries and rural population in those

[9] 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.

countries is a small percentage of the total. Hence one would not expect either positive or negative migration effects of temperature in these countries. In general we do not include rich countries of origin in our analysis, as agricultural productivity is much less relevant there (and possibly less subject to weather fluctuations). In column (7) of Table 2 we check that the irrelevance of temperature for net emigration rates in rich countries is confirmed by the data. In a specification similar to (1), including only OECD countries as origin, we find an estimate of the impact of temperature on emigration rates that is very small in value (1.04) and not significant at all.[10]

In Table 3 we also investigate whether the effect of temperatures on migration varies depending on the country being in the group of warmer (hotter than the median) or cooler (colder than the median) countries in the world within each income group. As the effect of our regressions (because of country fixed effects) are identified on the change in temperature over the considered decades, one might expect that countries starting with high temperatures might suffer worse consequences from average warming. Even if adaptation to increasing temperature is possible at any level of temperature by choosing the optimal crop mix and optimal mix of crops and animal activities, at high temperatures the overall profitability of agriculture declines (Mendelsohn et al., 1994; IPCC, 2014). For example, higher temperatures in the tropics reduce the size of the agro-climatic zones suitable for perennial crops. They also reduce the growing season length, influence the composition of farming systems towards livestock-dominated food production (IPCC, 2014), and force farmers to adopt climate-resistant crops. All these adaptation measures, however, prove to be less productive and therefore, at higher temperatures, average warming may be more detrimental. It may also be, however, that changes in temperature are damaging to any poor country's agricultural productivity, at least for a while, because local crops and production have been adapted and perfected for centuries to a certain yearly cycle of temperatures and a systematic alteration of that is damaging to productivity at any level of temperature. Moreover keep in mind that we are considering poor or middle income countries in which technological and scientific adjustment of agricultural practices to climate changes may be slow. Specifications (2), (4) and (6) include in the regression an interaction of the temperature variable with the dummy for countries that are warmer than the median. The stratification of the sample implies that (2) and (4) estimate the effect only on middle-income countries and (6) only on poor ones. In no case do we find significant interaction effects. Increases in temperature are equally damaging for agriculture both in cold and warm countries and they translate in more migration in middle-income countries while poor countries respond with less migration,

[10] A similar non-significant effect is found when the sample of rich countries is selected on the basis of GDP per capita.

possibly because of the tight liquidity constraint. This result is somewhat in contrast with Borha-Mishra et al (2014) who find a positive effect of temperature on emigration rates in Indonesian villages only for values above the median of 25 degree Celsius. Their identification is however based on variation over time, for one country only and their focus is on net emigration from a village rather than international emigration.

The opposite effects of temperature on the emigration rate in poor and middle-income countries is consistent with the model presented in section 3 and with simple economic logic that emphasize both the presence of incentives and constraints. If secular heating damages agricultural productivity, countries with a large dependence on agriculture and very low income experience a substantial worsening of their liquidity and hence of their ability to pay for emigration. On the other hand, middle-income countries experience a worsening of potential earnings but, as long as people can afford emigration costs, this increases their willingness to emigrate. 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 increase in income in very poor countries allows them to pay the costs and increases emigration rates. Past a certain level, however, higher income reduces the incentives to migrate. Most studies find the inversion in this relation takes place between 3,000 and 5,000 $ per person, which is a level in the low-range of the middle-income countries of our sample. Hence, consistently with that literature, the negative effect we find on poor countries can be fully due to worsening of income and of liquidity constraints.

In Tables A2 and A3 of the Appendix we explore two further robustness checks. In Table A2 we consider decade differences in emigration rates and temperature and 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 can happen if 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 (although not significant). Table A3, 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 in long differences. Comparing the long-run estimates of Table A3 and the corresponding medium-run coefficients of Table 2 we see that elasticities are larger in the second case. One may conclude that protracted 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 temperatures 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 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 and cities, is an alternative. While the economic returns to internal migration are lower, it is less costly than emigration. The same ideas, developed in the model of section 3, can be applied to rural-urban migrants. Increased temperatures 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 reason 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 their income perspectives in agriculture may increase inflow into cities. Thus, we can use a measure of "urbanization" as the outcome of interest, namely the share of total population of a country living in cities. The change in this variable is mainly due to rural-urban migration. We analyze the effects of increasing average temperatures and precipitation on urbanization, just as we did for international migration rates.

The structure of Table 4 follows exactly that of Table 2, except that the outcome variable is the share of population living in urban areas relative to total population in the country. Columns (1)-(4) and (7)-(8) calculate the average temperature in a country by using population weights, while Columns (5)-(6) use area weights. Columns (1)-(6) use the non-OECD sample, while (7)-(8) use the countries in the bottom and fourth quintiles of GDP per person as the sample. Considering the results in Columns (1) and (2), the findings suggest a similar behavior of rural-urban migration as was found for international migration. Namely, an increase in average temperatures increases the degree of urbanization, speeding up the rural-urban transition in middle-income countries, but slows it down in poor countries. A 5% increase in temperature at the average (22 degree Celsius), equal to about one degree Celsius, increases urbanization rates by 4 percentage points in middle-income countries, while it decreases it by the same amount in poor countries. Considering 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 one degree Celsius 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. On the contrary, the interaction between precipitation and the "poor country" dummy has a marginally significant effect in three specifications. 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 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.

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 from this as a consequence of crowding and a decrease in income/amenities in cities. This is a reasonable possibility and our results are consistent with it. However, rural populations may directly migrate abroad, and the crowding of cities may decrease income (crowding), or increase it (agglomeration), so that international migration may not be a direct consequence of urbanization. In our framework, we consider urbanization and international migrations as two possible outcomes, both driven by a decline in rural income, but not necessarily sequential 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 4 show increases in temperature have the same type of 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 somewhat 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. Table 5 presents the findings using this split. We then separate emigration between destinations within 1,000 Km from the origin and farther destinations and we calculate separate rates for short-distance and long-distance emigration. Table 6 shows the estimates in this case.

The estimates in Table 5 show a very interesting pattern of temperature-induced emigration. Columns 1-4 show the effect on emigration rates to non-OECD destinations. Columns 5-8 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 noting. First, increasing in temperatures 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 with those estimates, Table 6 – whose structure mirrors that of Table 5 – shows higher temperatures increase emigration rates to close destinations (<1000 Km.) for middle-income countries, while poor countries experience a decrease of emigration rates to any other country (the standard error on the estimated effects in Columns 2 and 4 are rather large, however). Combining the effect on poor and middle-income countries, it appears that increases in average temperatures 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 their household income and economic well-being.[11]

[11] 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 decreases the average distance of emigration from middle-income countries.

6 Robustness Checks

We conducted a variety of robustness checks and present the results in the Appendix at the end of the paper. 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 and also those whose productivity is more likely to be affected by temperature increases. Moreover, several of the previous studies (e.g. Barrios et al 2012 and Marchiori et al 2006) have considered only sub-Saharan African Countries in their analysis of extreme weather events and migration. In Column (1) of Table A4 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 increases looks in line with the response of other poor countries: 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 and that is the effect of Ln(precipitation). Drier climates are associated with higher emigration rates for non-SSA countries and lower emigration-rates for SSA countries. These effects are significant at the 10% level 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.

Table A5 includes a variable that captures the realization of extreme temperatures during a decade in a country. The variable measures the number of years of a decade in which the temperature was above or below two standard deviations of the 1960-2000 period mean for the country. 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)-(6) of Table A5 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 (7) and (8) focus specifically on extremely high temperature years (only anomalies in the high temperature range), but again we do not find significant effects.

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 A6 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 count of their occurrences in the decade. We do not find, however, any impact. It 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. Hence natural disasters may be responsible for the displacement of people in near areas, generating nonpermanent transitions, but in the long run, as they are rare and they only occur in some countries, they may not affect significantly rural-urban and international migration when looking at all countries. This finding is consistent with the analysis of Beine and Parsons (2015) who do not find direct impact of 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 A7 specifies temperature in levels, rather than logarithms. The estimated values are comparable to those obtained using the log specification. An increase in one degree Celsius 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 results reported in Table 2.

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 are consistent with the following interpretation: increased temperatures decrease agricultural productivity and exacerbates the liquidity constraint for rural populations in poor countries, reducing their ability to emigrate, but increases incentives for rural populations in middle-income countries to emigrate. While several checks confirmed this interpretation is plausible, and while the "exogenous" nature of temperature and its variation across countries relative to local economic and social conditions ensure that reverse causality problems are likely limited, it is hard to really identify the exact channels of the estimated effects. One could argue higher temperatures have other disruptive effects in poor countries besides their impact on agriculture (increased conflict, wars, affects 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 the migration response (or lack of it) is prevalently linked to rural income (agricultural productivity). Higher temperatures influence the emigration rates by lowering agricultural productivity both in poor and in 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 share of GDP is muted. This would imply that higher temperatures should have a negative impact on value added in agriculture as a share of GDP, and that 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 show the coefficient estimates in Table 7. 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 (Columns (2) and (4)). However, for poor countries the effect is more imprecisely estimated and not significantly different from 0 (although positive in point estimate, see 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 toward 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 8 in which the dependent variable is the logarithm of GDP per capita, obtained from the Penn World Table (2009) in Columns (1)-(2) and (5)-(6) or from the World Development Indicators (World Bank, 2015) in columns (3)-(4) and (7)-(8). Consistently with these predictions, middle-income countries experience growth in GDP per person (Columns (2), (4), (6), and (8)). 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 1.4 and 2.3. To the contrary, poor countries experience a negative impact of higher temperatures on income per person, with an interaction term that is negative and significant.

Overall, warming temperatures increase GDP per capita in middle-income countries while negatively affecting GDP per capita in poor countries. While this result confirms what was found by Dell et al 2012, and hence it is not new, our model and previous analysis provides an additional explanation, linked crucially to the role of mobility/migration as a margin of adjustment to these weather/agricultural productivity 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 these gains. However, in places in which agricultural productivity is so low as to leave rural populations liquidity constrained and limited to agriculture, then warming and subsequently lower agricultural productivity may slow economic transformation and growth. These effects ultimately contribute to a poverty trap.

8 Discussion and Conclusions

In this paper we have focused on the potential impact 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 decline in agricultural productivity. This channel, which should mainly affect rural populations, has a varied consequence 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 is associated with significantly higher emigration rates in middle-income countries and significantly lower rates in poor countries (income per capita lower than 1,500 $ per person, which includes many sub-Saharan Africa countries). We also show, 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, on the contrary, are made worse off and may be further trapped in poverty as a consequence of climatic warming.

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A 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 0.5X0.5 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, 115 and 116 countries. The exact number depends on the weights used to aggregate the weather station data (population or area), and on the way we defined "Poor or Middle-income" countries, whether by excluding OECD countries, or by considering the country GDP per capita.

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.

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

List of middle-income countries (population weights and excluding OECD countries)

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

List of middle-income countries (population weights and excluding top income countries according to GDP pc)

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

List of middle-income countries (area weights and excluding OECD countries)

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, Mongolia, Namibia, Nicaragua, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Puerto Rico, Qatar, Romania, 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.

Tables and Figures

Table 1: Summary Statistics

Countries Included in The Sample:	**Non-OECD Sample Middle-Income Countries**			**Non-OECD Sample Poor Countries**		
Variable	**Observations**	**Mean**	**Std. Dev.**	**Observations**	**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	22.334	5.037	120	23.606	4.200
Precipitation, 100s mm/year (area weight)	330	13.231	9.229	120	11.033	5.695
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	0.004
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
GDP per capita, constant, PPP (Penn World Table source)	332	8’197	12’896	114	1’167	776
GDP per capita, constant, local currency unit (WDI source)	290	467’717	1’512’382	96	179’070	419’531

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”.

Table 2: Temperature and Emigration

Poor and Middle-Income countries of origin included, years 1970-2000.

Dependent Variable= Ln(Emigration/Population)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Population weights. Non-OECD Countries of origin				Area weights. Non-OECD Countries of origin		Population weights. Countries of origin exclude top income quintile	
Ln(Temperature)	1.931	3.755**	2.695	3.836**	0.597***	0.627***	2.689	4.398***
	(1.892)	(1.661)	(1.904)	(1.790)	(0.074)	(0.064)	(1.746)	(1.224)
Ln(Temperature) X Poor		-19.967***		-17.546***		-17.203***		-20.134***
		(6.607)		(5.068)		(6.369)		(7.118)
Ln(Temperature) X prevalently agricultural			-23.996***	-15.939*				
			(8.457)	(8.285)				
Ln(Precipitation)	-0.309	-0.223	-0.032	-0.113	0.057	-0.018	-0.369	-0.276
	(0.352)	(0.325)	(0.396)	(0.395)	(0.350)	(0.342)	(0.422)	(0.393)
Ln(Precipitation)X Poor		-1.399		-0.373		-0.543		-1.313
		(1.912)		(2.623)		(1.978)		(1.921)
Ln(Precipitation) X prevalently agricultural			-2.246	-1.674				
			(1.423)	(1.577)				
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Region effects	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	458	458	414	414	450	450	462	462
R-squared	0.179	0.201	0.202	0.216	0.186	0.204	0.195	0.218
Number of countries of origin	115	115	104	104	114	114	116	116
Temperature effect on poor countries		-16.212**		-13.711*		-16.576**		-15.736**
Temperature effect on agricultural countries			-21.301**	-12.103				

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for columns 1-6 are all non-OECD countries. In columns 1-4 the weather station data are averaged using population weights. Columns 5-6 use area as weight. Columns 7-8 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table 3: Temperature and Emigration

Separate estimation for Poor and Middle-Income countries of origin 1970-2000

Dependent Variable= ln(Emigration rates).	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Non-OECD Middle Income Countries		Middle-income Countries, excluding top and bottom quintile of GDP per person		Poor countries: bottom quartile of GDP per person in Non-OECD sample		Rich countries (OECD)
ln Temperature	3.801**	3.933**	4.523***	4.179***	-21.531***	-17.661***	1.045
	(1.742)	(1.762)	(1.277)	(1.324)	(6.831)	(5.858)	(2.22)
ln Temp. interacted with hot		-1.695		4.815		14.475	
		(5.336)		(4.814)		(14.972)	
ln Precipitations	-0.253	-0.235	-0.306	-0.119	-1.617	1.595	-0.649
	(0.326)	(0.433)	(0.390)	(0.650)	(2.371)	(2.225)	(0.644)
ln Prec. Interacted with wet		-0.041		-0.332		-5.676***	
		(0.645)		(0.756)		(1.965)	
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes	yes
Decade X Region effects	yes	yes	yes	yes	yes	yes	yes
Observations	338	338	342	342	120	120	120
R-squared	0.225	0.226	0.256	0.259	0.250	0.312	0.28
Number of countries of origin	85	85	86	86	30	30	30
Temp. effect in hot countries		2.238		8.994*		-3.186	

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for columns 1-2 are non-OECD countries, excluding those in the bottom quartile of GDP per capita distribution. Columns 3-4 include countries that are not in the top or bottom quintile of the world GDP per capita distribution. Columns 5-6 use countries of origin in the bottom quartile of the per-capita GDP distribution. Column (7) includes only OECD countries. The weather station data are averaged using population weights. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table 4: Temperature and Urbanization

Poor and Middle-Income countries of origin included, years 1960-2000.

Dependent Variable= Urban Population as share of total	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Population weights. Non-OECD Countries of origin				Area weights. Non-OECD Countries of origin		Population weights. Countries of origin exclude top income quintile	
Ln(Temperature)	0.376	0.863*	0.656	0.908*	0.495	0.918*	0.165	0.455
	(0.342)	(0.461)	(0.422)	(0.496)	(0.398)	(0.482)	(0.274)	(0.356)
Ln(Temperature) X Poor		-1.661***		-1.365**		-1.785***		-1.175**
		(0.566)		(0.634)		(0.596)		(0.476)
Ln(Precipitation)	-0.017	0.003	-0.033	-0.033	-0.030	-0.020	0.001	0.024
	(0.037)	(0.039)	(0.043)	(0.044)	(0.036)	(0.038)	(0.039)	(0.044)
Ln(Precipitation)X Poor		-0.156*		-0.125		-0.169**		-0.159*
		(0.087)		(0.097)		(0.080)		(0.086)
Ln(Temperature) X prevalently agricultural			-1.580***	-0.824				
			(0.523)	(0.579)				
Ln(Precipitation) X prevalently agricultural			0.001	0.091				
			(0.073)	(0.083)				
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Region effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	565	565	510	510	448	448	570	570
R-squared	0.723	0.733	0.723	0.727	0.689	0.702	0.753	0.759
Number of countries of origin	114	114	103	103	113	113	115	115
Temp. effect on poor countries		-0.798**		-0.457		-0.867**		-0.720**

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for columns 1-6 are all non-OECD countries. In columns 1-4 the weather station data are averaged using population weights. Columns 5-6 use area as weight. Columns 7-8 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table 5: Temperature and Emigration, OECD versus non OECD destinations

Poor and Middle-Income countries of origin included, years 1970-2000.

Dependent Variable= ln(Emigration rates).	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	NON OECD destinations				**OECD destinations**			
	Non-OECD Countries of origin		Countries of origin exclude top income quintile		Non-OECD Countries of origin		Countries of origin exclude top income quintile	
ln Temperature	3.381	4.975***	4.397*	5.918***	-1.668	-0.486	-0.930	0.072
	(2.380)	(1.823)	(2.577)	(1.897)	(1.890)	(1.828)	(1.491)	(1.321)
ln Temp. interacted with poor		-17.172***		-18.079**		-12.923***		-12.000***
		(6.499)		(7.209)		(4.822)		(4.540)
ln Precipitations	0.091	0.126	0.446	0.515	-0.320	-0.226	-0.724	-0.659
	(0.360)	(0.369)	(0.462)	(0.485)	(0.411)	(0.423)	(0.458)	(0.476)
ln Prec. interacted with poor		-0.774		-1.062		-1.337		-0.889
		(1.703)		(1.711)		(1.385)		(1.401)
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Region effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	458	458	462	462	458	458	462	462
R-squared	0.115	0.129	0.080	0.095	0.407	0.413	0.441	0.446
Number of countries of origin	115	115	116	116	115	115	116	116
Tem effect on poor countries		-12.197*		-12.161*		-13.410***		-11.928***

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. In columns 1-4 we only include emigration to non-OECD destinations. In columns 5-8 we include emigrants to OECD destinations. Columns 1-2 and 5-6 use as a sample of poor/middle-income countries those non in OECD. Columns 3-4 and 7-8 instead use 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table 6: Temperature and Emigration by destination distance

Poor and Middle-Income countries of origin included, years 1970-2000.

Dependent Variable= ln(Emigration/population).	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Close destinations (<1000 km)				**Distant destinations (> 1000 km)**			
	Non-OECD Countries of origin		Countries of origin exclude top income quintile		Non-OECD Countries of origin		Countries of origin exclude top income quintile	
ln Temperature	8.953**	10.452***	7.892*	9.424**	-0.247	1.442	1.406	3.042**
	(3.505)	(3.242)	(4.185)	(3.736)	(2.057)	(1.530)	(1.861)	(1.346)
ln Temp. interacted with poor		-20.439		-22.198		-18.398**		-19.614**
		(13.260)		(13.563)		(7.080)		(7.563)
ln Precipitations	-0.668	-0.409	-0.764	-0.497	-0.396	-0.296	-0.496	-0.392
	(0.705)	(0.718)	(0.820)	(0.840)	(0.379)	(0.376)	(0.415)	(0.409)
ln Prec. interacted with poor		-4.050		-3.580		-1.540		-1.443
		(3.250)		(3.316)		(1.566)		(1.577)
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Region effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	393	393	391	391	458	458	462	462
R-squared	0.106	0.115	0.084	0.093	0.201	0.219	0.228	0.248
Number of countries of origin	106	106	106	106	115	115	116	116
Tem effect on poor countries		-9.987		-12.774		-16.956**		-16.572**

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. In columns 1-4 we only include emigration to close destinations (<1000 Km) destinations. In columns 5-8 we include emigrants to distant destinations (>1000 Km). Columns 1-2 and 5-6 use as a sample of poor/middle-income countries those non in OECD. Columns 3-4 and 7-8 instead use 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table 7: Temperature and agriculture share in GDP years 1970-2000

Poor and Middle-Income countries of origin included, years 1970-2000.

	(1)	(2)	(3)	(4)
Dependent variable (VA in agriculture/GDP)	Non-OECD Countries of origin		Countries of origin exclude top income quintile	
Temperature	-1.435	-2.205*	-1.502	-2.656*
	(1.341)	(1.256)	(1.685)	(1.566)
Temperature X poor		3.846		5.295
		(3.857)		(4.282)
Precipitations	-0.598**	-0.672**	-0.607**	-0.681**
	(0.277)	(0.295)	(0.288)	(0.307)
Precipitation X poor		0.895		0.795
		(1.052)		(1.111)
Country of origin Fixed Effects	Yes	Yes	Yes	Yes
Decade X Region effects	Yes	Yes	Yes	Yes
Decade X Poor effects	Yes	Yes	Yes	Yes
Observations	325	325	317	317
R-squared	0.328	0.334	0.338	0.346
Number of countries of origin	94	94	90	90
Temperature effect in poor countries		1.641		2.639

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for columns 1-2 are all non-OECD countries. Columns 3-4 use a sample of poor/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. Data on the share of agriculture in GDP are from a World Development Indicator database. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table 8: Temperature and GDP per capita

Poor and Middle-Income countries of origin included, years 1970-2000.

Dependent Variable= ln(GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Non-OECD Countries of origin				Countries of origin exclude top income quintile			
	Penn World Table source		WDI source		Penn World Table source		WDI source	
Ln(Temperature)	1.750**	2.283**	1.462*	1.909**	1.021	1.414**	1.106	1.492**
	(0.837)	(0.981)	(0.752)	(0.772)	(0.705)	(0.631)	(0.710)	(0.641)
Ln(Temperature) X poor		-5.910**		-5.147*		-4.785*		-4.747*
		(2.811)		(2.614)		(2.710)		(2.577)
ln Precipitations	0.382**	0.427**	0.358**	0.383**	0.392**	0.439**	0.373**	0.401**
	(0.169)	(0.174)	(0.149)	(0.158)	(0.178)	(0.184)	(0.146)	(0.156)
ln (Precipitations) X poor		-0.569		-0.499		-0.514		-0.443
		(0.512)		(0.498)		(0.539)		(0.488)
Country of origin Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Region effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Poor effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	446	446	386	386	450	450	392	392
R-squared	0.303	0.314	0.297	0.305	0.380	0.388	0.399	0.406
Number of countries of origin	113	113	107	107	114	114	109	109
Tem effect on poor countries		-3.626		-3.238		-3.370		-3.255

Note: Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample for columns 1-4 are all non-OECD countries. Columns 5-8 use a sample of poor/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. Columns 1-2 and 5-6 use data on GDP from Penn World Table. Columns 3-4 and 7-8 instead use data on GDP from a World Development Indicator database. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table Appendix

Table A1: Precipitations and emigration

Poor and Middle-Income countries of origin included, years 1970-2000.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable= Ln(Emigration/Population)	Population weights. Non-OECD Countries of origin		Area weights. Non-OECD Countries of origin		Population weights. Countries of origin exclude top income quintile	
ln Precipitations	-0.399	-0.364	-0.070	-0.164	-0.485	-0.451
	(0.364)	(0.342)	(0.361)	(0.360)	(0.426)	(0.406)
ln (Precipitations) X poor		-0.363		0.910		-0.305
		(2.067)		(1.690)		(2.097)
Country of origin Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Region effects	Yes	Yes	Yes	Yes	Yes	Yes
Decade X Poor effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	462	462	456	456	466	466
R-squared	0.162	0.162	0.154	0.155	0.175	0.175
Number of countries of origin	116	116	115	115	117	117
Predicted effect on poor countries		-0.727		0.746		-0.756

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for columns 1-4 are all non-OECD countries. In columns 1-2 and 5-6 the weather station data are averaged using population weights. Columns 5-6 use area as weight. Columns 7-8 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table A2: Temperature and emigration, decade differences

Poor and Middle-Income countries of origin included, years 1970-2000.

Dependent Variable= Δln(Emigration rates)	(1)	(2)	(3)	(4)
			Countries of origin exclude top income quintile	
	Non-OECD Countries of origin			
Δln(Temperature)	2.291*	2.911**	2.656**	3.408***
	(1.281)	(1.368)	(1.223)	(1.299)
Δ Ln(Precipitation)	-0.416		-0.361	
	(0.376)		(0.452)	
Δ ln(Temp) X poor		-6.302		-7.553
		(5.070)		(5.384)
Δ Ln(Precipitation) X poor		-0.648		-0.932
		(2.156)		(2.166)
Year X Area	yes	yes	yes	yes
Year X Poor	yes	yes	yes	yes
Observations	343	343	346	346
R-squared	0.156	0.159	0.175	0.179
Number of countries of origin	343	343	346	346
Country fixed effects	No	No	No	No
Δ ln(Temp) effect on poor countries		-3.391		-4.145

Note: Each column corresponds to a different estimated regression. The sample for columns 1-2 are all non-OECD countries. Columns 3-4 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table A3: Temperature and emigration. Long differences

Poor and Middle-Income countries of origin included, 1970-2000

	(1)	(2)	(3)	(4)
Dependent Variable= Δln(Emigration rates)	OECD origin countries excluded		Countries of origin exclude top income quintile	
Δln(Temperature)	2.904	4.277*	2.450	3.637*
	(2.792)	(2.481)	(2.457)	(2.040)
Δ ln(Temp) X poor		-35.339***		-35.299***
		(8.906)		(8.676)
Δ ln (Precipitations)	-0.269	-0.197	-0.524	-0.496
	(0.424)	(0.444)	(0.471)	(0.490)
Δ ln (Precipitations) X poor		-3.649**		-3.281*
		(1.808)		(1.757)
Area Dummies	Yes	Yes	Yes	Yes
Poor Dummy	Yes	Yes	Yes	Yes
Observations	114	114	115	115
R-squared	0.211	0.271	0.248	0.307
Tem effect on poor countries		-31.062***		-31.663***

Note: Each column corresponds to a different estimated regression. The sample for columns 1-2 are all non-OECD countries. Columns 3-4 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table A4: Temperature and emigration/urbanization. Additional Interactions with SSA

Poor and Middle-Income countries of origin included, 1970-2000

	(1)	(2)	(3)	(4)
	Dependent Variable Ln(Emigration rates)		Dependent variable: Urbanization Rates	
ln (Temperature)	3.274*	3.778**	0.848**	0.972**
	(1.666)	(1.715)	(0.398)	(0.430)
ln (Temp) X Poor		-19.966**		-1.237
		(8.721)		(0.964)
ln (Temp) X SSA	-11.139**	-0.249	-1.325*	-0.649
	(5.438)	(6.663)	(0.744)	(1.077)
Ln(Precipitation)	-0.680*	-0.583*	0.017	0.017
	(0.348)	(0.313)	(0.042)	(0.042)
Ln(Precipitation) X (poor)		-2.683		-0.085
		(1.742)		(0.090)
Ln(Precipitation)X 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 X Region effects	yes	Yes	Yes	yes
Decade X 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level

Table A5: Control for Extreme Temperatures and Emigration

Poor and Middle-Income countries of origin included, 1970-2000

Dependent Variable= ln(Emigration rates)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Population weights. OECD origin countries excluded			Population weights. Countries of origin exclude top income quintile			Population weights. OECD origin countries excluded. Only hotter extremes (excluded colder extremes)		
ln (Temperature)	1.390	3.101*	3.099*	2.048	3.641***	3.661***	1.477	3.240**	2.884*
	(1.998)	(1.578)	(1.601)	(1.989)	(1.304)	(1.315)	(1.967)	(1.590)	(1.604)
Ln(Precipitation)	-0.265	-0.321	-0.321	-0.277	-0.341	-0.348	-0.335	-0.382	-0.385
	(0.375)	(0.369)	(0.370)	(0.446)	(0.443)	(0.443)	(0.363)	(0.356)	(0.357)
Extreme Temperature	0.106	0.102	0.103	0.084	0.082	0.074	0.026	0.020	0.065
	(0.068)	(0.068)	(0.074)	(0.066)	(0.065)	(0.072)	(0.085)	(0.084)	(0.093)
ln (Temperature) X Poor		-18.338***	-18.336***		-18.442***	-18.466***		-18.566***	-17.475***
		(6.570)	(6.559)		(6.961)	(6.970)		(6.510)	(6.609)
Ln(Precipitation) X Poor		0.004	0.001		0.016	0.065		-0.067	-0.191
		(1.871)	(1.881)		(1.884)	(1.891)		(1.887)	(1.888)
Extreme Temperature X poor			-0.002			0.047			-0.278
			(0.176)			(0.176)			(0.236)
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Region effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	448	448	448	456	456	456	448	448	448
R-squared	0.183	0.203	0.203	0.198	0.219	0.219	0.177	0.198	0.201
Number of countries of origin	112	112	112	114	114	114	112	112	112
Temperature effect on poor countries		-15.237**	-15.237**		-14.800**	-14.805**		-15.326**	-14.591**

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample for columns 1-3 and 7-9 are all non-OECD countries. Columns 4-6 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. 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 column 7-9 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table A6: Control for natural Disasters and emigration

Poor and Middle-Income countries of origin included, 1970-2000

Dependent Variable= ln(Emigration rates)	(1)	(2)	(3)	(4)	(5)	(6)
	Population weights. OECD origin countries excluded			Population weights. Countries of origin exclude top income quintile		
ln (Temperature)	1.561	3.414**	3.382*	2.404	4.153***	4.141***
	(1.787)	(1.695)	(1.709)	(1.641)	(1.244)	(1.251)
Ln(Precipitation)	-0.264	-0.196	-0.196	-0.322	-0.248	-0.247
	(0.354)	(0.329)	(0.330)	(0.423)	(0.397)	(0.397)
Natural Disasters	-0.007*	-0.005	-0.005	-0.005	-0.004	-0.004
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
ln (Temperature) X Poor		-19.310***	-19.368***		-19.661***	-19.693***
		(6.628)	(6.641)		(7.134)	(7.195)
Ln(Precipitation) X Poor		-1.314	-1.446		-1.254	-1.324
		(1.901)	(1.826)		(1.914)	(1.858)
Natural Disasters X poor			0.010			0.005
			(0.031)			(0.031)
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes
Decade X Region effects	yes	yes	yes	yes	yes	yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes
Observations	458	458	458	462	462	462
R-squared	0.183	0.203	0.204	0.198	0.219	0.219
Number of countries of origin	115	115	115	116	116	116
Temperature effect on poor countries		-15.896**	-15.986**		-15.508**	-15.553**

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample for columns 1-3 are all non-OECD countries. Columns 4-6 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. 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. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Table A7: Temperature and emigration, Robustness check Temperature in levels

Poor and Middle-Income countries of origin included, 1970-2000

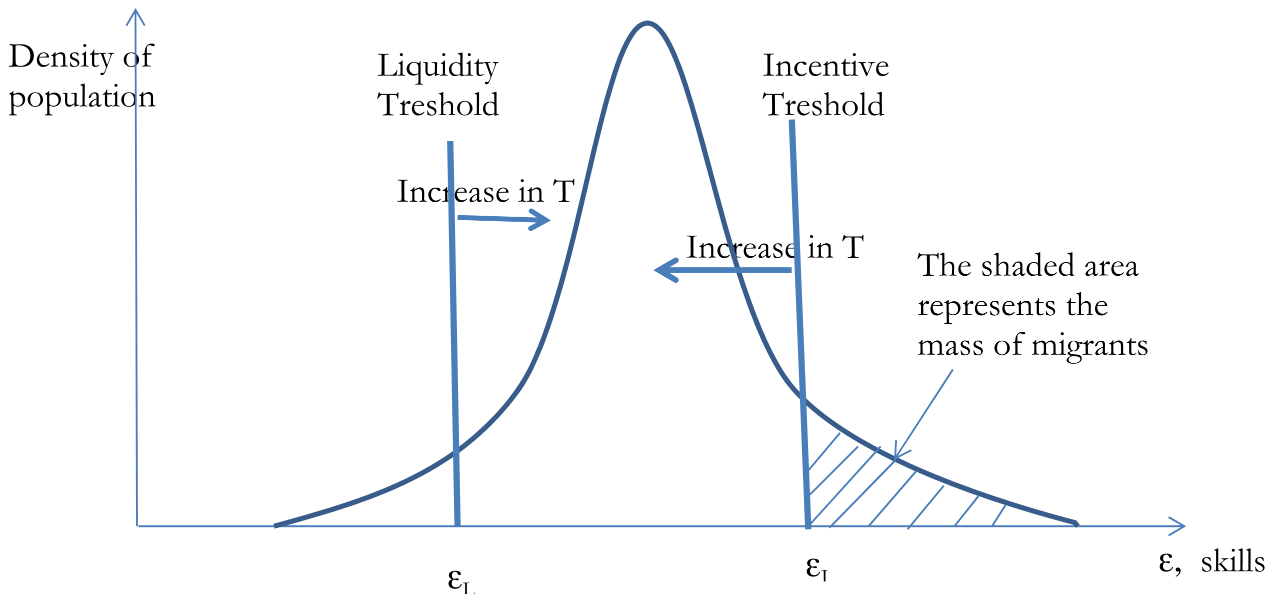
Dependent Variable= ln(Emigration rates).	(1)	(2)	(3)	(4)	(5)	(6)
	Population weights. OECD origin countries excluded		Area weights. OECD origin countries excluded		Population weights. Countries of origin exclude top income quintile	
Temperature	0.036	0.267*	-0.151	0.075	0.101	0.352**
	(0.161)	(0.155)	(0.150)	(0.166)	(0.166)	(0.157)
Precipitations	-0.030	-0.013	-0.025	-0.012	-0.037	-0.021
	(0.028)	(0.024)	(0.031)	(0.028)	(0.027)	(0.023)
Temperature X poor		-1.127***		-0.844**		-1.219***
		(0.336)		(0.343)		(0.352)
Precipitations X poor		-0.159		-0.120		-0.154
		(0.116)		(0.155)		(0.116)
Country of origin Fixed Effects	yes	yes	yes	yes	yes	yes
Decade X Region effects	yes	yes	yes	yes	yes	yes
Decade X Poor effects	yes	yes	yes	yes	yes	yes
Observations	458	458	452	452	462	462
R-squared	0.057	0.178	0.166	0.183	0.193	0.225
Number of countries of origin	115	115	114	114	116	116
Tem effect on poor countries		-0.860***		-0.7691**		-0.867***

Note: Each column corresponds to a different Least Square estimated regression with fixed effects. The sample of countries for columns 1-4 are all non-OECD countries. In columns 1-2 the weather station data are averaged using population weights. Columns 3-4 use area as weight. Columns 5-6 use a sample of poor/middle-income countries of origin in the bottom to the fourth quintiles in the per-capita GDP distribution. The standard errors are cluster by country of origin. *, **, *** indicate significance at the 10, 5 and 1% confidence level.

Figure 1: Temperature increase and Migration-Skill Thresholds

Illustration of the Theoretical model

Panel 1: Middle Income Country



Panel 2: Poor Country

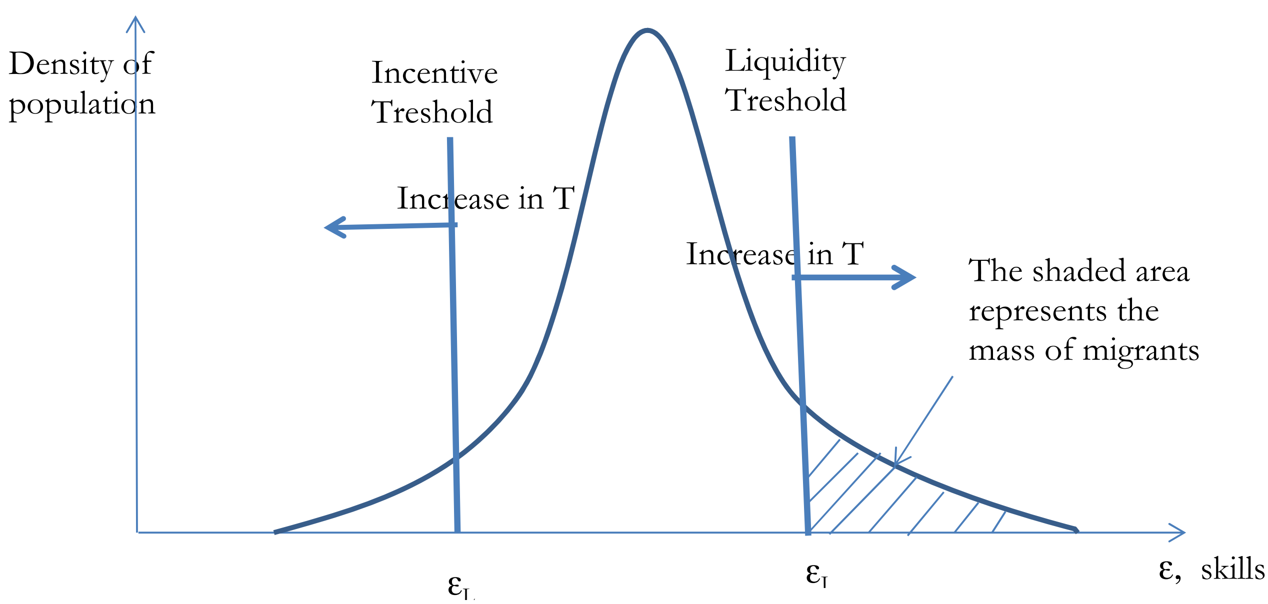


Figure 2: Cumulated Changes in Emigration Rates

Selected countries at each decile of the distribution, 1970-2010

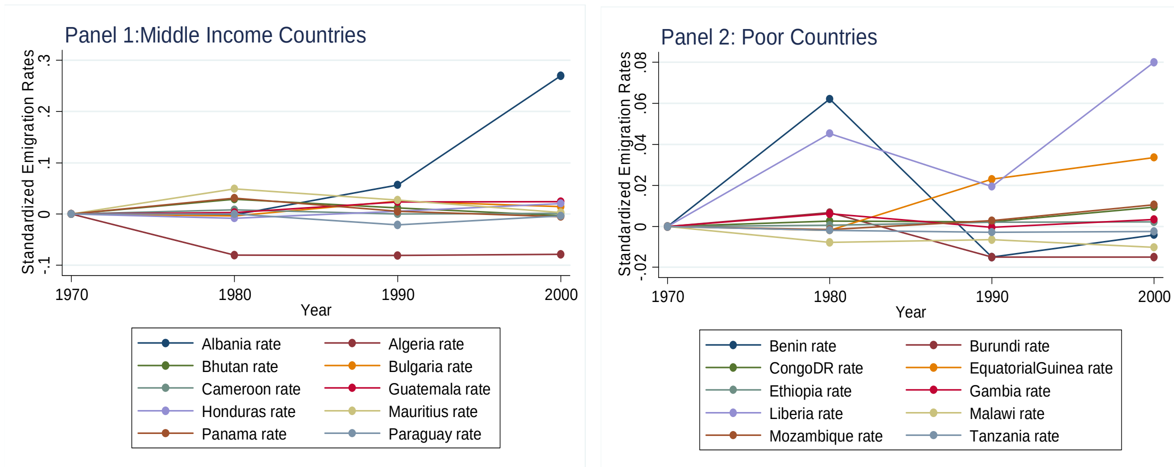


Figure 3: Cumulated Changes in Average Temperatures

Selected countries at each decile of the distribution, 1970-2000

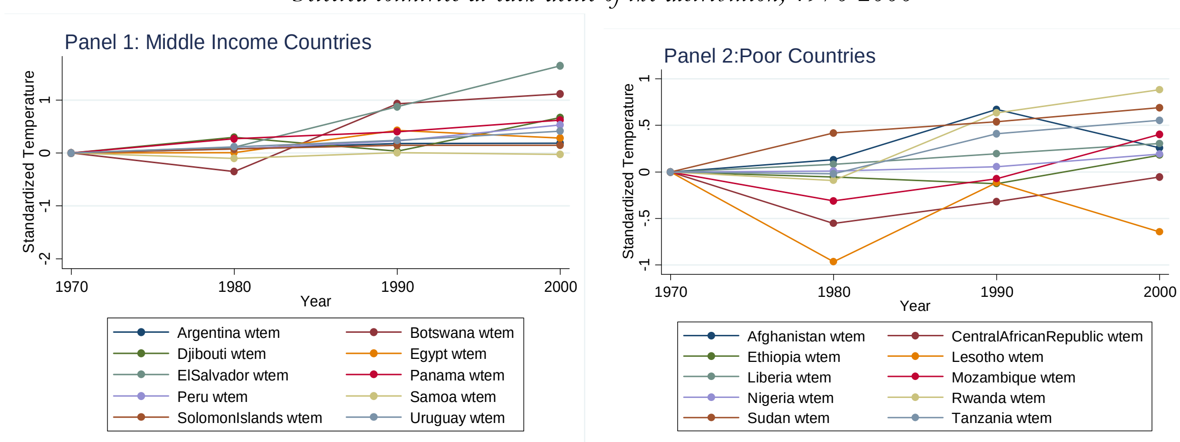
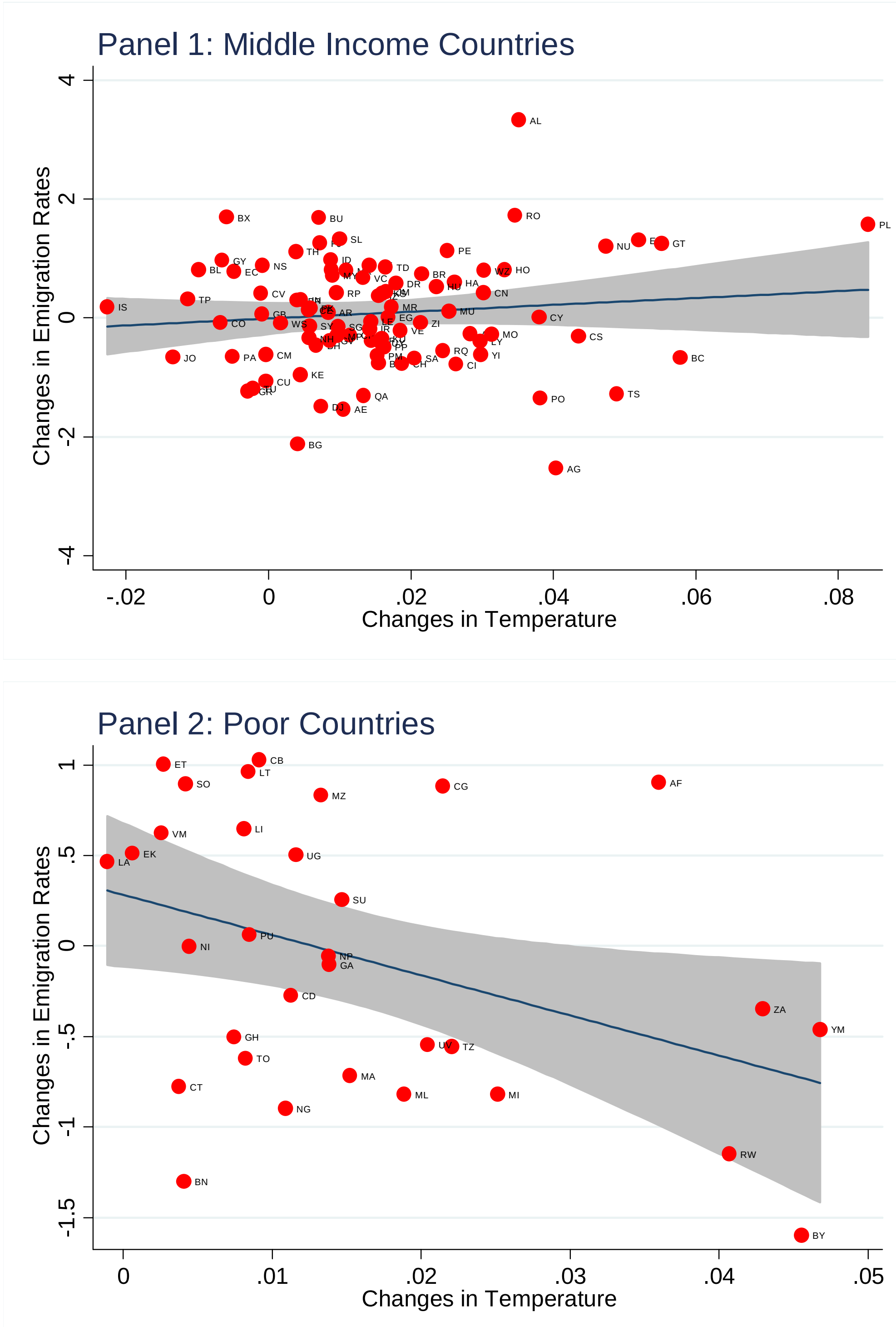


Figure 4: Change in Emigration Rates and in Average Temperature



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.