The Childhood Origins of Climate-Induced Mobility and Immobility

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Abstract

The existing literature on climate change and migration has focused largely on assessing short-term responses to temperature and precipitation shocks. In this paper, we suggest that this common “coping strategies” model can be extended to account for mechanisms that link environmental conditions to migration behavior over longer periods of time. We argue that early-life climate exposures may affect the likelihood of migration from childhood through early adulthood by influencing parental migration, community migration networks, human capital development, and decisions about household resource allocation, all of which are correlates of geographic mobility. We evaluate this expectation empirically using a “big data” approach, analyzing georeferenced records from 81 censuses implemented across 31 countries in tropical Africa, Latin America, and Southeast Asia. For each world region, we estimate multivariate regression models that predict lifetime migration through ages 30-39 as a function of temperature and precipitation in early life, defined as the year prior to birth through age four. Results suggest that early-life climate is systematically associated with changes in the probability of lifetime migration in most regions of the tropics, with the largest effects observed in sub-Saharan Africa. In East and Southern Africa, the effects of temperature shocks vary by sex and educational attainment and in a manner that suggests women and those with lower socioeconomic status are most vulnerable to climate shocks. Finally, we compare our main results with models using alternative measures of climate exposure. This comparison suggests climate exposures during the prenatal period and first few years of life are particularly (but not exclusively) salient for lifetime migration, which is most consistent with our proposed human capital mechanism.

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Introduction

For decades, policymakers and scientists have raised concerns about the potential for climate change to involuntarily displace human populations across the developing world (Houghton et al. 1990). Social scientists have evaluated these claims empirically over recent years in a growing number of studies and with increasing methodological rigor (Hunter et al., 2015; Carleton and Hsiang, 2016). Building on the rapid expansion of available micro-data on migration in low- and middle-income countries (Ruggles 2014), these studies have employed a common approach: linking geo-referenced census or survey data on migration to historical climate records and then applying statistical models to estimate the effects of climatic variability on the likelihood of out-migration (Fussell et al., 2014). These studies have revealed that climatic conditions have statistically and often substantively significant effects on migration, though the nature of this relationship varies by context (Bohra-Mishra et al., 2014, 2017; Feng et al., 2010; Gray and Mueller, 2012a; Gray and Wise, 2016; Mueller et al., 2014; Nawrotzki et al., 2015a, b; Thiede et al., 2016).

The current climate-migration literature has focused almost exclusively on measuring the short-term effects of climatic variability on geographic mobility. That is, prior studies examine migration outcomes occurring concurrent to, or very soon after, the climate exposures of interest. While this approach is consistent with many models of migration decision-making (e.g., De Jong and Gardner, 1981; Stark and Bloom, 1985), we argue that this *coping strategies model* can be extended to account for additional mechanisms that link environmental exposures to migration behavior over longer periods of time. We hypothesize that climatic conditions in early life can affect the likelihood of migration throughout the entire first half of the life course, from childhood through working ages. In our view, attention to what we are calling the *childhood origins model*

of climate and migration is merited since it accounts for the multiple pathways and temporal scales through and across which climate effects may operate. As such, this model has the potential to expand our understanding of climate-induced migration and in turn to raise fundamentally new questions for both researchers and policymakers about migration in an era of climate change. It also has the potential to raise new questions about the influence of other types of early-life shocks and stressors on spatial mobility across the life course.¹

With this argument in mind, the overall goals of this paper are to describe our proposed childhood origins model of climate effects on migration and to evaluate this approach empirically across countries in sub-Saharan Africa, Latin America, and Southeast Asia. We proceed as follows: In the next section, we describe our conceptual model and detail the channels through which early exposure to climate anomalies may affect lifetime migration through early adulthood. We then describe how we combine georeferenced data from over 80 censuses with high-resolution climate records to estimate the effects of early-life climate exposures on the probability of lifetime migration among adults ages 30 to 39 years. The fourth section of the paper describes our results. In the fifth and concluding section, we discuss the broader implications of our findings for demographic research and identify extensions of this study.

Early-life climate and lifetime migration

The extensive literature on climate and migration that has emerged in the past decade is largely premised on a single, common framework of migration decision-making. We refer to this framework as the coping strategies model (Figure 1, top). From this perspective, climatic

¹ Our study may also complement a small, largely United States-oriented literature on childhood experiences and adult residential attainment (Leibbrand et al. 2019; Pais 2017). While we cannot measure quality (e.g., neighborhood characteristics) in the destination in this study, future research on early-life climate and lifetime migration should leverage appropriate data to do so.

variability is expected to affect migration through immediate or minimally-lagged changes in livelihoods, risk, and related factors that alter the short-term calculus of an individual or household's decision to migrate. For example, rural households may cope with the socioeconomic consequences of a drought or heat wave by sending one or more members to work in another, less-affected location and remit or return with income (Gray and Mueller 2012b, Mueller et al., 2014). In other instances, households may temporarily cease or delay the out-migration of their members due to climate-induced reductions in the resources needed to fund such moves (Hirvonen, 2016; Mueller et al., 2020; Nawrotzki and DeWaard, 2018). This migration-suppressing effect has been observed in the cases of marriage-related migration in Ethiopia (Gray and Mueller 2012b) and United States-bound international migration from rural Mexico (Riosmena et al., 2018), among others. In these and other instances, the links between climate and migration are assumed to operate near-instantaneously or over short time periods—such as the months immediately after a failed or below-average harvest (Fussell et al., 2014) or in the several years after a rainfall or temperature shock (since households may first try to adapt *in situ* before sending migrants) (Nawrotzki and DeWaard 2016). The focus is thus squarely on whether and how migration is used as a response to climate-induced resource constraints in the short run, which is consistent with more general household-level models of migration and livelihood diversification (e.g., Ellis, 1998, 2000; Stark and Bloom, 1985).

(Figure 1)

This conceptual model has proven useful for motivating empirical analysis and is now supported by many studies that have documented changes in migration (both increases and decreases) caused by concurrent or recent climate shocks (Bohra-Mishra et al., 2014, 2017; Feng et al., 2010; Gray and Mueller, 2012a; Gray and Wise, 2016; Hunter et al. 2015; Mastorillo et al.

2016; Mueller et al., 2014; Mueller et al., 2020; Nawrotzki et al., 2015a, b; Thiede et al., 2016). However, we argue that this model can be extended to account for mechanisms that link climate to migration outcomes over considerably longer periods of time. We hypothesize that climatic conditions in early life can affect the likelihood of migration over the entire first half of the life course, from childhood through adulthood. We expect such effects to operate through at least four channels—two of which align directly with the commonly employed coping strategies model and two that account for the long-run effects of climate-induced changes in (a) human capital attainment and (b) household resource allocation on individuals’ spatial mobility over the life course (Figure 1, bottom).

First, and most consistent with the framework employed in previous research, early-life exposure to climate variability may affect children’s lifetime migration directly via the migration of their parents or larger household units. Climate exposures during an individual’s childhood may prompt changes in migration among caretakers as they mitigate shocks through the processes captured in the coping strategies model. To the extent that these responses involve changes in whole-household migration—as has been shown to occur in at least some cases of environmental change (Bohra-Mishra et al. 2014)—these processes will also affect the odds that children experience climate-related moves. In cases where this mechanism is operating, changes in climate-induced migration will occur in early life, soon after the early-life climate exposure in question.

Second, the changes in migration that occur immediately after an exposure to climate variability—as predicted in the coping strategies model—may change the strength and structure of migration networks across space. For instance, if responses to environmental change affect the prevalence of labor migration between an individual’s origin and a given destination(s), the theory of cumulative causation would suggest that the social and economic barriers to movement between

locales will decrease (Curran et al. 2016; Fussell 2010). The implication is that migration in the subsequent years will increase even in the absence of continued environmental stressors. Severe environmental shocks might also lead to more fundamental changes in migration patterns associated with the recovery from that event and in the corresponding likelihood that individuals will stay in or return to the affected area. For example, Curtis and colleagues (2015) have shown that the geographic scope and intensity of migration systems in the United States changed in the aftermath of Hurricane Katrina. The implication, again, is that environmental changes may result in the restructuring of migration networks and systems.

Third, early exposure to climatic variability may alter developmental processes central to human capital formation, which may affect migration by shaping later-life socioeconomic outcomes that are correlated with geographic mobility (Gray 2009; Mberu 2005; Williams 2009). Prenatal and early childhood exposure to climatic variability has been linked to fluctuations in birthweight and the prevalence of child malnutrition and related illnesses (Bakhtsiyarava et al, 2018; Bandyopadhyay et al. 2012; Davenport et al. 2017; Grace et al., 2012, 2015; Hoddinott & Kinsey 2001; Randell et al., 2020; Thiede and Gray, 2020). These conditions are known to cause substantial and sometimes irreversible changes in cognitive development, socioeconomic attainment, and health over the life course (Almond and Currie, 2011; Hayward and Gorman 2004; Maccini and Yang, 2009; Randell and Gray 2019; Torche and Conley 2016). These attainment levels are in turn expected be correlated with individuals' success in labor and marriage markets (Aslam 2009; Frye and Lopus 2018; Kashyap et al. 2015; Thomas 2008; Yu and Xie 2015), among other possible outcomes correlated with geographic mobility. As such, lifetime migration patterns may reflect the enduring developmental consequences of early-life climate exposures and their second-order effects on socioeconomic outcomes through adulthood.

Fourth and relatedly, households may respond to climate-induced changes in resource constraints by reallocating their investments (broadly defined) in children. For example, changes in household resources can be expected to affect a number of important decisions, including if, when and where to enroll (or unenroll) children in school, seek healthcare for them, retain them in the household (e.g., versus out-fostering), and invest in their marriage (Akresh 2009; Beegle et al. 2006; Eloundou-Enyegue and Stokes 2002; Kielland 2016; Jennings and Gray 2017; Jensen 2000). Such climate-induced changes in household resource allocation may affect the likelihood of migration both immediately after an exposure and over longer periods of time. In the short run, decisions pertaining to out-fostering and whether and where to send a child to school affect the likelihood that an individual will change residences during their childhood (Hashim 2007; Isiugo-Abanihe 1985). Resource allocation decisions related to investments in children's education and health may also have longer-run effects by affecting human capital formation through processes similar to the third pathway described above.

We point to these plausible pathways to extend the coping strategies model of climate-induced migration that has predominated in the literature to date. The childhood origins approach that we propose here aims to account for the influence of early-life exposures to climate variability on migration outcomes from childhood through early adulthood, identifying four sets of socioeconomic and developmental mechanisms that can explain these effects. This alternative framework explicitly accepts and builds upon the existing coping strategies model, and in our view represents a complementary rather than competing perspective on this issue.

Objectives

Drawing on the conceptual framework described above, we empirically test the hypothesized relationship between exposure to climatic variability in early life and the likelihood of migration through early adulthood (“lifetime migration” for brevity). In a demonstration of the power of publicly-available, georeferenced census data (Ruggles 2014), we examine this association across 31 countries in the global tropics. These regions are an appropriate focus since they generally face more acute environmental and development challenges than higher-latitude countries (Sachs 2001).

Toward this end, we address three specific objectives. First, we estimate the association between temperature and precipitation exposures during early childhood and the likelihood of inter-province migration from birth through adulthood (ages 30-39 years) in tropical sub-Saharan Africa, Latin America, and Southeast Asia. We estimate this model stratified by five regions—East and Southern Africa, West and Central Africa, Central America and the Caribbean, South America, and Southeast Asia—to account for important differences in development, demographics, baseline climate, and related contextual characteristics that are likely to moderate climate effects (Bongaarts and Casterline 2013; Randell and Gray 2019). Second, we test for variation in this relationship within region by sex and education, according to which vulnerability to climate shocks and migration behaviors are expected to vary (Adger 2006). Third and finally, we test the sensitivity of our findings to alternative modeling assumptions and measurement decisions. In addition to evaluating the robustness of our findings, these secondary analyses also inform our substantive interpretations by revealing the years in early childhood that are particularly critical for lifetime migration outcomes.

Data and methods

This study draws on two sources of data. We first extract census microdata for multiple countries from the Integrated Public Use Microdata Series-International (IPUMS-I) database (Minnesota Population Center, 2018). IPUMS-I harmonizes census microdata from around the world to facilitate comparative research across countries and over time. Our sample is drawn from 31 countries across the global tropics (see appendix Table A1 for a full list), which were selected based on the following criteria: (1) at least 50 percent of the land area is located within the global tropics (between approximately 23.5° N and 23.5° S latitude), (2) at least two census years of data are available since 1980 (to permit our analytic strategy), and (3) geographic identifiers that can be standardized over time are available for places of birth and enumeration.² Using these criteria, our final sample includes data from 81 censuses conducted between 1980 and 2012 in 31 countries across tropical East and Southern Africa (7 countries), West and Central Africa (6 countries), Central America and the Caribbean (7 countries), South America (7 countries), and Southeast Asia (4 countries). A map of the countries in our sample is included as Figure 2.

(Figure 2)

We use these data to create an individual-level dataset (described by region in Table 1)³ that includes measures of age, sex, primary school attainment, province and year of birth, and province of enumeration.⁴ We restrict the analytic sample to adults aged 30 to 39 years at the time of the census. This age range captures adults during and immediately after the ages of peak migration and excludes older age groups that are more likely to be affected by selective mortality

² 1980 is the most recent census year that can be included given the lookback period used in our measures of climate exposure and given that global climate data sources become scarce and unreliable before 1950.

³ A description of the pooled sample is included in the appendix (Table A2).

⁴ We use the term province to denote the administrative unit for which we can identify individuals' places of birth and enumeration. We use the lowest administrative unit for which time-consistent boundaries are available, and these vary between first- and second-level units across the sample.

and recall bias (i.e., when identifying their birth province).⁵ Some individuals may have been observed in consecutive censuses that took place within ten years of each other. For example, censuses in Ecuador were conducted in 2001 and 2010. An individual born in 1971 would have been age 30 in the 2001 census, age 39 in the 2010 census, and therefore observed twice in our dataset in the absence of mortality and international migration. We drop any such second occurrence of a birth cohort to avoid duplicate observations in the data.

(Table 1)

Data on temperature and precipitation were extracted from the Climate Research Unit Time Series (CRU TS) (Harris et al. 2014) available from the University of East Anglia. CRU TS provides monthly gridded estimates of mean temperature and total precipitation from 1900 to present with a resolution of 0.5° latitude by 0.5° longitude. The dataset is created by interpolating weather station data from over 4,000 locations throughout the world. We extract time-varying rainfall and temperature data at the province level as spatial means using time-stable geographic boundaries created by IPUMS-I. We use these data to construct a set of climate variables at the province-year scale (e.g., mean annual temperature in birth province b during year t).

Our main measures of climate variability are mean annual temperature (°C) and total annual precipitation (mm) for the year prior to birth through age 4, standardized as z-scores over all other consecutive five-year periods during the 1949-2012 reference period. We include the year prior to birth to capture the effects of climatic variability during the prenatal period, which is shown to be consequential for the human development mechanisms described in our model (Almond and Currie, 2011; Kumar et al. 2016; Torche and Conley 2016). Climate values standardized in this way are known as climate anomalies, and they have three major advantages over the use of raw

⁵ Our data exclude individuals born prior to 1950 since such individuals' prenatal year (1948) falls before our series of climate data begins in 1949.

climate values in this context: (1) they capture locally-relevant departures from historical climate conditions; (2) they can be treated as natural experiments because they are exogenous to birth provinces and uncorrelated with baseline climate (Nordkvelle et al., 2017); and (3) they have been shown to be stronger predictors of migration than raw climate values in previous cross-national studies (Gray and Wise, 2016; Mueller et al., 2020). To allow nonlinear climate effects as have also been documented by previous studies (Burke et al., 2015; Hsiang et al., 2013), we include both linear and squared terms in each regression as described below.

Our analyses center on a series of logistic regression models, which take the form:

$$\ln\left(\frac{p}{1-p}\right) = \alpha_b + \alpha_d + \delta C_{b(t)} + \theta C_{b(t)}^2 + \beta X_{i(s)}$$

where the log-odds that adult i resides outside of their birth province at the time of enumeration is a function of birthplace climate anomalies (C_b) during time period t —defined as the year prior to birth to age 4 in the main specification—and net of individual characteristics (X) measured at the time of the census (s), as well as birth province (α_b) and decade of enumeration (α_d) fixed effects.⁶ The main specifications control for individuals’ age, sex, and primary school attainment, and we cluster standard errors on individuals’ birth province. The inclusion of fixed effects for the birth province and decade of enumeration fully accounts for time-invariant characteristics of the birthplace as well as the common decade-on-decade contextual changes in each of the world regions we consider.

⁶ Our dataset covers 208 birth provinces in East and Southern Africa, 202 in West and Central Africa, 339 in South America, 86 in Central America and the Caribbean, and 265 in Southeast Asia.

Results

Overall estimates

We begin by estimating the overall association between early-life climate variability and lifetime migration for each of the five regions included in our sample (Table 2). We find significant non-linear temperature effects in East and Southern Africa as well as South America. Above-average early-life temperatures are associated with large reductions in lifetime migration in East and Southern Africa, where much below-average temperatures are also associated with lower rates of mobility. In contrast, anomalous temperatures—both above and below average—in early life are associated with modest increases in lifetime migration in South America. Early-life temperatures are not significant predictors of lifetime migration in other world regions. However, we find significant non-linear rainfall effects in West and Central Africa and Southeast Asia. In both regions, the odds of lifetime migration grow (non-linearly) as the level of early-life rainfall increases.

(Table 2)

To put the magnitude of these effects in context, we predict the probability of lifetime migration across a range of early-life temperature and precipitation exposures while holding all other variables at their means (Figure 3). In East and Southern Africa (Panel a), experiencing hotter-than-normal early-life conditions is associated with decreased odds of lifetime migration. A shift in temperatures from average ($z = 0$) to two standard deviations above average ($z = 2$) is associated with a 12-percentage point decline in the predicted probability of migration, from approximately 25 percent to 13 percent. In West and Central Africa (Panel b), experiencing above-average rainfall in early life is associated with an increased odds of lifetime migration. At average

rainfall ($z = 0$), the predicted probability of migration is 23 percent, but increases to 33 percent when early-life rainfall is two standard deviations above average ($z = 2$).

In contrast, the magnitude of the temperature and rainfall effects in South America (Panel c) and Southeast Asia (Panel d), respectively, are much smaller. In South America, hotter-than-normal early-life conditions are associated with a slight increase in the predicted probability of lifetime migration, from 19 percent at average early-life temperatures ($z = 0$) to 21 percent at temperatures two standard deviations above average. In Southeast Asia, wetter-than-normal conditions in early life are associated with a slightly greater odds of migration. A shift from average ($z = 0$) to above-average rainfall ($z = 2$) is associated with a 2 percentage-point increase in the predicted probability of migration, from 14 percent to 16 percent.

(Figure 3)

Sex and educational differences in climate effects

We next test for variation in climate effects across sub-populations that we expect may differ in terms of their vulnerability to environmental conditions and the extent to which they are likely to be influenced by one or more of the four proposed mechanisms in our childhood origins model. Specifically, we focus on individual's sex (Table A3) and educational attainment (Table A4). We begin by comparing the effects of early-life temperature and precipitation anomalies between men and women. The relationship between early-life temperature and migration varies by sex in East and Southern Africa as well as Central America and the Caribbean (see jointly significant interaction terms in Table A3). In East and Southern Africa, the relationship between temperature and migration is not statistically significant for men. However, for women, experiencing hotter-than-normal early life temperatures is associated with a statistically and

substantively significant decline in the odds of migration. To interpret these estimates, we again produce predicted probabilities of lifetime migration across a range of early-life temperatures (Figure 4, Panel e). These analyses show that a shift in early-life temperatures from average ($z = 0$) to two standard deviations above average ($z = 2$) is associated with an 18 percentage-point decline in the probability of women's migration (from 21 percent to 3 percent) in East and Southern Africa. In Central America and the Caribbean, there is a statistically significant relationship between temperature and lifetime migration for women, but the magnitude of the effect is substantively small. For example, the probability of lifetime migration is just 3 percentage points lower among adults exposed to much above-average temperatures ($z = 2$) during early childhood than peers exposed to average conditions (Figure 4, panel f).

(Figure 4)

The second set of interaction models tests for differences by educational attainment, which represents a proxy for socioeconomic status. We find that the effects of both early-life temperature and precipitation vary by primary school completion in East and Southern Africa (as indicated by jointly significant interactions in Table A4). Exposure to hotter-than-normal early-life temperatures are associated with lower odds of migration among those with less than a primary education. Among these less-educated individuals, a shift in early-life temperatures from average to two standard deviations above average is associated with a 14-percentage point decline in the predicted probability of migration, from 15 percent to 1 percent (Figure 4, Panel g). In contrast, above-average early-life temperatures are associated with a higher probability of migration among those with a primary education or higher. For this group, a shift in early-life temperatures from average to two standard deviations above average nearly double the odds of migration, from 36 percent to 64 percent. Among individuals in East and Southern Africa with less than a primary

education, there is also a significant negative relationship between early-life rainfall and the odds of migration. However, the magnitude of the relationship is small. The difference in predicted lifetime migration probabilities between adults exposed to average ($z = 0$) and much above-average ($z = 2$) precipitation in early life is just 2 percentage points (19% and 17%, respectively).

Alternative climate exposures

As a final step in the main analysis, we return to our overall models of lifetime migration and evaluate the influence of using an alternative time interval to measure early-life climate. This exercise is designed to answer substantive questions rather than simply serve as a robustness check: If our main findings are driven by developmental mechanisms that operate strongest during the *in-utero* period and first years of life, the lengthening of the exposure period to include older ages (i.e., ages -1 to 9) should attenuate our estimates. Alternatively, the proposed whole-household migration and migration network mechanisms are likely to be less correlated with a child's age. If these mechanisms are most important, our estimates should be insensitive to the choice of a 5- or 10- year exposure period.

Following the logic above, our results suggest that observed temperature effects occur mainly through developmental pathways (Table A5). When early-life climate exposures are measured to include ages -1 to 9, the early-life temperature effects that were observed in East and Southern Africa and South America are no longer statistically significant. Likewise, in no other region are temperature exposures during ages -1 to 9 statistically associated with lifetime migration. The salience of this developmental pathway is consistent with other evidence from these regions, which shows early-life exposure to hot spells is associated with increased stunting and lower birthweight (Andalón et al. 2016; Randell et al. 2020). In contrast, the rainfall effects

observed in West and Central Africa and Southeast Asia are only attenuated slightly and remain statistically significant when measured over this ten-year period. Moreover, precipitation exposures from ages -1 to 9 are significantly and positively associated with lifetime migration in Central American and the Caribbean, where no climate effects were observed when measuring exposures from years -1 to 4. The implication is that rainfall effects in these other regions are unlikely to be explained solely by the proposed developmental mechanisms, with whole-household migration and migration network effects also playing a role (Bohra-Mishra et al. 2014; Curran et al. 2016; Entwisle et al. 2020).

Robustness checks

Finally, we conduct a set of supplemental analyses to test the robustness of our findings, focusing on concerns that educational attainment may be endogenous to our early-life climate variables. We first re-estimate our main models excluding primary school education as a control (Table A6). All of the temperature and precipitation effects observed in the main model remain statistically significant. The statistical strength of temperature effects in West and Central Africa increases in this model (and substantively follows the same pattern as in East and Southern Africa), suggesting our main model is conservative. We also re-estimate our models excluding primary school education but including a control for an additional proxy of socioeconomic status: the share of the parental cohort (i.e., ages 55-64 in an individual's birth province) that has less than a primary school education (Table A7). The substantive conclusions from the main models are again supported by these findings.

Discussion and conclusion

In this paper, we have developed a conceptual model that identifies plausible linkages between early-life exposure to climate anomalies and migration through the first parts of the life course, from childhood through early adulthood. To assess this model empirically, we examined the relationship between early-life temperature and rainfall exposures and lifetime migration among individuals aged 30-39 years, using data from 81 censuses and across 31 tropical countries. Our results provide support for the expectation that early-life climate exposures may influence migration behavior over relatively long periods of time, with evidence that exposure to spells of anomalous temperatures and rainfall in early life affect the probability of migration by ages 30-39 years. Our estimates vary across regions and model specifications in a manner that supports at least three specific findings.

First, we observe the strongest effects among the sub-Saharan African countries that are included in our sample. In East and Southern Africa, hotter-than-normal early-life temperatures are associated with much lower odds of migration, while wetter-than-normal early-life rainfall conditions are linked with increased lifetime migration in West and Central Africa. Overall effects are substantively much weaker, or not statistically significant, in the other three regions we consider. Sixty percent of the population of sub-Saharan Africa resides in rural areas, the vast majority relying on rainfed agriculture, while Latin America and Southeast Asia have higher aggregate levels of urbanization (World Bank 2018; FAO 2020). This suggests that rural, primarily agriculture-dependent individuals are most sensitive to the early-life effects of climate on migration over the life course. One likely mechanism is through the impacts of climatic conditions on agricultural production. In much of sub-Saharan Africa, hotter temperatures and lower rainfall are negatively associated with vegetation growth, indicating that cooler and wetter conditions are

favorable for crop production throughout most of the region (Quetin and Swann 2017). Such dynamics suggest that the positive effects of early-life rainfall (in West and Central Africa) and negative effects of early-life temperature (in East and Southern Africa) may be driven by changes in agriculture, which may influence both the human capital and demographic mechanisms that we propose. For example, adverse early-life conditions may undermine socioeconomic attainment, effectively trapping individuals in their province of birth through negative effects on human capital development (Currie and Vogl 2013; Grace et al. 2015; Maccini and Yang 2009; Randell and Gray 2019). In contrast, more favorable conditions may support human capital formation or lead to more robust economic growth, spurring demand for migrant labor.

Second, early-life climate effects vary across groups in a substantively meaningful way, especially in East and Southern Africa. Within that region, we find evidence that climate effects on migration vary according to both sex and educational attainment. Hotter-than-normal early-life temperatures reduce lifetime migration for women and those with less than a primary education—and in fact, particularly hot spells (e.g., $z = 2$) may lead to the near elimination of lifetime migration, as defined here. In contrast, above-average temperatures are positively associated with migration among those with at least a primary education. These findings suggest that girls and individuals from socioeconomically disadvantaged households experience the greatest constraints on migration when exposed to early-life climate shocks. For example, members of these groups may be most likely to experience climate-induced nutritional deficits that impede life migration via human capital formation; or they may live in households that are most likely to be “trapped” (i.e., unable to migrate) because of climate-induced resource constraints (Nawrotzki and DeWaard 2018).

Third, supplemental analyses using an alternative, 10-year measure of climate exposures (from ages -1 to 9) are consistent with the proposed developmental, or human capital formation, mechanism in East and Southern Africa and South America, but suggest a more complicated picture elsewhere. Early-life temperature effects in the former two regions are attenuated when expanding the exposure period from ages -1 to 4 to -1 to 9, which suggests that conditions in the critical under-5 age period are driving the relationship. This attenuation is of course particularly notable in East and Southern Africa, where the estimated effects in the main model are substantively large. In contrast, the significant rainfall effects observed in the main models for West and Central Africa and Southeast Asia remain statistically significant when using an extended, 10-year exposure period. The implication is that the mechanisms less sensitive to age—including whole-household migration and migration networks—are more likely to be operating in these contexts (Bohra-Mishra et al. 2014; Curran et al. 2016; Entwisle et al. 2020).

In general, these findings suggest that attention to the proposed childhood origins model of climate-related migration is merited. Researchers have given considerable attention to the effects of early-life environmental shocks on many later-life socioeconomic and demographic outcomes (Almond and Currie, 2011; Hayward and Gorman 2004; Maccini and Yang, 2009; Randell and Gray 2019; Torche and Conley 2016)—but little-to-no research has examined migration through such a framework to date. Addressing this gap may not only improve theoretical understandings of how environmental change may affect migration, but it may also draw attention to the links between early-life socioeconomic conditions in general and geographic mobility over the life course. Such linkages are substantively important in the context of climate change since migration out of shock-affected contexts may represent an effective adaptation strategy that influences life chances (Black et al. 2011). They are also important more broadly since migration

is often associated with improved residential attainment and socioeconomic mobility. Any early-life conditions—social, economic, or environmental—that decrease one’s likelihood of moving out of disadvantaged contexts are likely to compound the effects of such initial insults. The “long arm” of childhood conditions may not only reach to affect health and socioeconomic attainment (Hayward and Gorman 2004), but also correlated outcomes such as migration. Such processes are important since migration has implications for individual and household wellbeing, and for population change at the aggregate level.

To extend this line of research, future studies should work to address at least two significant limitations inherent to our analyses. For one, we are not able to distinguish between non-migrants and individuals who left their province of birth but returned prior to enumeration. While treated the same in our study due to data constraints, these two outcomes and their second-order socioeconomic effects are qualitatively different and should be separated whenever possible. Second, we cannot determine the timing of the moves observed in our data. Our conceptual framework identifies multiple mechanisms through which early-life climate may affect lifetime migration, and the importance of these respective mechanisms is expected to differ by age. Our supplemental models using alternative climate exposure periods took advantage of this fact to assess pathways as much as possible, but even this approach allowed only provisional insights. Future studies that are able to identify the timing of migration (e.g., via panel data) are needed to provide further insights into causal pathways.

Despite these limitations, this study provides a fundamentally new framework for studying the relationship between climatic variability and human migration and supports these claims with evidence from across the global tropics. We hope that this framework and our findings spur additional research that accounts for the complex ways in which climate change may affect

demographic processes over the short- and long-runs. Our results should also raise new questions for policymakers and development practitioners, since they suggest that future changes in temperature and precipitation are likely to have long-lasting effects on migration that cannot be easily reversed.

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Table 1. Descriptive statistics, by region

Variable	East and Southern Africa				West and Central Africa				South America				Central America and the Caribbean				Southeast Asia			
	<u>Mean</u>	<u>SD</u>	<u>Min</u>	<u>Max</u>	<u>Mean</u>	<u>SD</u>	<u>Min</u>	<u>Max</u>	<u>Mean</u>	<u>SD</u>	<u>Min</u>	<u>Max</u>	<u>Mean</u>	<u>SD</u>	<u>Min</u>	<u>Max</u>	<u>Mean</u>	<u>SD</u>	<u>Min</u>	<u>Max</u>
<u>Outcome</u>																				
Migrant = yes	0.275	-	0	1	0.270	-	0	1	0.224	-	0	1	0.265	-	0	1	0.166	-	0	1
<u>Climate anomalies, ages -1 to 4</u>																				
Temperature	-0.742	0.354	-1.964	0.863	-0.823	0.608	-2.342	1.155	-0.646	0.684	-2.912	2.454	-0.733	0.606	-2.572	0.851	-0.779	0.548	-2.346	1.384
Rainfall	0.344	0.910	-2.393	3.013	0.341	0.934	-1.519	2.800	-0.096	0.968	-3.073	3.102	0.028	1.007	-2.531	3.059	-0.029	1.007	-2.625	2.789
<u>Controls</u>																				
Age	33.8	2.9	30	39	33.6	2.9	30	39	34.0	2.8	30	39	34.1	2.8	30	39	33.6	2.9	30	39
Sex = female	0.512	-	0	1	0.534	-	0	1	0.513	-	0	1	0.519	-	0	1	0.502	-	0	1
Primary school = yes	0.555	-	0	1	0.363	-	0	1	0.623	-	0	1	0.731	-	0	1	0.716	-	0	1
<u>Decade</u>																				
1980-1989	0.141	-	0	1	0.173	-	0	1	0.046	-	0	1	0.034	-	0	1	0.118	-	0	1
1990-1999	0.205	-	0	1	0.168	-	0	1	0.295	-	0	1	0.172	-	0	1	0.202	-	0	1
2000-2009	0.454	-	0	1	0.472	-	0	1	0.365	-	0	1	0.515	-	0	1	0.372	-	0	1
2010-2012	0.201	-	0	1	0.187	-	0	1	0.295	-	0	1	0.279	-	0	1	0.308	-	0	1
N (unweighted)	3,210,234				1,630,755				7,095,627				752,732				7,787,325			
N (weighted)	34,187,834				16,307,550				105,779,389				7,633,004				123,318,625			

Table 2. Logistic regression models of lifetime migration, by region

	East and Southern Africa <u>Model 1</u>			West and Central Africa <u>Model 2</u>			South America <u>Model 3</u>			Central America and the Caribbean <u>Model 4</u>			Southeast Asia <u>Model 5</u>		
	β		(SE)	β		(SE)	β		(SE)	β		(SE)	β		(SE)
<u>Climate anomalies, ages -1 to 4</u>															
Temperature	-0.142		(0.091)	-0.104	+	(0.054)	0.007		(0.016)	-0.007		(0.036)	0.003		(0.039)
Temperature ²	-0.134	**	(0.048)	-0.055		(0.035)	0.025	+	(0.013)	-0.012		(0.014)	0.019		(0.029)
Rainfall	-0.020	*	(0.009)	0.129	**	(0.041)	-0.010		(0.014)	0.011		(0.010)	0.026		(0.018)
Rainfall ²	0.003		(0.009)	0.062	***	(0.014)	-0.004		(0.008)	0.005		(0.005)	0.025	***	(0.007)
<u>Controls</u>															
Age	0.002		(0.002)	-0.008		(0.006)	0.020	***	(0.001)	0.026	***	(0.002)	-0.008	+	(0.004)
Sex = female	-0.187	***	(0.033)	-0.119	***	(0.018)	-0.024	*	(0.010)	0.093	***	(0.013)	-0.121	***	(0.017)
Primary school = yes	0.748	***	(0.061)	0.844	***	(0.093)	0.264	***	(0.047)	0.502	***	(0.057)	0.653	***	(0.046)
Decade fixed effects	Yes			Yes			Yes			Yes			Yes		
Birthplace fixed effects	Yes			Yes			Yes			Yes			Yes		
Pseudo R ²	0.114			0.092			0.090			0.115			0.077		
Joint test, temperature	13.27**			4.79+			8.77*			1.10			1.43		
Joint test, rainfall	4.94+			21.09***			0.48			2.81			12.23**		
Joint test, all climate variables	28.57***			28.86***			10.08*			2.94			13.83**		

+p<0.10, *p<0.05, **p<0.01

Note: Standard errors clustered on birth province.

Figures

Figure 1 Conceptualization of coping strategies and childhood origins models

Figure 2 Countries and sub-national administrative units of observation included in the analytic sample

Figure 3 Predicted probability of lifetime migration, by early-life temperature and rainfall anomalies

Figure 4 Predicted probability of lifetime migration by early-life temperature and rainfall anomalies, including sex-climate interactions (Panels e and f) and education-climate interactions (Panels g and h)

APPENDIX

Table A1. Share of sample by region and country (weighted)

East and Southern Africa	11.9%	West and Central Africa	5.7%	South America	36.4%	Central America and the Caribbean	2.7%	Southeast Asia	42.9%
Botswana	0.16	Burkina Faso	0.82	Bolivia	0.55	Costa Rica	0.42	Cambodia	1.03
Kenya	3.28	Cameroon	0.9	Brazil	25.98	Dominican Republic	0.75	Indonesia	33.34
Malawi	0.71	Ghana	2.03	Colombia	4.06	El Salvador	0.46	Malaysia	1.72
Mozambique	1.33	Guinea	0.35	Ecuador	1.61	Jamaica	0.24	Thailand	6.84
Tanzania	3.84	Mali	1.01	Paraguay	0.42	Nicaragua	0.38		
Uganda	1.44	Senegal	0.57	Peru	2.32	Panama	0.31		
Zambia	1.13			Venezuela	1.89	Trinidad and Tobago	0.09		

Table A2. Descriptive statistics, pooled sample

Variable	Global			
	Mean	SD	Min	Max
<u>Outcome</u>				
Migrant = yes	0.209	-	0	1
<u>Climate anomalies, ages -1 to 4</u>				
Temperature	-0.727	0.593	-2.912	2.454
Rainfall	0.013	0.990	-3.073	3.102
<u>Controls</u>				
Age	33.8	2.9	30	39
Sex = female	0.509	-	0	1
Primary school = yes	0.643	-	0	1
<u>Census decade</u>				
1980-1989	0.095	-	0	1
1990-1999	0.233	-	0	1
2000-2009	0.389	-	0	1
2010-2012	0.283	-	0	1
N (unweighted)	20,476,673			
N (weighted)	287,226,401			

Table A3. Logistic regression models of lifetime migration by region, including sex-climate interactions

	East and Southern Africa			West and Central Africa			South America			Central America and the Caribbean			Southeast Asia		
	Model 6			Model 7			Model 8			Model 9			Model 10		
	β		(SE)	β		(SE)	β		(SE)	β		(SE)	β		(SE)
<u>Climate anomalies, ages -1 to 4</u>															
Temperature	0.139		(0.090)	-0.092	+	(0.054)	0.010		(0.017)	0.012		(0.038)	-0.001		(0.043)
Temperature ²	0.020		(0.049)	-0.049		(0.034)	0.024	+	(0.014)	0.010		(0.016)	0.018		(0.031)
Rainfall	-0.024	*	(0.010)	0.141	***	(0.041)	-0.01		(0.013)	0.011		(0.010)	0.019		(0.019)
Rainfall ²	0.006		(0.008)	0.061	***	(0.013)	-0.003		(0.008)	0.006		(0.006)	0.024	**	(0.007)
<u>Interactions</u>															
Temperature × Female	-0.582	***	(0.098)	-0.025		(0.036)	-0.006		(0.013)	-0.037		(0.030)	0.008		(0.030)
Temperature ² × Female	-0.321	***	(0.059)	-0.013		(0.023)	0.002		(0.006)	-0.042	**	(0.014)	0.003		(0.017)
Rainfall × Female	0.009		(0.008)	-0.023		(0.016)	0.002		(0.005)	-0.000		(0.006)	0.014		(0.009)
Rainfall ² × Female	-0.005		(0.011)	0.003		(0.012)	-0.001		(0.003)	-0.002		(0.006)	0.002		(0.005)
<u>Controls</u>															
Age	0.002		(0.002)	-0.008		(0.006)	0.020	***	(0.001)	0.026	***	(0.002)	-0.008	+	(0.004)
Sex = female	-0.402	***	(0.045)	-0.122	***	(0.024)	-0.028	*	(0.012)	0.106	***	(0.016)	-0.120	***	(0.021)
Primary school = yes	0.748	***	(0.061)	0.844	***	(0.093)	0.264	***	(0.047)	0.502	***	(0.057)	0.653	***	(0.047)
Decade fixed effects		Yes			Yes			Yes			Yes			Yes	
Birthplace fixed effects		Yes			Yes			Yes			Yes			Yes	
Pseudo R ²		0.114			0.092			0.090			0.115			0.077	
Joint test, temperature interaction		36.24***			0.86			2.14			20.83***			0.11	
Joint test, rainfall interaction		1.11			2.22			0.28			0.12			2.41	
Joint test, all climate variables		29.20***			40.97***			7.27			6.18			13.19*	

+p<0.10, *p<0.05, **p<0.01

Note: Standard errors clustered on birth province. Reference group for interaction models = male.

Table A4. Logistic regression models of lifetime migration by region, including education-climate interactions

	East and Southern Africa			West and Central Africa			South America			Central America and the Caribbean			Southeast Asia		
	Model 11			Model 12			Model 13			Model 14			Model 15		
	β		(SE)	β		(SE)	β		(SE)	β		(SE)	β		(SE)
Climate anomalies, ages -1 to 4															
Temperature	-0.713	***	(0.168)	-0.081		(0.060)	-0.042		(0.035)	0.143	+	(0.073)	0.139		(0.118)
Temperature ²	-0.402	***	(0.086)	-0.042		(0.037)	-0.001		(0.019)	0.081		(0.058)	0.086		(0.070)
Rainfall	-0.043	**	(0.014)	0.098	*	(0.045)	-0.018		(0.022)	0.011		(0.015)	0.050	**	(0.019)
Rainfall ²	-0.021		(0.017)	0.078	***	(0.023)	0.006		(0.012)	0.006		(0.012)	0.033	***	(0.010)
Interactions															
Temperature × Primary school = yes	1.076	***	(0.206)	-0.084		(0.077)	0.073	+	(0.038)	-0.203	+	(0.106)	-0.164		(0.120)
Temperature ² × Primary school = yes	0.511	***	(0.111)	-0.040		(0.043)	0.036	+	(0.019)	-0.121	+	(0.074)	-0.081		(0.068)
Rainfall × Primary school = yes	0.038	*	(0.016)	0.082	*	(0.036)	0.017		(0.019)	-0.000		(0.018)	-0.032		(0.020)
Rainfall ² × Primary school = yes	0.034	+	(0.018)	-0.038		(0.025)	-0.016	+	(0.009)	-0.000		(0.014)	-0.012		(0.009)
Controls															
Age	0.005	*	(0.002)	-0.009		(0.006)	0.020	***	(0.001)	0.025	***	(0.002)	-0.008	+	(0.004)
Sex = female	-0.186	***	(0.034)	-0.118	***	(0.018)	-0.024	*	(0.011)	0.093	***	(0.013)	-0.121	***	(0.017)
Primary school = yes	1.165	***	(0.105)	0.829	***	(0.088)	0.295	***	(0.044)	0.457	***	(0.062)	0.615	***	(0.056)
Decade fixed effects		Yes			Yes			Yes			Yes			Yes	
Birthplace fixed effects		Yes			Yes			Yes			Yes			Yes	
Pseudo R ²		0.115			0.093			0.090			0.115			0.077	
Joint test, temperature interaction		26.58***			1.63			4.40			3.87			1.94	
Joint test, rainfall interaction		28.38***			5.45+			4.93+			0.00			5.12+	
Joint test, all climate variables		9.73**			19.44***			4.87			7.64			19.34***	

+p<0.10, *p<0.05, **p<0.01

Note: Standard errors clustered on birth province. Reference group for interaction models = primary school = no.

Table A5. Logistic regression models of lifetime migration, alternative climate exposure interval: ages -1 to 9

	East and Southern Africa		West and Central Africa		South America		Central America and the Caribbean		Southeast Asia	
	Model 16		Model 17		Model 18		Model 19		Model 20	
	β	(SE)	β	(SE)	β	(SE)	β	(SE)	β	(SE)
Climate anomalies, ages -1 to 9										
Temperature	0.082	(0.068)	-0.049	(0.041)	-0.011	(0.021)	-0.025	(0.065)	-0.025	(0.053)
Temperature ²	0.022	(0.053)	-0.031	(0.034)	0.031 +	(0.016)	-0.017	(0.030)	0.026	(0.035)
Rainfall	0.002	(0.012)	0.153 **	(0.052)	-0.019	(0.023)	0.039 *	(0.016)	0.037 *	(0.017)
Rainfall ²	0.000	(0.011)	0.054 *	(0.027)	-0.007	(0.014)	-0.000	(0.008)	0.016 +	(0.009)
Controls										
Age	0.002	(0.002)	-0.011	(0.009)	0.019 ***	(0.001)	0.026 ***	(0.003)	-0.005	(0.005)
Sex = female	-0.187 ***	(0.033)	-0.119 ***	(0.018)	-0.024 *	(0.010)	0.094 ***	(0.013)	-0.121 ***	(0.017)
Primary school = yes	0.748 ***	(0.061)	0.842 ***	(0.094)	0.264 ***	(0.047)	0.501 ***	(0.057)	0.656 ***	(0.047)
Decade fixed effects	Yes		Yes		Yes		Yes		Yes	
Birthplace fixed effects	Yes		Yes		Yes		Yes		Yes	
Pseudo R ²	0.114		0.092		0.090		0.115		0.077	
Joint test, temperature	1.94		1.4		3.7		0.89		2.87	
Joint test, rainfall	0.03		8.81*		0.73		7.72*		9.19*	
Joint test, all climate variables	2.00		27.91***		9.40+		9.02+		9.23+	

+p<0.10, *p<0.05, **p<0.01
Note: Standard errors clustered on birth province.

Table A6. Logistic regression models of lifetime migration, excluding primary education

	East and Southern Africa			West and Central Africa			South America			Central America and the Caribbean			Southeast Asia		
	Model 21			Model 22			Model 23			Model 24			Model 25		
	β		(SE)	β		(SE)	β		(SE)	β		(SE)	β		(SE)
<u>Climate anomalies, ages -1 to 4</u>															
Temperature	-0.154	+	(0.084)	-0.135	*	(0.056)	0.007		(0.015)	-0.001		(0.035)	-0.028		(0.035)
Temperature ²	-0.141	**	(0.045)	-0.065	+	(0.036)	0.023	+	(0.013)	-0.010		(0.014)	-0.001		(0.027)
Rainfall	-0.014	+	(0.009)	0.134	***	(0.038)	-0.009		(0.014)	0.011		(0.010)	0.025		(0.015)
Rainfall ²	0.001		(0.009)	0.060	***	(0.015)	-0.004		(0.007)	0.006		(0.006)	0.024	***	(0.006)
<u>Controls</u>															
Age	-0.001		(0.002)	-0.010	+	(0.006)	0.018	***	(0.001)	0.023	***	(0.002)	-0.014	***	(0.003)
Sex = female	-0.290	***	(0.035)	-0.239	***	(0.021)	-0.020	+	(0.010)	0.096	***	(0.014)	-0.166	***	(0.016)
Decade fixed effects		Yes			Yes			Yes			Yes			Yes	
Birthplace fixed effects		Yes			Yes			Yes			Yes			Yes	
Pseudo R ²		0.100			0.076			0.088			0.109			0.069	
Joint test, temperature		14.81***			12.11**			8.30*			1.07			2.22	
Joint test, rainfall		2.78			20.10***			0.40			3.07			16.84***	
Joint test, all climate variables		24.09***			35.02***			9.53*			3.13			22.06***	

+p<0.10, *p<0.05, **p<0.01

Note: Standard errors clustered on birth province.

Table A7. Logistic regression models of lifetime migration, excluding primary education and including parental cohort education

	East and Southern Africa			West and Central Africa			South America			Central America and the Caribbean			Southeast Asia		
	Model 26			Model 27			Model 28			Model 29			Model 30		
	β		(SE)	β		(SE)	β		(SE)	β		(SE)	β		(SE)
<u>Climate anomalies, ages -1 to 9</u>															
Temperature	-0.157	+	(0.085)	-0.126	*	(0.056)	0.006		(0.016)	0.001		(0.037)	-0.027		(0.035)
Temperature ²	-0.141	**	(0.045)	-0.075	*	(0.032)	0.022		(0.013)	-0.006		(0.015)	-0.004		(0.024)
Rainfall	-0.014		(0.009)	0.097	*	(0.049)	-0.011		(0.013)	0.006		(0.009)	0.025		(0.015)
Rainfall ²	0.001		(0.009)	0.060	***	(0.015)	-0.004		(0.007)	0.003		(0.005)	0.023	***	(0.006)
<u>Controls</u>															
Age	-0.001		(0.002)	-0.006		(0.005)	0.018	***	(0.001)	0.022	***	(0.002)	-0.014	***	(0.003)
Sex = female	-0.290	***	(0.035)	-0.240	***	(0.021)	-0.020	+	(0.010)	0.096	***	(0.014)	-0.166	***	(0.017)
<Primary school (%), parental cohort	-0.072		(0.293)	-1.060		(0.721)	0.493		(0.591)	0.843		(0.828)	-0.247		(0.318)
Decade fixed effects		Yes			Yes			Yes			Yes			Yes	
Birthplace fixed effects		Yes			Yes			Yes			Yes			Yes	
Pseudo R ²		0.100			0.077			0.088			0.109			0.069	
Joint test, temperature		14.38***			5.41+			6.84*			0.37			1.65	
Joint test, rainfall		2.53			16.08***			0.74			1.48			17.92***	
Joint test, all climate variables		20.45***			16.28**			9.08+			1.77			22.09***	

+p<0.10, *p<0.05, **p<0.01

Note: Standard errors clustered on birth province.