Long-term migration trends and rising temperatures: The role of irrigation

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Abstract

Climate variability has the potential to affect both international and internal migration profoundly. Earlier work finds that higher temperatures reduce agricultural yields, which in turn reduces migration rates in low-income countries, due to liquidity constraints. We test whether access to irrigation modulates this temperature–migration relationship, since irrigation buffers agricultural incomes from high temperatures. We regress measures of international and internal migration on decadal averages of temperature and rainfall, interacted with country-level data on irrigation and income. We find robust evidence that, for poor countries, irrigation access significantly offsets the negative effect of increasing temperatures on internal migration, as proxied by urbanisation rates. Our results demonstrate the importance of considering access to alternative adaptation strategies when analysing the temperature-migration relationship.

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1 Introduction

In 2020, the number of international migrants reached 281 million, 3.6% of the global population (United Nations, Department of Economic and Social Affairs, Population Division, 2020). The worldwide stock of internal migrants is estimated to be 763 million (United Nations, Department of Economic and Social Affairs, Population Division, 2013). Climate change, in the form of increased temperatures and increased frequency of extreme events, could further increase future numbers of migrants. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change accorded high agreement and medium evidence to the finding that climate change will increase displacement of people over the 21st century (IPCC, 2014). The World Bank estimates that between 31 and 143 million people in Sub-Saharan Africa, South Asia, and Latin America could have to move internally by 2050 because of reduced crop productivity from lower water availability and because of sea-level rise and storm surges (Rigaud et al., 2018).

A rapidly growing literature analyses international migration and weather variations in order to explore the mechanisms underlying the climate–migration relationship (Barrios et al., 2006; Marchiori et al., 2012; Beine and Parsons, 2015; Backhaus et al., 2015; Coniglio and Pesce, 2015; Feng et al., 2015; Cai et al., 2016; Cattaneo and Peri, 2016; Missirian and Schlenker, 2017). This literature shows that weather variations affect international migration more in countries for which agriculture is more important (Marchiori et al., 2012; Backhaus et al., 2015; Beine and Parsons, 2015; Coniglio and Pesce, 2015; Cai et al., 2016; Maurel and Tuccio, 2016; Falco et al., 2019). In particular, following the two-stage estimation approach of Feng et al. (2010), Auffhammer and Vincent (2012), and Feng et al. (2015), Falco et al. (2019) show that exogenous weather shocks in a first stage reduce agricultural income, and then, in a second stage, that this reduction in income increases migration.

Typically, the migration literature has found that higher income helps to overcome liquidity constraints that limit the capacity to pay migration costs. The outcome of the balancing between incentives to migrate and capacity to incur the costs of migrating typically increases migration in low-income countries and decreases it in high-income countries. When adding adverse weather factors to such a model, higher temperatures have been found to decrease emigration from low-income countries, due to the reduction in the capacity to pay for migration costs, but increase it in middle-income countries, due to reduced returns to farming (Cattaneo and Peri, 2016; Beine and Parsons, 2017; Gröschl and Steinwachs, 2017). Recent meta-analyses of both international and internal migration highlight several studies using different methods that suggest that populations may be trapped following climate change (Beine and Jeusette, 2021; Hoffmann et al., 2020). The World Bank's Groundswell Report also warns about the risk that vulnerable populations may remain trapped (Rigaud et al., 2018). Bryan et al. (2014) and Tiwari and Winters (2019) show micro-economic evidence of migration-related liquidity constraints in Bangladesh and Indonesia, respectively, and explore the extent to which cash transfers and credit can increase migration.

The evidence on temperature-induced liquidity constraints suggests that any factor that protects incomes from high temperatures may have an impact on migration. Access to irrigation has been documented to protect crop yields from high temperatures (Siebert et al., 2017). Yet to date, irrigation, a critical agricultural factor, has not been fully incorporated into the analysis of migration and rising temperatures. In this article, we seek to fill this gap by integrating irrigation infrastructure into the analysis of climatic variability and migration. We test how long-term trends in international migration and urbanisation respond to slow changes in weather, how this response varies by income level, and the extent to which irrigation access modulates the response.

Our empirical strategy is to regress decadal migration rates on a triple interaction of decadal averages of weather, a low-income country dummy, and the fraction of irrigated cropland in 1960. We include country fixed effects and decade fixed effects, relying on decadal fluctuations in weather for identification. We use decadal data on bilateral migrant stocks from Özden et al. (2011), urbanisation rates[1] from the World Urbanisation Prospects

[1] We analyse the effect on urbanisation rates as a proxy for rural-urban migration. Despite high natural urban population growth rates, rural-urban migration is the main factor of urbanisation (Jedwab et al.,

(United Nations, 2014), GDP data from the Penn World Tables (Penn World Table, 2009), weather data from the University of Delaware (Willmott and Matsuura, 2018), and irrigation data from Siebert et al. (2015). Our final sample consists of 112 poor and middle-income countries.

Our results are as follows. We first demonstrate that higher temperatures decrease emigration and urbanisation rates in the low-income countries in our sample, as in Cattaneo and Peri (2016), Beine and Parsons (2017), Gröschl and Steinwachs (2017) and Sasahara and Peri (2019). Next we explore the role of irrigation, looking at the triple interaction of weather, a low-income country dummy, and the share of irrigated cropland. In this specification, we find robust evidence that irrigation access attenuates the negative impact of higher temperatures on internal migration in low-income countries. We fail to find evidence of a role of irrigation for international migration. Our results for internal migration (proxied by urbanisation rate), are especially relevant as rural-urban migration is considered a very likely migration response following climate change (Barrios et al., 2006; Henderson et al., 2017; Rigaud et al., 2018).

We contribute to the literature on climatic variability and migration reviewed in Millock (2015). Especially relevant papers include Beine and Parsons (2015), who find no direct impact of weather anomalies on long-term international migration rates, but find significant indirect effects of weather anomalies and natural disasters on the wage ratio and that natural disasters increase urbanisation rates in developing countries; Cattaneo and Peri (2016) who find that higher temperatures increase urbanisation rates and international migration from middle-income countries but decrease rural-urban and international migration from the poorest countries in the world; and Cai et al. (2016) who find that higher temperatures in the origin country increase annual bilateral migration rates but only in agriculture-dependent countries. We also complement district-level analysis from India that suggests that irrigation access reduces internal migration (Sedova and Kalkuhl, 2020; Zaveri et al., 2020). We

2017).

contribute to this literature because our article is the first to integrate irrigation access into the analysis of migration for a global sample of countries.

The rest of the article is organised as follows. Section 2 provides additional background on water scarcity, irrigation, and migration. Section 3 describes the data sources and presents summary statistics. In Section 4, we outline our empirical strategy. In Section 5, we present the results. In Section 6, we run robustness checks. In Section 7, we conclude.

2 Background

Irrigation and migration are two adaptive responses available to farmers. When hit by weather shocks, will farmers choose to irrigate their farms or to migrate? And, what factors will modulate this decision? The choice of which adaptation to pursue will be driven by the relative costs and benefits of each adaptive investment and may also be shaped by the extent to which individuals are embedded in the larger economy (Laube et al., 2012). An extensive literature has studied the response of farmers' irrigation investments to weather shocks. Researchers have found that farmers adjust their irrigation investments in response to weather shocks in a wide range of settings, including Africa (Kurukulasuriya et al., 2011), Latin America (Mendelsohn and Seo, 2007), Australia, (Wheeler et al., 2013), Bangladesh (Delaporte and Maurel, 2018), India (Taraz, 2017), and the United States (Bigelow and Zhang, 2018).

Since the literature on the response of irrigation to weather shocks has been extensively studied, this paper focuses on a separate but related question: to what extent does access to *existing* irrigation infrastructure modulate the temperature-migration relationship? This is a critical question to explore because, currently, two thirds of the global population live under conditions of severe water scarcity at least one month per year, and half a billion people face severe water scarcity year round (Mekonnen and Hoekstra, 2016). Climate change and increasing water scarcity are likely to severely affect agricultural outcomes and food security and, hence, have consequences for population mobility. Irrigation is an important means to protect yields from high temperatures and water scarcity. The protective effect of irrigation on crop yields is well-known from empirical work across Africa (Kurukulasuriya et al., 2006) and Asia (Auffhammer et al., 2012; Taraz, 2018). Agronomic studies show that irrigation reduces heat stress on crops by cooling local temperatures and also increasing soil moisture (Bonfils and Lobell, 2007; Siebert et al., 2014). Irrigation acts as a form of self-insurance, since irrigating farmers typically have higher mean yields and a lower variance of profits (Troy et al., 2015). Irrigation is an important adaptation in any country that is facing negative climate impacts, not just poor countries. But, the impact of irrigation access on the temperature-migration relationship is likely to be greatest in poor countries, where a greater fraction of the population is reliant on agriculture.

Despite the increased importance of irrigation, no global analysis of international migration accounts for it. Beine and Parsons (2015) analyse access to groundwater and find that shortfalls in precipitation increase migration from countries whose groundwater reserves fall below the median of the world groundwater distribution. Access to groundwater is different from being equipped for irrigation, though, which is a more direct measure of access to an alternative means of adaptation than migration.

The current article addresses this gap. The relation between climate change, irrigation, and migration is obviously difficult to investigate, since investment in irrigation depends partially on perceptions of climate change. Here, we make a first test of its importance by examining whether countries that were equipped for irrigation at the start of the period over which migration occurs, display a smaller migratory response following temperature and precipitation changes, all else equal. We thus treat irrigation as pre-existing infrastructure that was set up prior to the migration decision. Since we study long-run migration trends from 1960 onward, the specific measure we use is area equipped for irrigation in 1960 (Siebert et al., 2015). There are several features of this measure that are worth noting. First, it measures the area that is equipped with infrastructure to provide water to crops.[2] Since the measure reflects access to irrigation infrastructure built in the past, it should reduce concerns related to reverse causality. Second, it is different from the area that is actually irrigated. By considering irrigation as a fixed, exogenous factor, we do not account for irrigation investments that are likely to occur simultaneously with, and because of, climate change. Irrigation systems are typically capital intensive and the equipment has a long life-time. There is also considerable inertia in irrigation investments (McKinsey and Evenson, 1999), which justifies our treatment of irrigation as a fixed infrastructure. In addition, up to 1960, irrigation was mainly based on surface water and less dependent on the drilling of groundwater sources that are more directly endogenous to individual farmers. The use of groundwater pumping for agricultural purposes took off globally only after innovations in tubewell and pump technology in the 1950s (Schoengold and Zilberman, 2007; Shah, 2014).

Some studies of internal migration in India indicate a potential importance of irrigation for migration. In an analysis of census data, Dallmann and Millock (2017) find some evidence that Indian states with higher rates of irrigation display a smaller rate of migration following drought. At a more disaggregated level, Fishman et al. (2017) studied adaptation to water scarcity among farmers in Gujarat and found a relation between groundwater access and internal migration. Also in India, Zaveri et al. (2020) find that higher rates of irrigation in a district are associated with a lower probability of temporary migration, using cross-sectional data, and Sedova and Kalkuhl (2020), who analyse panel data from the India Human Development Survey (IHDS) also find that households with irrigation access are less likely to move. To the best of our knowledge, however, there is no global analysis of international and internal migration that integrates irrigation access into the migration analysis.

[2]The measure includes area equipped for full/partial irrigation, and areas equipped for spate irrigation, but excludes rainwater harvesting.

3 Data

3.1 Migration data

For international migration, we use decadal data on bilateral migrant stocks from Özden et al. (2011), spanning 1960 to 2000. We convert migrant stocks to emigration rates (emigrant flow divided by total population) by differencing the stocks over consecutive periods, summing all flows from a specific country and then dividing by the population in the initial period.[3] For internal migration, we use urbanisation rates from the World Urbanisation Prospects, spanning 1960 to 2010, as a proxy for rural-urban migration (United Nations, 2014). Due to limited data on internal migration flows for an international panel of countries, we cannot capture the effects of irrigation on rural-rural migration, but only on rural-urban migration, as proxied by the urbanisation rate.

3.2 Irrigation data

Our irrigation data are from a global data set on the area equipped for irrigation from 1900 to 2005 for 231 countries and territories (Siebert et al., 2015). Siebert et al. (2015) harmonise data from international databases (including FAOSTAT, Eurostat, and Aquastat), national surveys, census reports, and statistical yearbooks. The area *equipped* for irrigation represents irrigation infrastructure and differs from actual irrigated area, which should reduce contemporaneous endogeneity with weather factors. We are interested in the proportion of cropland equipped for irrigation for each country. To calculate this, we use gridded data on 1960's cropland areas from the History Database of the Global Environment, HYDE 3.2, produced by Klein Goldewijk and van Drecht (2006). Appendix Figure B1 displays the proportion of cropland equipped for irrigation in 1960 in each country. The cross-decade autocorrelation of irrigation is high: the correlation between 1960's share of area equipped

[3] Negative values are put equal to zero, as in the main specification of Beine and Parsons (2015) and in Cattaneo and Peri (2016), which implies assuming negligible return migration flows and mortality.

for irrigation and subsequent decades ranges from 79% to 85%.

3.3 Weather data

We use monthly data on average temperature and total precipitation from the University of Delaware (Willmott and Matsuura, 2018).[4] These data are gridded on a 0.5 by 0.5 degree resolution, and we use backcasted 1970's gridded population weights from the Global Population Count Grid Time Series Estimates (CIESIN, 2017) to aggregate the gridded data to the country level (Dell et al., 2014). These weights were developed in CIESIN (2011) and adjusted to UN population data to give the best possible population estimate in those years.

Rather than using annual weather, we follow Missirian and Schlenker (2017) and use average weather during the maize growing season in each origin country. We do this because maize is a staple commodity grown in many countries around the world, and it provides the highest fraction of humans' caloric intake (Roberts and Schlenker, 2013). In addition, maize is more water-intensive than other key staples such as rice, soybeans, and wheat (Brouwer and Heibloem, 1986). We use country-specific data on maize growing seasons from Sacks et al. (2010).[5] In the Appendix, we test the robustness of our results to using weather from the rice or wheat growing season or from the calendar year.

3.4 Other data

We use GDP per capita data from the Penn World Table (2009) to classify countries as poor or middle-income. We use data on the share of agriculture in GDP from World Bank (2017), to classify countries as high- or low-agriculture, used in an alternative specification

[4]Daily temperature data would be ideal to explore agricultural channels, as it would allow us to construct daily temperature bins (Schlenker and Roberts, 2009) or degree days (D'Agostino and Schlenker, 2016). Unfortunately, widely used daily gridded weather data sets such as ERA-Interim (Dee et al., 2011) and the Modern-Era Retrospective Analysis for Research and Applications (Rienecker et al., 2011) begin in 1979, corresponding to the modern era of remotely sensed data, and are hence unsuitable to use with our emigration and urbanisation data (which begin in 1960).

[5]For countries missing data on maize growing season dates, we instead use average monthly weather based on the entire twelve-month calendar year.

in Section 5.

In robustness tests that are explained in Section 6, we explore the robustness of our results to controls for government social expenditure and for political institutions, each of which may be correlated with both irrigation levels and migration trends. For government expenditures, data on explicit government *social* expenditures are rare, so instead, as a proxy, we use government final *consumption* expenditure as percentage of GDP from the World Bank Development Indicators (World Bank, 2017). We use data from 2000, since there is a lot of missing data for earlier years. For political institutions, we focus on the influence of democracy, since Bentzen et al. (2017) highlight its links with irrigation infrastructure. Following Bentzen et al. (2017) and Bertocchi and Strozzi (2008), we use the Revised Combined Polity Score (*polity*2) from The Polity IV Project (Marshall et al., 2018). The *polity*2 score is obtained by subtracting the score on autocracy from the score of democracy. The resulting measure ranges from -10 (strongly autocratic) to +10 (strongly democratic). We further scale the measure so that it ranges from 0 to 1, to increase interpretability. We use the average of the variable *polity*2 during the preceding decade (1950-1959).

3.5 Summary statistics

Since we centre our analysis on an agricultural channel and focus on the role of irrigation, we exclude OECD countries from our sample, as agriculture will be less of a driver for migration in those countries, since it accounts for a smaller fraction of the economy. Our final sample consists of 112 countries, 28 of which we classify as poor countries (the bottom quartile of our sample by GDP per capita in 1990) and the remaining 84 of which we classify as middle-income countries. Appendix A provides a list of the countries in each group.

Table 1 presents summary statistics for our sample of countries, disaggregating the poor versus middle-income countries. The poor countries have a lower emigration rate (1.33%) than the middle-income countries (2.80%), and a lower average urbanisation rate (19.1% compared to 42.5%. The average share of irrigated cropland in 1960 was 13.4% in the middle-income countries versus 3.78% in the poor countries. The poor countries have lower precipitation and higher temperatures than the middle-income countries, on average. As expected, the poor countries also have lower government final consumption expenditure as percentage of GDP (12.3% compared to 14.8%) and a lower score on the scaled *polity*2 measure (0.36 compared to 0.44).

4 Empirical strategy

Our empirical strategy explores the relationships between temperature, income, irrigation, and migration. We estimate:

$$
\begin{aligned}
M_{it} = & \delta_1 Temp_{it} + \delta_2 Temp_{it} \times Irrig_i + \delta_3 Temp_{it} \times Poor_i + \delta_4 Temp_{it} \times Poor_i \times Irrig_i + \\
& \delta_5 Prec_{it} + \delta_6 Prec_{it} \times Irrig_i + \delta_7 Prec_{it} \times Poor_i + \delta_8 Prec_{it} \times Poor_i \times Irrig_i + \\
& \phi_i + \phi_{r,t} + \phi_{p,t} + \epsilon_{it}
\end{aligned} \tag{1}
$$

where M_{it} is the natural logarithm of the emigration rate for the decade ending in year t or the urbanisation rate in year t.[6] The variables $Temp_{it}$ and $Prec_{it}$ are the averages of temperature and precipitation, respectively, during the maize growing season in the origin country, over the decade prior to t. $Poor_i$ is a dummy for whether a country's GDP per capita is in the bottom quartile of the distribution in 1990.[7] $Irrig_i$ is the country's proportion of cropland equipped for irrigation in 1960. We include country fixed effects (ϕ_i) and a set of decade-by-region dummies ($\phi_{r,t}$) that absorb regional factors related to migration that may vary over time. The term $\phi_{p,t}$ represents decade fixed effects interacted with the poor country dummy, to capture potential differences, over time, in migration rates from poor countries versus middle-income countries. We cluster our standard errors at the country level, to account for potential serial correlation. Following Cattaneo and Peri (2016), Beine

[6] Contrary to the urbanisation rates, the emigration rates are skewed and taking the natural logarithm normalises the distribution.

[7] Following other authors (Beine and Parsons, 2015; Cai et al., 2016; Cattaneo and Peri, 2016) we use the 1990 income distribution rather than the initial time period distribution, because of missing values for GDP for earlier years.

and Parsons (2017), and Gröschl and Steinwachs (2017), we expect to find $\delta_1 + \delta_3 < 0$: higher temperatures reduce migration in poor countries. We also expect to find $\delta_4 > 0$: having access to high levels of irrigation offsets the negative impact of high temperatures on migration in poor countries, relative to the impact of irrigation on middle-income countries. The effect of higher temperatures on migration from the middle-income countries in our sample is captured by δ_1. We also expect that $\delta_1 > 0$ and that irrigation access reduces the impact of higher temperatures on migration from such countries, $\delta_2 < 0$. To test the stability of our coefficient estimates, in the tables we begin with a specification with minimal controls and subsequently include additional controls in each column.

In this regression our emphasis is on the agricultural channel: higher temperatures reduce agricultural incomes, which, combined with liquidity constraints, reduces migration in poor countries. However, higher temperatures affect many outcomes, including conflict (Hsiang et al., 2013), mortality (Deschênes and Greenstone, 2011), health (Deschênes, 2014), and labour productivity (Somanathan et al., 2021), each of which may, in turn, affect migration. Thus our regressions do not capture only the agricultural channel, but, in fact, capture the total effect of temperature on migration, which may include non-agricultural mechanisms. However, we do not attempt to control for these other channels, due to the "bad control" problem described in Angrist and Pischke (2008). Furthermore, our focus is the modulating role of irrigation. Irrigation affects agricultural incomes directly and, moreover, either does not affect the other factors listed above, or, only affects them via agricultural income. Thus, we feel confident that the agricultural channel drives our irrigation results.

5 Results

Panel A of Table 2 presents the main results of the effect of irrigation on emigration. In column (1), we regress emigration rates on temperature, precipitation, and country and decade fixed effects. In column (2) we add an interaction between temperature and irrigation.

In column (3), we drop that interaction but add an interaction between temperature and a poor country dummy. In column (4), we add an interaction between temperature and irrigation and also a triple interaction between the poor country dummy, the share of cropland equipped for irrigation in 1960, and temperature. In columns (5) and (6) we add, successively, region-by-decade fixed effects and poor-by-decade fixed effects.

Looking at column (1), we find, as expected, that temperature does not have a statistically significant effect on migration when poor and middle income countries are pooled together. In column (2) we find that irrigation does not have a statistically significant modulating effect on the temperature–migration relationship when poor and middle income countries are pooled together. In column (3), in contrast, once we include an interaction term between temperature and the poor country dummy, we find a large, negative, and statistically significant effect of temperatures on emigration rates. The sign of the coefficient suggests the presence of liquidity constraints: higher temperatures reduce incomes in poor countries, blocking the ability of individuals to migrate. The size of the effect is large: a 1°C increase in decadal temperature would reduce the emigration rate by 54%. Turning to our main result of interest—the extent to which access to irrigation modulates this effect—we look at column (4), where we include the triple interaction of temperature, the poor country dummy, and 1960's irrigation. This triple interaction term captures the differential effect that temperature has on migration for a poor country with comparatively lower (or higher) levels of irrigation. We find that irrigation access offsets the climate-migration liquidity constraint effect and that the coefficient is significant at a 5% level. However, in columns (5) and (6) we include additional controls, and although the coefficient on the triple interaction remains large and positive, it is no longer statistically significant. We conclude that we have an insufficiently large sample to detect whether irrigation modulates the impact of temperature on emigration in poor countries.

The interaction between temperature and irrigation is positive and statistically significant in columns 5 and 6 of Panel A of Table 2. In Section 4, we discussed that we expected the coefficient on temperature to be positive and the coefficient on the temperature and irrigation interaction to be negative. Namely, for middle-income countries, we assume that they are not subject to a binding liquidity constraint, so higher temperatures should increase migration, as they make agriculture in the home country less productive and less appealing, but furthermore irrigation access should attenuate this effect, as it makes agricultural productivity less susceptible to rising temperatures. In contrast to these expected signs, we find that the main effect of temperature is insignificant, and the interaction between temperature and irrigation is actually positive, rather than negative. One potential explanation is that even amongst our sample of middle-income countries,[8] some countries are liquidity constrained, which would mean that rising temperatures could reduce migration (at least for some of the countries), while irrigation access could offset this, hence the positive coefficient on the irrigation-temperature interaction term.

In Table 2 and subsequent tables, we control for precipitation, as well as interactions between precipitation, the poor country dummy, and the 1960 share of cropland equipped for irrigation. Temperature and precipitation may be correlated with each other and failing to include precipitation as a control could potentially lead to omitted variable bias (Auffhammer et al., 2013). At the same time, precipitation is subject to localised regional patterns and is less spatially homogeneous than temperature (Lobell and Asseng, 2017) and, as a result, the analysis of precipitation is better suited to more disaggregated data (Hossain and Ahsan, 2018; Damania et al., 2020). Therefore, we do not place emphasis on the precipitation coefficients.

In Panel B of Table 2, we explore the effects of irrigation access on urbanisation rates, our proxy for rural-urban migration. Here we find a negative, large, and statistically significant coefficient on the interaction of temperature and the poor country dummy, again suggesting evidence of liquidity constraints. Looking at column 3, the effect implies that a 1°C increase in decadal average temperatures reduces the urbanisation rate by almost

[8] See Appendix A.

5.5 percentage points in poor countries. Our results are in line with earlier literature that finds rising temperatures reduce internal migration and urbanisation (Cattaneo and Peri, 2016; Hirvonen, 2016; Henderson et al., 2017). The triple interaction term is positive and large, and it is statistically significant in columns (5) and (6), the columns that include region-by-decade fixed effects, suggesting there may be important regional heterogeneity in urbanisation rates, which the region-by-decade fixed effects capture. Looking at column (6), the most saturated model, we find that poor countries with irrigation display a much smaller negative response to higher temperatures. For poor countries that had the mean level of cropland equipped for irrigation in 1960, a 1°C increase in decadal average temperatures leads to a 6.7 percentage points reduction in urbanisation. For poor countries which were one standard deviation above the mean share of cropland equipped for irrigation in 1960, we only see a 4.6 percentage points reduction in urbanisation.[9] Thus, this amount of difference in the area equipped for irrigation reduces the impact of temperature on internal migration by 32%. Importantly, we note that the net effect of higher temperatures on urbanisation remains negative, although irrigation access attenuates the impact.

Our sample excludes OECD countries in order to focus on the hypothesis of constrained migration in poor- and middle-income countries and how irrigation access may modulate it. The baseline effect of temperature on urbanisation and its interaction with irrigation is never significant in our estimations, although of the expected sign: a positive effect of temperature on urbanisation and a negative effect from the interaction with irrigation. India, for example, is among the middle-income countries in the sample, and our results on rural-urban migration at the country level are thus compatible with the previously cited household- and district-level analyses of internal migration and irrigation access. Furthermore, we also explore the differential effects we find for international migration versus internal migration. The stronger significance that we find for the triple interaction for internal migration suggests perhaps that such migration is the most strongly affected by agricultural conditions in rural areas, whereas

[9]For this exercise we use the mean and standard deviation of 1960's irrigation relative to the set of poor countries: in other words, we use the summary statistics from the third column of Table 1.

international migration is influenced by both urban and rural conditions and conditions in other sectors of the economy. Hence, the influence of access to irrigation as alternative means of adaptation is not as important for such migration. The fact that liquidity constraints tend to limit migratory responses to higher temperatures to short-distance or regional movements also goes in the direction of this result (Cattaneo et al., 2019; Hoffmann et al., 2020).

In Table 3, we explore how a focus on agricultural countries—rather than poor countries—affects our results. Column 1 of Table 3 is the same as the column 6 from Table 2, for comparison purposes. In column 2, we control for interactions between temperature, irrigation, and an agricultural country dummy, which is defined to be one for countries that are in the upper quartile of agricultural share of GDP for the year 2000. In column 3, we include interactions between both the poor dummy and the agricultural dummy, to see which one dominates. All columns control for poor-by-decade fixed effects and region-by-decade fixed effects. All columns also control for a full set of precipitation interaction terms, which are not reported due to space reasons. Looking at column 2 of Panel A, we see that the triple interaction of agricultural country, irrigation and temperature is positive, large, and significant. This suggests that irrigation does modulate the impact of temperature on emigration, if we focus on agricultural countries. Looking at column 3, we see that this significant effect persists when we add interactions with the poor country dummy. In Panel B, which looks at impacts on urbanisation, we find that the effect is significant only for agricultural countries when including both the poor country dummy and the agricultural dummy. This again indicates that irrigation access works mainly through the channel of agricultural productivity, and is the strongest for internal migration, as proxied by the urbanisation rate.

6 Robustness

6.1 Institutional factors

A potential concern with our results is that there may be confounding, omitted variables that are correlated with the irrigation measure. First, it is possible that countries with historically higher rates of irrigation have more capable governments, and hence have more effective safety nets or social protection programs. These programs could attenuate the effect of increasing temperatures on household incomes and thus reduce the effect on migration of higher temperatures, independently of irrigation access. For example, Chort and de la Rupelle (2017), Imbert and Papp (2020) and Mueller et al. (2019) find evidence that social protection programs affect migration rates, in Mexico, India, and Zambia, respectively.

To explore this issue, we add a control for government final consumption as percentage of GDP, as a proxy for government social spending. These data are available only for 2000 and onwards, which is not ideal, but we still think it worthwhile to explore.[10] Table 4 presents the results of this analysis. For reference, column (1) of both tables presents the most saturated model from the main estimations (e.g. column (6) of Table 2). Column (2) in Table 4 shows the results controlling for government expenditure. We focus our interpretation on urbanisation and Panel B, since the moderating effect of irrigation on emigration is not significant in the most saturated model in our main tables. In the estimations of urbanisation in Panel B, the interaction terms with government expenditure are not significant. The triple interaction term of poor country, irrigation and temperature remains large although its significance level falls from the 5% level to the 10% level.

A second concern is that the share of cropland equipped for irrigation may be correlated with the political institutions of a country (Bentzen et al., 2017). The migration literature finds evidence that low institutional quality in the origin country acts as a push factor for

[10]We lose 10 countries in the sample for these estimations: Djibouti, Ethiopia, Fiji, Haiti, Sao Tome and Principe, Somalia, Saint Vincent and the Grenadines, Trinidad and Tobago, United Arab Emirates, and Yemen.

migration (Ariu et al., 2016; Bergh et al., 2015). If irrigation is positively correlated with a measure of autocracy (Bentzen et al., 2017), and if emigration is negatively correlated with the same measure of political freedom in the origin country, then the attenuating effect on emigration that we have inferred on behalf of irrigation access could, partially, be due to this confounding factor.

In column 3 of Table 4, we control for the level of democratic freedoms, using the average of the *polity*2 score during the preceding decade (1950-1959). Again focusing on Panel B, we find that the *polity*2 score has no effect on its own on urbanisation rates, and the irrigation interaction term remains significant, and of a similar magnitude to column (1). Furthermore, when controlling for both government expenditure and *polity*2 in Column (4) of Table 4, the irrigation interaction term remains significant, and of a similar magnitude. The effect of irrigation access for emigration and urbanisation is thus robust to these institutional controls.

6.2 Additional robustness tests

Appendix B presents several additional sets of robustness tests, with regards to our weather measure, our sample of countries, and our irrigation measure.

First, we note that our baseline results use weather from the maize growing season in each country, following the approach used in Missirian and Schlenker (2017). One may be concerned about intra-national variation in the maize-growing season in large countries, about non-random variation in maize planting across countries and years, and about countries dependent on another main food crop. In Appendix Tables B1, B2, and B3 we therefore re-estimate our regressions using weather from the rice growing season, wheat growing season, or annual 12-month calendar, respectively. Our urbanisation results are largely consistent with our main results.

Second, in Appendix Table B4, we test whether our results are robust to dropping countries with small populations, which we define as countries in the bottom quartile of population, relative to our sample, in the year 1960.[11] The magnitude of our urbanisation results is robust to excluding these countries, although the significance of the triple interaction falls from the 5% level to the 10% level.

Third, Appendix Table B5 explores the robustness of our main results to using a "high irrigation" dummy that equals one if a country's proportion of 1960's irrigated land is above the sample median. Interestingly, while the temperature-irrigation interaction was not significant in column 2 of Table 2, the interaction is positive and significant in column 2 of Table B5, indicating that higher temperatures increase migration from high irrigation countries. In column 3, the poor-temperature interaction is negative and significant: higher temperatures reduce migration from poor countries. In column 4, when we include both interactions, these signs and significance levels are preserved. Finally, in columns 5 through 7 we include the triple interaction between poor, irrigation, and temperature, but it is not significant. However, out of our 28 poor countries, only 7 qualify as high irrigation. Hence the triple interaction coefficient is only identified off of a small number of countries, which may explain the insignificant coefficient. The coefficients in Panel B, for urbanisation, follow a similar pattern.

Finally, in Appendix Table B6, we explore the robustness of our agricultural country results to using a high irrigation dummy. In column 3, we again see that for high irrigation countries, higher temperatures increase migration, with a statistically significant coefficient. In contrast, the coefficient on the agriculture-temperature interaction is negative, but only significant at the 10% level. When we add the triple interaction in column 4, it is significant for urbanisation but not for emigration, as in our main results. In column 5, we interact temperature with irrigation, poor country, and agricultural country respectively, but do not include any triple interactions. Here we find a positive significant coefficient on irriga-

[11] The list of countries dropped in this specification is the Bahamas, Belize, Bhutan, Botswana, Brunei Darussalam, Cape Verde, Comoros, Cyprus, Djibouti, Equatorial Guinea, Fiji, Gabon, Gambia, Guinea-Bissau, Guyana, Kuwait, Lesotho, Mauritius, Namibia, Oman, Qatar, Saint Vincent and the Grenadines, Sao Tome and Principe, Solomon Islands, Saint Vincent and the Grenadines, Suriname, Swaziland, United Arab Emirates, and Vanuatu.

tion*temperature, a negative significant coefficient on poor*temperature, and the coefficient on agricultural country*temperature is not significant. When we add triple interactions in column 6, it is significant and positive for agricultural countries, as in the main specification. Taken together, the results confirm that irrigation access reduces the effect of higher temperatures on internal migration as proxied by urbanisation rates, and also suggest that the cushioning effect of irrigation on migration responses to higher temperatures is more important in agricultural countries.

7 Conclusion

Understanding the drivers behind international and internal migration is of paramount importance, particularly in light of accelerating climate change. We explore the effect of increased temperatures on international migration and urbanisation rates and examine the role of irrigation access in shaping these relationships. Recent literature has emphasised that it is only in poor or in agricultural countries that rising temperatures affect migration, and this has motivated our focus on irrigation, as it protects crop yields from high temperatures. Using a global data set of low- and middle-income countries, we find robust evidence that irrigation offsets the negative impact of higher temperatures on rural-urban migration in poor countries and fail to find evidence that it offsets the impact on international migration.

Future work could use detailed, single-country data sets to study international and internal migration, thus testing whether the broad, global patterns we have uncovered hold at the subnational level. Such work would allow for deeper analysis of irrigation investment as an alternative adaptation strategy to migration involving trade-offs between the adaptation strategies according to their costs, rather than as fixed existing infrastructure as in this analysis. The use of micro data would permit the exploration of heterogeneity in the migration response across different types of individuals or farms and the role of institutional factors.

More broadly, although in the short-run irrigation can shield yields from weather shocks, in the long-run irrigation access can induce farmers to plant more water-intensive crops, increasing the weather sensitivity of agriculture, an effect termed maladaptation (Hornbeck and Keskin, 2014). Researchers have raised concerns about the impacts of irrigation on global and regional water supplies (Haddeland et al., 2014; Zaveri et al., 2016), the limited feasibility of irrigation as a long-term climate adaptation strategy (Fishman, 2018), and the social costs of water overextraction (Sayre and Taraz, 2019). The present analysis should therefore not be interpreted in a normative manner—endorsing, say, irrigation as a climate adaptation strategy—but rather as a positive analysis of how access to irrigation infrastructure may shape climate-induced migration behaviours.

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Tables

Table 1: Summary statistics

	Full Sample	Middle-Income	Poor
Emigration rate (emigration flow/population)	0.0243	0.0280	0.0133
	(0.0387)	(0.0432)	(0.0153)
Share of urban population	0.366	0.425	0.191
	(0.222)	(0.219)	(0.111)
Share of 1960 cropland irrigated	0.110	0.134	0.0378
	(0.194)	(0.215)	(0.0705)
Real GDP per capita, 2011 USD	6809.8	8672.5	1312.7
	(20274.8)	(23168.8)	(770.4)
Average temperature, C	23.59	23.40	24.15
	(4.134)	(4.048)	(4.350)
Average precipitation, 100mm/month	1.306	1.340	1.205
	(0.884)	(0.967)	(0.560)
Share of agriculture in GDP in 2000	0.257	0.114	0.692
	(0.437)	(0.318)	(0.463)
Government final consumption expenditure (% of GDP) in 2000	14.20	14.83	12.26
	(5.739)	(5.416)	(6.270)
Polity	0.418	0.438	0.364
	(0.310)	(0.315)	(0.292)
Number of countries	112	84	28

Note: Mean coefficients. Standard deviations in parentheses. Sample consists of 112 poor and middle-income countries. The table presents averages of each variable for each decade that the variable is available. Temperature and precipitation values are calculated over the maize growing season in each country.

Table 2: Emigration and urbanisation: Main results.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	0.228	0.00916	0.405*	0.226	0.105	0.196
	(0.220)	(0.242)	(0.225)	(0.245)	(0.238)	(0.233)
Irrigation * Temperature		2.409		1.763	2.812**	2.767**
		(1.730)		(1.680)	(1.228)	(1.228)
Poor * Temperature			-1.179***	-1.394***	-1.155**	-1.781***
			(0.429)	(0.447)	(0.490)	(0.562)
Poor * Irrigation * Temperature				7.675**	3.674	4.533
				(3.509)	(3.123)	(3.456)
Precipitation	-0.381	-0.427	-0.317	-0.270	-0.106	-0.114
	(0.330)	(0.411)	(0.331)	(0.429)	(0.434)	(0.454)
Irrigation * Precipitation		-1.141		-1.878	-0.393	-0.639
		(4.230)		(4.389)	(3.726)	(3.734)
Poor * Precipitation			-0.689	-1.513	-1.215	-1.336
			(0.854)	(0.922)	(0.894)	(0.928)
Poor * Irrigation * Precipitation				29.46*	12.14	11.71
				(15.91)	(21.74)	(22.74)
Constant	-9.355*	-10.41*	-6.310	-6.905	-7.380	-5.445
	(5.243)	(5.294)	(5.282)	(5.330)	(4.938)	(4.987)
Observations	448	448	448	448	448	448
R^2	0.071	0.090	0.097	0.118	0.235	0.245
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-0.00839	-0.0106	0.00177	0.00212	0.00916	0.00641
	(0.0118)	(0.0149)	(0.0127)	(0.0161)	(0.0171)	(0.0166)
Irrigation * Temperature		0.0185		-0.00723	-0.0404	-0.0418
		(0.0691)		(0.0699)	(0.0591)	(0.0589)
Poor * Temperature			-0.0565***	-0.0700***	-0.120***	-0.0875***
			(0.0206)	(0.0260)	(0.0385)	(0.0311)
Poor * Irrigation * Temperature				0.194	0.386**	0.365**
				(0.147)	(0.150)	(0.151)
Precipitation	-0.0228	-0.0256	-0.0148	-0.0131	-0.00981	0.00459
	(0.0251)	(0.0306)	(0.0274)	(0.0334)	(0.0357)	(0.0358)
Irrigation * Precipitation		0.0308		-0.0144	-0.137	-0.175
		(0.343)		(0.351)	(0.353)	(0.347)
Poor * Precipitation			-0.0471	-0.0727	-0.102*	-0.155***
			(0.0541)	(0.0652)	(0.0598)	(0.0559)
Poor * Irrigation * Precipitation				0.721	0.908	0.967
				(0.872)	(0.872)	(0.860)
Constant	0.484*	0.488*	0.588**	0.641**	0.880***	0.816***
	(0.285)	(0.286)	(0.282)	(0.288)	(0.321)	(0.299)
Observations	672	672	672	672	672	672
R^2	0.736	0.736	0.741	0.741	0.768	0.773
Country FE	Y	Y	Y	Y	Y	Y
Decade FE	Y	Y	Y	Y	N	N
Region x decade FE					Y	Y
Poor x decade FE						Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable is the natural logarithm of emigration rates in Panel A and the urban population share in Panel B. Decadal average growing season temperature (C) and precipitation (100 mm/month). Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Emigration and urbanisation: Agricultural countries.

Panel A: Emigration	(1)	(2)	(3)
Temperature	0.196	0.0533	0.168
	(0.233)	(0.240)	(0.250)
Irrigation * Temperature	2.767**	2.982**	2.889**
	(1.228)	(1.251)	(1.286)
Poor * Temperature	-1.781***		-1.144**
	(0.562)		(0.576)
Poor * Irrigation * Temperature	4.533		-5.747
	(3.456)		(6.516)
Agri * Temperature		-1.340**	-1.104*
		(0.556)	(0.571)
Agri * Irrigation * Temperature		17.49**	21.94**
		(7.381)	(9.772)
Constant	-5.445	-5.939	-2.687
	(4.987)	(4.922)	(4.826)
Observations	448	420	420
R^2	0.245	0.254	0.273
Panel B: Urbanisation	(1)	(2)	(3)
Temperature	0.00641	-0.00170	0.00255
	(0.0166)	(0.0181)	(0.0181)
Irrigation * Temperature	-0.0418	-0.0557	-0.0606
	(0.0589)	(0.0750)	(0.0755)
Poor * Temperature	-0.0875***		-0.0349
	(0.0311)		(0.0547)
Poor * Irrigation * Temperature	0.365**		-0.303
	(0.151)		(0.436)
Agri * Temperature		-0.0786**	-0.0785*
		(0.0307)	(0.0425)
Agri * Irrigation * Temperature		0.880**	1.301***
		(0.413)	(0.468)
Constant	0.816***	0.896***	1.016***
	(0.299)	(0.311)	(0.312)
Observations	672	630	630
R^2	0.773	0.774	0.778
Country FE	Y	Y	Y
Poor x decade FE	Y	Y	Y
Region x decade FE	Y	Y	Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable is the natural logarithm of emigration rates in Panel A and the urban population share in Panel B. Decadal average growing season temperature (C). Regressions control for precipitation (100 mm/month) and full set of precipitation interaction terms. Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation. The agricultural dummy equals one for countries whose share of agriculture in GDP is in the top quartile of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Emigration and urbanisation: Additional controls.

Panel A: Emigration	(1)	(2)	(3)	(4)
Temperature	0.196	0.838*	0.897***	1.340***
	(0.233)	(0.468)	(0.314)	(0.491)
Irrigation * Temperature	2.767**	2.557*	2.237**	2.245
	(1.228)	(1.446)	(1.115)	(1.380)
Poor * Temperature	-1.781***	-2.264*	-2.746***	-0.355
	(0.562)	(1.240)	(0.768)	(1.261)
Poor * Irrigation * Temperature	4.533	5.698	6.460*	6.210
	(3.456)	(3.595)	(3.416)	(3.770)
Gov. Exp. * Temperature		-0.0413		-0.0354
		(0.0296)		(0.0289)
Poor * Gov. Exp. * Temperature		0.0435		-0.134*
		(0.0801)		(0.0730)
Polity * Temperature			-1.286**	-1.178**
			(0.605)	(0.590)
Poor * Polity * Temperature			1.648	-0.101
			(1.421)	(1.409)
Constant	-5.445	-6.010	-5.741	-6.555
	(4.987)	(4.912)	(5.080)	(4.697)
Observations	448	408	408	376
R^2	0.245	0.246	0.298	0.320
Panel B: Urbanisation	(1)	(2)	(3)	(4)
Temperature	0.00641	-0.0552	0.0318	-0.0592
	(0.0166)	(0.0434)	(0.0254)	(0.0525)
Irrigation * Temperature	-0.0418	-0.0252	-0.0900*	-0.0678
	(0.0589)	(0.0965)	(0.0521)	(0.0821)
Poor * Temperature	-0.0875***	-0.0406	-0.139***	-0.0949
	(0.0311)	(0.0677)	(0.0430)	(0.0998)
Poor * Irrigation * Temperature	0.365**	0.308*	0.418***	0.405**
	(0.151)	(0.168)	(0.159)	(0.169)
Gov. Exp. * Temperature		0.00377		0.00615*
		(0.00296)		(0.00318)
Poor * Gov. Exp. * Temperature		-0.00267		-0.00291
		(0.00408)		(0.00551)
Polity * Temperature			-0.0458	-0.0496
			(0.0543)	(0.0552)
Poor * Polity * Temperature			0.102	0.117
			(0.0751)	(0.0896)
Constant	0.816***	0.988***	0.908**	1.039***
	(0.299)	(0.321)	(0.351)	(0.366)
Observations	672	612	612	564
R^2	0.773	0.775	0.782	0.791
Country FE	Y	Y	Y	Y
Poor x decade FE	Y	Y	Y	Y
Region x decade FE	Y	Y	Y	Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable is the natural logarithm of emigration rates in Panel A and the urban population share in Panel B. Decadal average growing season temperature (C). Regressions control for precipitation (100 mm/month) and full set of precipitation interaction terms. Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation. Government expenditure is government final consumption expenditure as a fraction of GDP in 2000. Polity measures the degree of democracy versus autocracy in each country in 1960.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A Appendix: List of countries in the sample

A.1 List of poor countries (28)

Afghanistan, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Congo (DRC), Ethiopia, Gambia, Ghana, Guinea-Bissau, Laos, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Somalia, Sudan, Tanzania, Togo, Uganda, Yemen, and Zambia.

A.2 List of middle-income countries (84)

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

B Appendix Tables and Figures

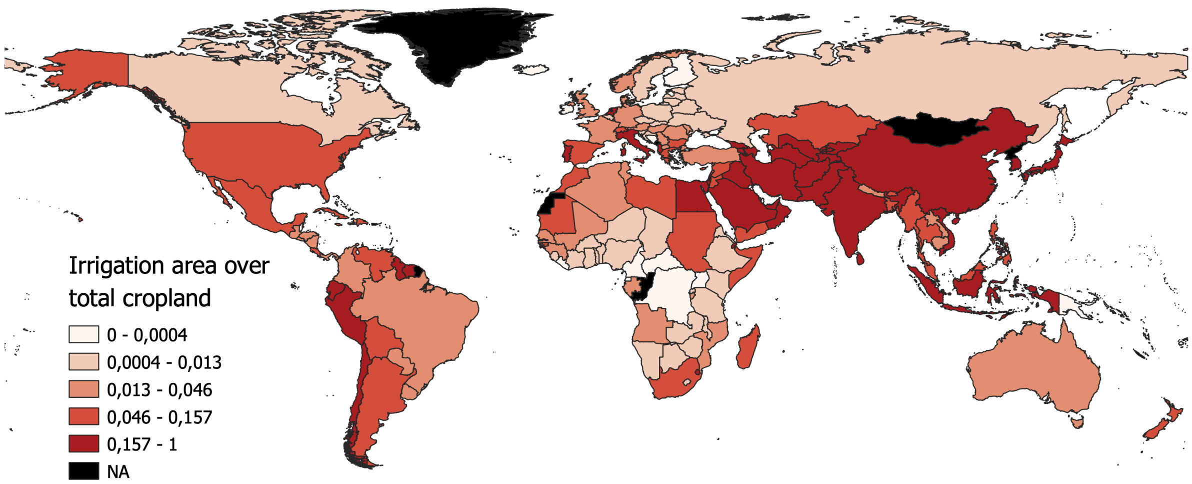

Figure B1: Map of area equipped for irrigation in 1960. *Data source*: Siebert et al. (2015).

Table B1: Emigration and urbanisation. Rice growing season weather.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	0.0634	-0.100	0.215	0.0744	0.0126	0.0923
	(0.209)	(0.237)	(0.206)	(0.236)	(0.231)	(0.227)
Irrigation * Temperature		2.065		1.556	2.552**	2.527**
		(1.588)		(1.556)	(1.159)	(1.161)
Poor * Temperature			-0.915**	-1.069**	-0.845*	-1.297**
			(0.399)	(0.430)	(0.465)	(0.569)
Poor * Irrigation * Temperature				6.358	2.330	3.007
				(3.866)	(2.987)	(3.369)
Precipitation	-0.517	-0.419	-0.587*	-0.399	-0.267	-0.275
	(0.314)	(0.389)	(0.352)	(0.467)	(0.474)	(0.489)
Irrigation * Precipitation		-3.272		-3.566	-2.026	-2.256
		(5.281)		(5.652)	(4.258)	(4.225)
Poor * Precipitation			-0.0578	-0.702	-0.545	-0.676
			(0.606)	(0.655)	(0.700)	(0.790)
Poor * Irrigation * Precipitation				27.54**	8.896	7.994
				(12.95)	(20.82)	(22.61)
Constant	-5.333	-6.763	-3.344	-4.442	-5.936	-4.979
	(4.821)	(5.054)	(4.881)	(5.044)	(4.674)	(4.871)
Observations	448	448	448	448	448	448
R^2	0.069	0.084	0.086	0.103	0.222	0.229
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-0.00771	-0.00967	0.00273	0.00326	0.0103	0.00548
	(0.0122)	(0.0148)	(0.0131)	(0.0159)	(0.0171)	(0.0165)
Irrigation * Temperature		0.0163		-0.00910	-0.0385	-0.0398
		(0.0686)		(0.0693)	(0.0596)	(0.0591)
Poor * Temperature			-0.0559***	-0.0675***	-0.111***	-0.0734**
			(0.0204)	(0.0253)	(0.0374)	(0.0303)
Poor * Irrigation * Temperature				0.183	0.343**	0.326**
				(0.136)	(0.142)	(0.139)
Precipitation	-0.0258	-0.0362	-0.00515	-0.0106	-0.00981	0.00966
	(0.0245)	(0.0297)	(0.0271)	(0.0335)	(0.0371)	(0.0380)
Irrigation * Precipitation		0.211		0.113	0.0176	-0.0384
		(0.388)		(0.403)	(0.406)	(0.403)
Poor * Precipitation			-0.0777*	-0.100**	-0.119***	-0.169***
			(0.0411)	(0.0452)	(0.0454)	(0.0462)
Poor * Irrigation * Precipitation				1.237*	1.357*	1.150
				(0.701)	(0.713)	(0.736)
Constant	0.465	0.464	0.551*	0.589**	0.830**	0.719**
	(0.282)	(0.282)	(0.279)	(0.287)	(0.324)	(0.295)
Observations	672	672	672	672	672	672
R^2	0.736	0.736	0.741	0.742	0.768	0.774
Country FE	Y	Y	Y	Y	Y	Y
Decade FE	Y	Y	Y	Y	N	N
Region x decade FE					Y	Y
Poor x decade FE						Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable in Panel A is the natural logarithm of emigration rates. The dependent variable in Panel B is the urban population share. Decadal average temperature (C) and precipitation (100 mm/month) are for the rice growing season. Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B2: Emigration and urbanisation. Wheat growing season weather.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	0.0467	-0.167	0.209	0.0254	-0.106	0.00531
	(0.229)	(0.254)	(0.225)	(0.260)	(0.248)	(0.242)
Irrigation * Temperature		2.844**		2.151*	2.735***	2.673***
		(1.178)		(1.247)	(0.848)	(0.846)
Poor * Temperature			-0.984**	-1.109***	-0.896**	-1.483***
			(0.393)	(0.413)	(0.442)	(0.518)
Poor * Irrigation * Temperature				6.010	1.173	1.884
				(3.688)	(3.439)	(3.965)
Precipitation	-0.733*	-0.463	-0.748	-0.380	-0.183	-0.214
	(0.440)	(0.474)	(0.460)	(0.482)	(0.517)	(0.525)
Irrigation * Precipitation		-5.228		-5.310	-4.128	-4.425
		(5.511)		(5.668)	(4.949)	(4.961)
Poor * Precipitation			-0.183	-0.753	-0.352	-0.414
			(1.207)	(1.239)	(1.447)	(1.669)
Poor * Irrigation * Precipitation				12.12	-21.37	-24.10
				(17.91)	(30.00)	(33.13)
Constant	-4.788	-6.567	-2.569	-3.857	-2.434	-0.919
	(5.044)	(4.776)	(5.024)	(4.725)	(4.313)	(4.286)
Observations	448	448	448	448	448	448
R^2	0.070	0.092	0.088	0.110	0.222	0.231
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-0.00861	-0.0112	0.00186	0.00130	0.00590	0.00303
	(0.0125)	(0.0152)	(0.0133)	(0.0165)	(0.0171)	(0.0167)
Irrigation * Temperature		0.0245		0.000288	-0.0139	-0.0154
		(0.0554)		(0.0575)	(0.0480)	(0.0476)
Poor * Temperature			-0.0565***	-0.0661**	-0.111***	-0.0790**
			(0.0209)	(0.0257)	(0.0376)	(0.0312)
Poor * Irrigation * Temperature				0.166	0.334**	0.320**
				(0.126)	(0.135)	(0.127)
Precipitation	-0.0227	-0.0317	-0.00607	-0.00820	-0.0204	-0.00351
	(0.0354)	(0.0429)	(0.0365)	(0.0441)	(0.0467)	(0.0470)
Irrigation * Precipitation		0.117		0.0342	0.0252	-0.00446
		(0.393)		(0.396)	(0.395)	(0.393)
Poor * Precipitation			-0.111	-0.152	-0.177*	-0.290***
			(0.0883)	(0.0964)	(0.0901)	(0.0770)
Poor * Irrigation * Precipitation				1.678	1.955*	1.993**
				(1.106)	(1.071)	(0.907)
Constant	0.466*	0.467*	0.572**	0.609**	0.887***	0.790***
	(0.275)	(0.273)	(0.272)	(0.274)	(0.310)	(0.275)
Observations	672	672	672	672	672	672
R^2	0.735	0.736	0.740	0.741	0.767	0.774
Country FE	Y	Y	Y	Y	Y	Y
Decade FE	Y	Y	Y	Y	N	N
Region x decade FE					Y	Y
Poor x decade FE						Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable in Panel A is the natural logarithm of emigration rates. The dependent variable in Panel B is the urban population share. Decadal average temperature (C) and precipitation (100 mm/month) are for the wheat growing season. Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B3: Emigration and urbanisation. Annual weather.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	0.0673	-0.149	0.214	0.0214	-0.0885	0.0100
	(0.223)	(0.253)	(0.220)	(0.253)	(0.238)	(0.235)
Irrigation * Temperature		3.080*		2.472	3.374***	3.354***
		(1.688)		(1.724)	(1.145)	(1.152)
Poor * Temperature			-1.019**	-1.146**	-0.927**	-1.525***
			(0.416)	(0.439)	(0.467)	(0.560)
Poor * Irrigation * Temperature				5.959	0.928	1.676
				(3.763)	(3.427)	(3.844)
Precipitation	-0.0455	-0.0265	-0.0416	-0.0125	0.00430	0.00196
	(0.0357)	(0.0424)	(0.0370)	(0.0444)	(0.0450)	(0.0459)
Irrigation * Precipitation		-0.439		-0.479	-0.342	-0.368
		(0.475)		(0.496)	(0.372)	(0.371)
Poor * Precipitation			-0.0636	-0.125	-0.0911	-0.108
			(0.0947)	(0.0925)	(0.101)	(0.105)
Poor * Irrigation * Precipitation				1.720	-1.116	-1.406
				(1.415)	(2.475)	(2.739)
Constant	-5.445	-7.958	-2.615	-4.612	-4.730	-3.344
	(4.999)	(5.136)	(5.118)	(5.233)	(4.653)	(4.631)
Observations	448	448	448	448	448	448
R^2	0.067	0.092	0.085	0.110	0.228	0.237
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-0.00797	-0.0103	0.00159	0.000974	0.00605	0.00229
	(0.0120)	(0.0147)	(0.0130)	(0.0159)	(0.0167)	(0.0164)
Irrigation * Temperature		0.0218		-0.000957	-0.0238	-0.0259
		(0.0633)		(0.0653)	(0.0544)	(0.0539)
Poor * Temperature			-0.0566***	-0.0676**	-0.114***	-0.0790**
			(0.0212)	(0.0264)	(0.0387)	(0.0333)
Poor * Irrigation * Temperature				0.184	0.363**	0.351**
				(0.143)	(0.144)	(0.141)
Precipitation	-0.00200	-0.00317	-0.000740	-0.00143	-0.00237	-0.000591
	(0.00296)	(0.00361)	(0.00303)	(0.00368)	(0.00389)	(0.00395)
Irrigation * Precipitation		0.0169		0.0107	0.00617	0.00203
		(0.0361)		(0.0364)	(0.0361)	(0.0359)
Poor * Precipitation			-0.00962	-0.0124	-0.0149*	-0.0254***
			(0.00738)	(0.00809)	(0.00754)	(0.00628)
Poor * Irrigation * Precipitation				0.115	0.134	0.139
				(0.0922)	(0.0938)	(0.0871)
Constant	0.461*	0.459*	0.590**	0.634**	1.034***	0.704**
	(0.273)	(0.268)	(0.280)	(0.284)	(0.325)	(0.284)
Observations	672	672	672	672	672	672
R^2	0.735	0.736	0.740	0.741	0.767	0.774
Country FE	Y	Y	Y	Y	Y	Y
Decade FE	Y	Y	Y	Y	N	N
Region x decade FE					Y	Y
Poor x decade FE						Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable in Panel A is the natural logarithm of emigration rates. The dependent variable in Panel B is the urban population share. Decadal average temperature (C) and precipitation (100 mm/month) for the calendar year. Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B4: Emigration and urbanisation. Results dropping small population countries.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)
Temperature	0.262	0.523**	0.488**	0.504**	0.584**
	(0.236)	(0.218)	(0.239)	(0.228)	(0.231)
Irrigation * Temperature			0.374	1.788	1.758
			(1.435)	(1.162)	(1.165)
Poor * Temperature		-1.532***	-1.930***	-1.728***	-2.219***
		(0.469)	(0.465)	(0.523)	(0.579)
Poor * Irrigation * Temperature			9.802***	4.459	4.420
			(3.679)	(3.408)	(3.520)
Precipitation	-0.891**	-0.619	-0.167	-0.172	-0.252
	(0.396)	(0.379)	(0.772)	(0.699)	(0.743)
Poor * Precipitation		-1.577	-2.554**	-2.416**	-2.120**
		(0.966)	(1.121)	(0.968)	(1.060)
Irrigation * Precipitation			-6.652	-4.627	-4.290
			(7.690)	(5.995)	(6.299)
Poor * Irrigation * Precipitation			25.75	3.675	0.104
			(27.57)	(39.61)	(39.20)
Constant	-9.594*	-4.438	-3.969	-7.203	-5.874
	(5.675)	(5.660)	(5.514)	(5.131)	(5.202)
Observations	336	336	336	336	336
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)
Temperature	-0.0125	0.000857	0.00545	0.000850	0.00199
	(0.0117)	(0.0129)	(0.0164)	(0.0187)	(0.0182)
Irrigation * Temperature			-0.0435	-0.0754	-0.0771
			(0.0921)	(0.0883)	(0.0884)
Poor * Temperature		-0.0597***	-0.0800***	-0.0902**	-0.0812**
		(0.0217)	(0.0277)	(0.0376)	(0.0343)
Poor * Irrigation * Temperature			0.232	0.332*	0.340*
			(0.167)	(0.169)	(0.175)
Precipitation	-0.00761	-0.00224	0.00940	0.0160	0.0350
	(0.0276)	(0.0270)	(0.0316)	(0.0328)	(0.0356)
Poor * Precipitation		-0.0157	-0.0484	-0.0965	-0.158
		(0.0939)	(0.111)	(0.0998)	(0.102)
Irrigation * Precipitation			-0.159	-0.603	-0.691
			(0.437)	(0.436)	(0.449)
Poor * Irrigation * Precipitation			0.369	1.055	1.065
			(1.292)	(1.370)	(1.401)
Constant	0.544*	0.659**	0.741**	1.192***	0.920***
	(0.284)	(0.298)	(0.310)	(0.351)	(0.333)
Observations	504	504	504	504	504
Country FE	Y	Y	Y	Y	Y
Decade FE	Y	Y	Y	N	N
Region x decade FE				Y	Y
Poor x decade FE					Y

Note: Standard errors in parentheses. This table drops the bottom quartile of countries from our sample, based on 1960 population. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable in Panel A is the natural logarithm of emigration rates. The dependent variable in Panel B is the urban population share. Decadal average temperature (C) and precipitation (100 mm/month) are based on annual weather. Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects are included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. Irrigation variable measures the share of 1960's cropland that was equipped for irrigation. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B5: Emigration and urbanisation: Irrigation dummy.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Temperature	0.228	-0.324	0.405*	-0.109	-0.105	-0.230	-0.137
	(0.220)	(0.279)	(0.225)	(0.282)	(0.299)	(0.286)	(0.276)
High irrigation * Temperature		1.069***		0.924***	0.946**	1.156***	1.131***
		(0.342)		(0.338)	(0.376)	(0.330)	(0.325)
Poor * Temperature			-1.179***	-0.925**	-0.947*	-0.789	-1.340**
			(0.429)	(0.419)	(0.506)	(0.513)	(0.585)
Poor * High irrigation * Temperature					0.0263	-0.343	-0.310
					(0.867)	(0.644)	(0.684)
Precipitation	-0.381	-1.004**	-0.317	-0.943**	-0.707	-0.500	-0.524
	(0.330)	(0.442)	(0.331)	(0.446)	(0.457)	(0.475)	(0.499)
High irrigation * Precipitation		1.037*		0.960	0.457	0.536	0.527
		(0.613)		(0.593)	(0.630)	(0.607)	(0.617)
Poor * Precipitation			-0.689	-0.342	-1.066	-1.162	-1.187
			(0.854)	(0.788)	(0.960)	(0.884)	(0.914)
Poor * High Irrigation * Precipitation					2.575**	2.004*	1.911*
					(1.262)	(1.060)	(0.992)
Constant	-9.355*	-8.502*	-6.310	-6.286	-6.516	-6.255	-4.558
	(5.243)	(5.043)	(5.282)	(4.999)	(5.002)	(4.791)	(4.923)
Observations	448	448	448	448	448	448	448
R^2	0.071	0.105	0.097	0.121	0.127	0.244	0.252
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Temperature	-0.00839	-0.0369*	0.00177	-0.0249	-0.0221	-0.0163	-0.0193
	(0.0118)	(0.0187)	(0.0127)	(0.0193)	(0.0214)	(0.0217)	(0.0210)
High irrigation * Temperature		0.0510**		0.0454**	0.0407	0.0411*	0.0408*
		(0.0215)		(0.0210)	(0.0262)	(0.0245)	(0.0245)
Poor * Temperature			-0.0565***	-0.0492**	-0.0601**	-0.106***	-0.0727**
			(0.0206)	(0.0191)	(0.0291)	(0.0394)	(0.0318)
Poor * High irrigation * Temperature					0.0245	0.0420	0.0385
					(0.0344)	(0.0344)	(0.0338)
Precipitation	-0.0228	-0.0441	-0.0148	-0.0334	-0.0253	-0.0162	-0.00106
	(0.0251)	(0.0334)	(0.0274)	(0.0349)	(0.0367)	(0.0373)	(0.0362)
High irrigation * Precipitation		0.0277		0.0201	0.00114	-0.0331	-0.0401
		(0.0460)		(0.0449)	(0.0522)	(0.0514)	(0.0511)
Poor * Precipitation			-0.0471	-0.0401	-0.0713	-0.106*	-0.161***
			(0.0541)	(0.0531)	(0.0660)	(0.0571)	(0.0530)
Poor * High Irrigation * Precipitation					0.0948	0.148**	0.158**
					(0.0779)	(0.0701)	(0.0674)
Constant	0.484*	0.575*	0.588**	0.655**	0.675**	0.842***	0.769***
	(0.285)	(0.291)	(0.282)	(0.276)	(0.274)	(0.300)	(0.281)
Observations	672	672	672	672	672	672	672
R^2	0.736	0.741	0.741	0.745	0.746	0.772	0.777
Country FE	Y	Y	Y	Y	Y	Y	Y
Decade FE	Y	Y	Y	Y	Y	N	N
Region x decade FE						Y	Y
Poor x decade FE							Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable is the natural logarithm of emigration rates in Panel A and the urban population share in Panel B. Decadal average growing season temperature (C) and precipitation (100 mm/month). Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. The high irrigation dummy equals one for countries that were above the median for the share of 1960's cropland that was equipped for irrigation.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B6: Emigration and urbanisation: Irrigation dummy and agricultural dummy.

Panel A: Emigration	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-0.0999	-0.137	-0.200	-0.153	-0.0447	-0.0859
	(0.262)	(0.276)	(0.276)	(0.292)	(0.283)	(0.308)
High irrigation * Temperature	1.053***	1.131***	1.037***	0.965***	0.947***	0.998***
	(0.294)	(0.325)	(0.307)	(0.341)	(0.299)	(0.349)
Poor * Temperature	-1.443***	-1.340**			-1.356**	-0.898
	(0.515)	(0.585)			(0.534)	(0.588)
Poor * High irrigation * Temperature		-0.310				-1.104
		(0.684)				(0.900)
Agri * Temperature			-0.884*	-1.069*	-0.455	-0.891
			(0.459)	(0.568)	(0.455)	(0.582)
Agri * High irrigation * Temperature				0.561		0.869
				(0.719)		(1.057)
Constant	-4.394	-4.558	-4.937	-4.902	-2.129	-1.577
	(4.854)	(4.923)	(4.811)	(4.814)	(4.712)	(4.818)
Observations	448	448	420	420	420	420
R^2	0.247	0.252	0.247	0.250	0.259	0.273
Panel B: Urbanisation	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	-0.0233	-0.0193	-0.0273	-0.0184	-0.0242	-0.0169
	(0.0189)	(0.0210)	(0.0208)	(0.0225)	(0.0209)	(0.0229)
High irrigation * Temperature	0.0480**	0.0408*	0.0478**	0.0251	0.0458**	0.0256
	(0.0197)	(0.0245)	(0.0221)	(0.0264)	(0.0220)	(0.0271)
Poor * Temperature	-0.0552**	-0.0727**			-0.0311	-0.00588
	(0.0225)	(0.0318)			(0.0398)	(0.0559)
Poor * High irrigation * Temperature		0.0385				-0.0452
		(0.0338)				(0.0494)
Agri * Temperature			-0.0408	-0.0799**	-0.0287	-0.0860*
			(0.0287)	(0.0314)	(0.0358)	(0.0442)
Agri * High irrigation * Temperature				0.0989***		0.131***
				(0.0373)		(0.0437)
Constant	0.730**	0.769***	0.745**	0.788***	0.715**	0.837***
	(0.288)	(0.281)	(0.315)	(0.293)	(0.297)	(0.296)
Observations	672	672	630	630	630	630
R^2	0.776	0.777	0.772	0.776	0.774	0.779
Country FE	Y	Y	Y	Y	Y	Y
Poor x decade FE	Y	Y	Y	Y	Y	Y
Region x decade FE	Y	Y	Y	Y	Y	Y

Note: Standard errors in parentheses. Sample is 112 poor and middle-income countries. Years 1960-2000 for emigration and 1960-2010 for urbanisation. The dependent variable is the natural logarithm of emigration rates in Panel A and the urban population share in Panel B. Decadal average growing season temperature (C) and precipitation (100 mm/month). Country fixed effects and decade fixed effects in all columns. Decade-by-region fixed effects and decade-by-poor fixed effects included as indicated. Standard errors clustered at the country level. The poor dummy equals one for countries in the bottom quartile of the GDP per capita distribution. The agricultural dummy equals one for countries whose share of agriculture in GDP is in the top quartile of the distribution. The high irrigation dummy equals one for countries that were above the median for the share of 1960's cropland that was equipped for irrigation.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$