Climate Change and Lifetime Migration in the Global Tropics

Brian Thiede[1], Heather Randell[2], and Clark Gray[3]
[1]Pennsylvania State University
[2]University of Maryland, College Park
[3]University of North Carolina-Chapel Hill

March 22, 2019

Paper Prepared for the
2019 PAA Annual Meeting, Austin, TX

Abstract

The existing literature on climate change and migration has, conceptually and analytically, focused almost exclusively on assessing whether and how climatic variability affects migration patterns over the short run. In this paper, we suggest that this common "coping strategies" model can be extended to account for mechanisms that link climate to migration behavior over longer periods of time. We hypothesize that climatic conditions in early life may affect the likelihood of migration from childhood through early adulthood by influencing parental migration, human capital development, and decisions about household resource allocation that are correlated with geographic mobility. We evaluate this expectation across a sample drawn from 91 rounds of census data from 31 tropical countries. We estimate a series of multivariate regression models that predict lifetime migration through ages 30-39 as a function of temperature and precipitation during the year prior to birth to age four. Results suggest that early-life climate is systematically associated with changes in the probability of lifetime migration, so defined, with early exposure to hot-and-dry and cool-and-wet conditions leading to decreased odds of migration. These associations vary according to individuals' educational attainment, as well as across different geographic regions of the tropics. In general, we demonstrate a new pathway for climatic effects on migration that persist over the life course. In many regions of the world, future hot-and-dry conditions are likely to have long-lasting effects on migration that cannot be easily reversed

Acknowledgements

Thiede acknowledges assistance provided by the Population Research Institute at Penn State University, which is supported by an infrastructure grant by the Eunice Kennedy Shriver National Institute of Child Health and Human Development (P2CHD041025).

1. Introduction

For many decades, policymakers and scientists have raised concerns about the potential for climate change to displace human populations in the developing world (Houghton, Jenkins and Ephraums, 1990). Social scientists have evaluated these claims empirically over recent years in a rapidly-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 multivariate statistical methods to estimate the effects of climatic variability on the likelihood of out-migration (Fussell et al., 2014). These studies have revealed that climatic conditions—particularly temperature—have persistent effects on migration, though the direction and form that this relationship takes 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).

Notably, this existing literature has focused almost exclusively on measuring the immediate effects of climatic variability on migration. That is, these analyses examine migration outcomes occurring concurrent to, or soon after, the climate event 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 mechanisms that link climatic changes to migration behavior over longer periods of time. We hypothesize that climatic conditions in early life can affect the likelihood of migration throughout the first half of the life course, from childhood itself through working ages. In our view, attention to this "life course model" of the links between climatic variability and migration is merited since it accounts for the multiple pathways and temporal scales through which climate effects may operate.

The overall goals of this paper are to describe this life course model of climate-induced migration, and then evaluate it by drawing on demographic and climate records from 91 censuses conducted in 31 tropical countries between 1980 and 2012. To this end, 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 migration during early stages of the life course through early adulthood. We then describe the data and analytic methods used to assess the relationship between early-life exposure to climatic anomalies and the probability of lifetime migration among adults ages 30 to 39 years. The fourth section of the paper describes our results, and in the fifth and concluding section we discuss the broader implications of our findings for population-environment research, and identify areas for future work.

2. Early-life climate and lifetime migration

The extensive and geographically-diverse literature on climate and migration that has emerged over recent years is largely premised on a common framework of migration decision-making, which we refer to as the coping strategies model (Figure 1, top). From this perspective, climate 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 constraints on the resources needed to fund such moves. 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 during the months after a failed or sub-par harvest. 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 livelihoods (e.g., Ellis, 2000; Stark and Bloom, 1985).

(Figure 1)

This conceptual model has proven useful for motivating empirical analysis, and is now supported by a wide range of studies that have documented changes in migration (both upward and downward) 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; Mastrorillo et al. 2016; Mueller et al., 2014; 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 behavior over considerably longer periods of time. In particular, there is reason to expect that climatic conditions in early life can affect the likelihood of migration over the first half of the life course, from childhood through adulthood. We expect such effects to operate through at least three channels—one of which aligns directly with the commonly employed coping strategies model, and the other two of which account for the effects of climate-induced changes in human capital attainment and household resource allocation on individuals' geographic mobility (Figure 1, bottom).

First, and most consistent with the framework of previous research, early-life exposure to climate variability may affect children's lifetime migration odds strictly through the migration behavior of their parents and corresponding household unit. A climate shock during a given individual's childhood may prompt changes in migration among their parents and household members as they cope with the resulting changes in resources through the processes captured in the coping strategies model. To the extent that these responses involve *whole-household* migration—as has been shown to occur in some cases of environmental change (Bohra-Mishra et al. 2014)—these processes will also affect the odds that children experience climate-related moves. If this mechanism is operating, such moves will occur in early life, soon after exposure to the early-life climate shock in question.

Second, early exposure to climatic variability may alter developmental processes central to human capital formation, and this in turn affects migration odds 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 early-life malnutrition and related illnesses (Bakhtsiyarava et al, 2018; Bandyopadhyay et al. 2012; Davenport et al. 2017; Grace et al., 2012, 2015; Hoddinott & Kinsey 2001). These conditions are known to cause substantial, and in many cases irreversible, changes in cognitive development, education, and socioeconomic attainment over the life course (Almond and Currie, 2011; Maccini and Yang, 2009; Randell and Gray 2016; Torche and Conley 2016). These attainment levels are in turn expected be correlated with individuals' success in the labor and marriage markets, as well as other outcomes correlated with geographic mobility. The implication is that lifetime migration patterns may reflect the enduring developmental consequences of climate shocks experienced early in childhood and their second-order effects on socioeconomic outcomes through adulthood.

Third 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 decisions about if, when, and where to enroll (or unenroll) children in school, purchase healthcare, retain them in the household (e.g., versus out-fostering), and invest in their marriage, among other important questions (Akresh 2009; Beegle et al., 2006; Eloundou-Enyegue and Stokes, 2002; Kielland 2016; Jennings and Gray 2017; Jensen, 2000). We expect such climate-induced changes in household resource allocation to affect the likelihood of migration both immediately after a shock 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. Resource allocation decisions related to investments in education and health may also have longer run effects by affecting human capital formation, through a process similar to what was described above.

With these hypothesized pathways in mind, we extend the coping strategies model of climate-related human migration that has predominated the literature to date. We aim to account for the ways in which early-life exposure to climate variability may affect migration odds both during childhood and throughout early adulthood, and identify a series of socioeconomic and developmental mechanisms that can explain these effects. This alternative framework explicitly accepts and builds upon the existing approach to climate-induced migration, and therefore represents a complementary rather than competing perspective on this issue.

3. Research objectives

Our overall goal is to examine the association between exposure to climatic variability in early life and the likelihood of migration through early adulthood. We examine this association across 31 countries in the global tropics, which generally face more acute environmental and development challenges than higher-latitude countries (Sachs 2001). Toward this end, we address four specific objectives. *First,* we estimate the overall association between temperature and precipitation variability during early-childhood and the likelihood of inter-province migration from birth through adulthood, defined as ages 30 to 39 years. *Second,* we test for variation in these relationships by sex, educational attainment, and a measure of rural/urban residence, which together represent the best correlates of vulnerability to climate change available in our data. *Third*, we evaluate whether and how these relationships vary spatially across the tropics, with groupings respectively defined by geographic region and historical climatic conditions. *Fourth* and finally, we test the robustness of our findings to alternative modeling assumptions and measurement decisions.

4. Data and methods

We use two sources of data for our analysis. 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 in order to facilitate comparative research across countries and over time. Our sample is drawn from 31 countries across the global tropics, which were selected based on the following criteria: at least 50 percent of the land area is located within the global tropics (between approximately 23.5° N and 23.5° S latitude), at least two census years of data are available, and birthplace and enumeration geographic identifiers available.

We use these data to create an individual-level dataset (described in Table 1) that includes variables for: gender; primary school attainment; province and year of birth; and province of enumeration.[1] Using these criteria, our sample is composed of data from 91 censuses conducted between 1980 and 2012 in 31 countries across Sub-Saharan Africa, Latin America and the Caribbean, and Southeast Asia. For our main analysis, we restrict the analytic sample to adults aged 30 to 39 years at the time of enumeration, which captures adults during and after the ages of peak migration and excludes older age groups, among whom selective mortality and recall bias are more likely to occur.[2]

(Table 1)

Data on temperature and precipitation were derived from the Climate Research Unit (CRU) Time Series (Harris et al. 2014) available from the University of East Anglia. CRU 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 stations throughout the world. We extract rainfall and temperature data at the province level as spatial means using time-stable geographic boundaries created by IPUMS-I, allowing us to construct a set of climate variables at the province-year scale. Our main measures of climate variability are mean annual temperature (˚C) and total annual rainfall (mm) for the year prior to birth to age 4, standardized over all other consecutive periods of the same duration 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 developmental mechanisms described in our model (Almond and Currie, 2011; Torche and Conley 2016).

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

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

where the log-odds that individual i resides outside of their birth province at the time of enumeration is a function of birthplace climate (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), and both birthplace (α_b) and census-decade (α_d) fixed effects. The main specifications control for individuals' age, sex, and primary school attainment, and cluster standard errors on individuals' birth province (n=1,179).

5. Results

5.1. Overall estimates

We begin by estimating the average association between early-life climate variability and lifetime migration across the entire population captured in our sample (Table 2). Since the direction and functional form of climate effects on migration and other demographic outcomes have varied across previous studies, we estimate three different models which respectively assume linear climate effects (Model 1), allow climate effects to vary non-linearly via a quadratic function (Model 2), and allow temperature and precipitation effects to interact (Model 3). The results of Model 1 provide evidence of a negative association between early-life precipitation and lifetime migration odds (odds ratio, OR = 0.923), but the association between early-life temperature and migration is not statistically significant. We test for non-linearities in both precipitation and temperature effects in Model 2. The results of these tests are non-significant, so we proceed by

---

[1] We use the term province to denote the administrative unit for which we can identify individuals' places of birth and enumeration. In all cases, 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.

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

assuming that the association between early-life climate and lifetime migration is monotonic. Under this assumption, we then analyze possible interactions between temperature and precipitation (Model 3) and find evidence that these variables interact to shape lifetime migration patterns. That is, early exposure to certain combinations of temperature and precipitation may lead to statistically significant changes in the likelihood of lifetime migration relative to what is observed among populations exposed to average conditions in early life.

(Table 2)

To understand these interaction effects, we illustrate the relationships estimated in Model 3 by plotting the predicted probability of lifetime migration across a range of early-life precipitation levels (z-scores, x-axis) under both above-average (z = 2) and below-average (z = -2) early-life temperature regimes (Figure 2). This figure shows the declining likelihood that individuals exposed to spells of (a) above-average temperatures and below-average precipitation and (b) below-average temperatures and above-average precipitation in early life had moved (and remained) outside of their birth province by the time of enumeration. In contrast, individuals with early-life exposure to spells of (c) above-average temperatures and precipitation; and (d) below-average temperatures and precipitation were more likely to have lived outside of their birth province at the time of the census.

These associations are not only statistically but also substantively significant. For example, a child exposed to temperatures and precipitation that are two standard deviations above- and below-average, respectively, will be approximately 10 percentage points less likely to have migrated, and remained outside of their birth province, by early adulthood than children exposed to similarly above-average temperatures but average precipitation. Likewise, that same child exposed to simultaneously hot-and-dry-conditions in early life will be more than 30 percentage points less likely to have moved by adulthood than a child who experience cool-and-dry conditions—with temperatures and precipitation both two standard deviations below-average—in early childhood. Overall, these patterns are consistent with two complementary scenarios. First, adverse environmental conditions—such as droughts or excessive rainfall—may reduce the likelihood of whole-household migration during childhood due to climate-induced resource constraints. Second, early exposure to such conditions may reduce human capital formation, which in turn reduces odds of migration in adulthood given the tendency for migrants to be positively selected.

(Figure 2)

5.2. Climate effects by demographic group

In the next set of analyses, we test for variation in the associations between early-life climate and lifetime migration by individuals' sex, educational attainment, and the rural/urban status of their birthplace, as measured by the density of births (births/square kilometers) in their birth province and birth year. The results (Table 3) yield no evidence of systematic variation in the association between early-life climate and lifetime migration between men and women (Model 3). However, primary school attainment does significantly moderate the effects of early exposure to climate anomalies on lifetime migration (Model 4). Third, we test for variation in climate effects between children born in rural and urban areas, as proxied by birth-province birth density (Model 5). We find no evidence that this indicator of urbanicity is a significant modifier of early-life climate effects on migration.

The limited variation in these associations is in some respects surprising given between-group differences in vulnerability to climate change and in the types of adaptive strategies that individuals are likely to employ. On the other hand, these between-group differences are likely to manifest in unique ways across social and geographic contexts and therefore be difficult to detect across the large and diverse sample that we analyze. Similarly, each of the multiple pathways through which climate may affect migration in our model may have differential and potentially offsetting effects across these groups.

(Table 3)

5.3. Climate effects by historical climate and geography

Our third set of analyses assess whether and how the effects of early-life climate on lifetime migration vary by historical climatic conditions and geographic region of the world. We begin by examining differences across historical climate regimes, distinguishing between typically (a) cool-and-wet; (b) cool-and-dry; (c) hot-and-dry; and (d) hot-and-wet provinces. Each category is defined according to whether the province was above or below the sample median with respect to average annual temperature and precipitation during the 1949-2012 reference period. We estimate a model (Table 4, Model 6) that allows the associations between early-life temperature and precipitation to vary across these four groups, but find limited evidence of systematic differences. Although two individual interactions terms are statistically significant at marginal levels or greater, the joint effect of the historical climate-by-early life climate interaction terms is non-significant.

(Table 4)

In the next model, we test for geographic differences in the association between climate variability and lifetime migration (Table 4, Model 7). We distinguish between (a) East and Southern Africa, (b) West and Central Africa, (c) South America, (d) Central America and the Caribbean, and (e) Southeast Asia. A joint test of the region-by-early life climate interaction terms suggests that the relationship between early-life climate and lifetime migration varies across major world regions, which represent fundamentally different ecological and socioeconomic contexts.

5.4. Robustness checks

We conduct a final set of analyses that test the sensitivity of our findings to the use of alternative measures and assumptions. These analyses also provide substantive insights into the periods of early life that exposure to shocks is most consequential for lifetime migration (Table 5). First, we re-estimate our preferred specification (Model 3) but include measures of climate variability that span from the prenatal year to age 9 (Model 8), thus capturing insults that occur in later childhood when the proposed developmental mechanisms are less likely to be salient. The results reveal non-significant climate effects, so defined. When interpreted in the context of our findings from Model 3, these results point to the importance of *early-life* exposure—rather than any childhood exposure—and are therefore supportive of the developmental mechanisms outlined in our life course model.

(Table 5)

Relatedly, in our second robustness check we measure climate from birth to age four (Model 9), excluding the prenatal year since it is possible that fertility and child survival may be endogenous to climate during this full year prior to birth (Grace 2017; Sellers and Gray 2019). We find little substantive difference between the results of this model and our preferred specification (Model 3). As additional robustness checks, we re-estimate this preferred specification five additional times and respectively make the following modifications: clustering standard errors on the country rather than birth province (Model 10); controlling for period effects using country-specific linear time trends (Model 11); excluding the control for educational attainment, which may be endogenous to early-life climate (Model 12); and using analytic samples of individuals ages 20-29 (Model 13) and 25-34 (Model 14), respectively. All five models support our main conclusions, and only in Model 14 does the joint effect of the climate terms fall below conventional thresholds for statistical significance. As such, these supplemental analyses provide broad support for the robustness of our findings.

6. Discussion and conclusion

In this paper, we have developed a conceptual model that identifies plausible linkages between early-life exposure to anomalous climatic conditions 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 precipitation and lifetime migration among individuals aged 30-39 years, using data from 91 censuses implemented in 31 tropical countries. Our results provide overall support for the expectation that early-life climate may influence migration behavior over relatively long periods of time, with evidence that exposure to spells of (a) above-average temperatures and below-average precipitation and (b) below-average temperatures and above-average precipitation during the prenatal period to age four is associated with reduced odds of migration by early adulthood. These associations do not vary systematically by sex or urbanicity of birth province but do differ according to educational attainment. Perhaps more saliently, we find evidence of variation in the association between early-life climate and lifetime migration by major geographic region.

In general, our findings suggest that attention to the proposed extended model of climate-related migration is merited. Researchers have made considerable efforts toward understanding the effects of early-life environmental shocks on later-life socioeconomic and demographic outcomes, with the exception of migration to date. Addressing this gap may not only improve theoretical understandings of the determinants of migration in contexts of environmental change, but may also more generally draw attention to the links between early-life socioeconomic conditions and geographic mobility over the life course. Moreover, this broader framework can provide practical insights 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 a number of 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 could not determine the timing of the moves observed in our data. Our conceptual framework identifies a number of mechanisms through which early-life climate may affect lifetime migration, and the importance of these respective mechanisms is expected to differ by age. As such, future studies that are able to identify the timing of migration will be able to provide further insights into causal pathways.

Despite these limitations, this study provides a new perspective on the relationship between climatic variability and human migration. It should 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 hot and dry conditions are likely to have long-lasting effects on migration that cannot be easily reversed

References

Akresh, R. (2009). Flexibility of household structure child fostering decisions in Burkina Faso. *Journal of Human Resources*, 44(4), 976-997.

Almond, D., & Currie, J. (2011). Killing me softly: The fetal origins hypothesis. *Journal o Economic Perspectives*, *25*(3), 153-72.

Bandyopadhyay, S., Kanji, S., & Wang, L. (2012). The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. *Applied Geography*, 33, 63-72.

Bakhtsiyarava, M., Grace, K., & Nawrotzki, R. J. (2018). Climate, birth weight, and agricultural livelihoods in Kenya and Mali. *American Journal of Public Health*, *108*(S2), S144-S150.

Beegle, K., Dehejia, R. H., & Gatti, R. (2006). Child labor and agricultural shocks. *Journal of Development Economics*, *81*(1), 80-96.

Bohra-Mishra, P., Oppenheimer, M., & Hsiang, S. M. (2014). Nonlinear permanent migration response to climatic variations but minimal response to disasters. *Proceedings of the National Academy of Sciences*, *111*(27), 9780-9785.

Bohra-Mishra, P., Oppenheimer, M., Cai, R., Feng, S., & Licker, R. (2017). Climate variability and migration in the Philippines. *Population and environment*, *38*(3), 286-308.

Carleton, T. A., & Hsiang, S. M. (2016). Social and economic impacts of climate. *Science*, *353*(6304), 9837.

Davenport, F., Grace, K., Funk, C., & Shukla, S. (2017). Child health outcomes in sub-Saharan Africa: A comparison of changes in climate and socio-economic factors. *Global Environmental Change*, 46, 72-87.

De Jong, G. F., & Gardner, R. W. (1981). *Migration decision making: Multidisciplinary approaches to microlevel studies in developed and developing countries*. Pergamon Press.

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press.

Eloundou-Enyegue, P. M., & Stokes, C. S. (2002). Will economic crises in Africa weaken rural-urban ties? Insights from child fosterage trends in Cameroon. *Rural Sociology*, *67*(2), 278-298.

Feng, S., Krueger, A. B., & Oppenheimer, M. (2010). Linkages among climate change, crop yields and Mexico–US cross-border migration. *Proceedings of the National Academy of Sciences*, *107*(32), 14257-14262.

Fussell, E., Hunter, L. M., & Gray, C. L. (2014). Measuring the environmental dimensions of human migration: The demographer's toolkit. *Global Environmental Change*, *28*, 182-191.

Grace, K. (2017). Considering climate in studies of fertility and reproductive health in poor countries. Nature climate change, 7(7), 479.

Grace, K., Davenport, F., Funk, C., & Lerner, A. M. (2012). Child malnutrition and climate in Sub-Saharan Africa: An analysis of recent trends in Kenya. *Applied Geography*, *35*(1-2), 405-413.

Grace, K., Davenport, F., Hanson, H., Funk, C., & Shukla, S. (2015). Linking climate change and health outcomes: examining the relationship between temperature, precipitation and birth weight in Africa. *Global Environmental Change*, *35*, 125-137.

Gray, C. L. (2009). Environment, land, and rural out-migration in the southern Ecuadorian Andes. *World Development*, 37(2), 457-468.

Gray, C. L., & Mueller, V. (2012a). Natural disasters and population mobility in Bangladesh.

Proceedings of the National Academy of Sciences, *109*(16), 6000-6005.

Gray, C., & Mueller, V. (2012b). Drought and population mobility in rural Ethiopia. *World Development*, 40(1), 134-145.

Gray, C., & Wise, E. (2016). Country-specific effects of climate variability on human migration. *Climatic Change*, *135*(3-4), 555-568.

Hoddinott, J., & Kinsey, B. (2001). Child growth in the time of drought. *Oxford Bulletin of Economics and Statistics*, 63(4), 409-436.

Hunter, L. M., Luna, J. K., & Norton, R. M. (2015). Environmental dimensions of migration. *Annual Review of Sociology*, *41*, 377-397.

Jennings, J. A., & Gray, C. L. (2017). Climate and marriage in the Netherlands, 1871–1937. *Population and Environment*, 38(3), 242-260.

Jensen, R. (2000). Agricultural volatility and investments in children. *American Economic Review*, *90*(2), 399-404.

Kielland, A. (2016). The role of risk perception in child mobility decisions in West Africa, Empirical evidence from Benin. *World Development*, 83, 312-324.

Maccini, S., & Yang, D. (2009). Under the weather: Health, schooling, and economic consequences of early-life rainfall. *American Economic Review*, *99*(3), 1006-26.

Mastrorillo, M., Licker, R., Bohra-Mishra, P., Fagiolo, G., Estes, L. D., & Oppenheimer, M. (2016). The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, 39, 155-169.

Mberu, B. U. (2005). Who moves and who stays? Rural out-migration in Nigeria. *Journal of Population Research*, 22(2), 141-161.

Minnesota Population Center. (2018). *Integrated Public Use Microdata Series, International: Version 7.0* [dataset]. Minneapolis, MN: IPUMS.

Mueller, V., Gray, C., & Kosec, K. (2014). Heat stress increases long-term human migration in rural Pakistan. *Nature Climate Change*, *4*(3), 182.

Nawrotzki, R. J., Hunter, L. M., Runfola, D. M., & Riosmena, F. (2015a). Climate change as a migration driver from rural and urban Mexico. *Environmental Research Letters*, *10*(11), 114023.

Nawrotzki, R. J., Riosmena, F., Hunter, L. M., & Runfola, D. M. (2015b). Amplification or suppression: Social networks and the climate change—migration association in rural Mexico. *Global Environmental Change*, 35, 463-474.

Randell, H., & Gray, C. (2016). Climate variability and educational attainment: Evidence from rural Ethiopia. *Global Environmental Change*, 41, 111-123.

Riosmena, F., Nawrotzki, R., & Hunter, L. (2018). Climate migration at the height and end of the great Mexican emigration era. *Population and Development Review*, 44(3), 455-488.

Ruggles, S. (2014). Big microdata for population research. *Demography*, 51(1), 287-297.

Sachs, J. D. (2001). Tropical underdevelopment. Working paper #8119. National Bureau of Economic Research.

Sellers, S., & Gray, C. (2019). Climate shocks constrain human fertility in Indonesia. *World Development*, 117, 357-369.

Stark, O., & Bloom, D. E. (1985). The new economics of labor migration. *The American Economic Review*, *75*(2), 173-178.

Thiede, B., Gray, C., & Mueller, V. (2016). Climate variability and inter-provincial migration in South America, 1970–2011. *Global Environmental Change*, *41*, 228-240.

Torche, F., & Conley, D. (2016). A Pound of Flesh: The Use of Birthweight as a Measure of

Human Capital Endowment in Economics Research. *In The Oxford Handbook of Economics and Human Biology*.

Williams, N. (2009). Education, gender, and migration in the context of social change. *Social Science Research*, 38(4), 883-896.

Tables

Table 1. Descriptive statistics

	Mean	SD	Min	Max
Outcome	0.199	-	0	1
Migrant = yes				
Climate, ages -1 to 4				
Temperature	-0.730	0.609	-2.912	2.454
Precipitation	0.010	1.012	-3.073	3.102
Controls				
Age	33.99	2.91	30	39
Sex = female	0.509	-	0	1
Primary school = yes	0.614	-	0	1
Census decade				
1980-1989	0.092	-	0	1
1990-1999	0.305	-	0	1
2000-2009	0.357	-	0	1
2010-2012	0.246	-	0	1
N (weighted)		293,278,022		

Distribution of population by birth province not shown. Excludes observations in provinces with 0% or 100% migration, which are not retained in regression analysis.

Table 2. Logistic regression models of lifetime migration

	Model 1			Model 2			Model 3		
	β		(SE)	β		(SE)	β		(SE)
Climate, ages -1 to 4									
Temperature	-0.171		(0.117)	-0.143		(0.127)	-0.125		(0.102)
Temperature^2				0.010		(0.060)			
Precipitation	-0.080	**	(0.038)	-0.083	**	(0.038)	0.172	**	(0.075)
Precipitation^2				0.039		(0.045)			
Temperature X precipitation							0.294	***	(0.072)
Joint test, climate variables	6.54**			8.00†			21.74***		

†p<0.10, **p<0.05, ***p<0.01

Note: Control variables not show n. Standard errors clustered on birth province.

Table 3. Logistic regression models of lifetime migration, with climate-by-demographic group interactions

	Model 3		Model 4		Model 5	
	β	(SE)	β	(SE)	β	(SE)
Climate, ages -1 to 4						
Temperature	-0.129	(0.102)	-0.208	(0.168)	-0.018	(0.081)
Precipitation	0.173 **	(0.075)	0.017	(0.138)	0.151 †	(0.080)
Temperature X precipitation	0.294 ***	(0.072)	0.401 **	(0.203)	0.243 ***	(0.066)
Interaction terms						
Female X temperature	0.007	(0.004)				
Female X precipitation	-0.001	(0.004)				
Female X temperature X precipitation	-0.001	(0.005)				
Primary school X temperature			0.110	(0.146)		
Primary school X precipitation			0.268	(0.183)		
Primary school X temperature X precipitation			-0.129	(0.238)		
Birth density X temperature					-0.005	(0.004)
Birth density X precipitation					0.001	(0.001)
Birth density X temperature X precipitation					0.001	(0.001)
Joint test, interaction terms	3.92		9.26**		2.93	
Joint test, climate variables	35.71***		17.85***		21.29**	

†p<0.10, **p<0.05, ***p<0.01

Note: Control variables not shown. Standard errors clustered on birth province.

Table 4. Logistic regression models of lifetime migration, with climate-by-historical climate interactions

	Model 6		Model 7	
	β	(SE)	β	(SE)
Climate, ages -1 to 4				
Temperature	-0.111	(0.108)	0.183	(0.235)
Precipitation	-0.015	(0.117)	0.011	(0.224)
Temperature X precipitation	0.131	(0.143)	0.023	(0.233)
Interaction terms				
Cool + dry X temperature	0.329 **	(0.165)		
Cool + dry X precipitation	0.228	(0.215)		
Cool + dry X temperature X precipitation	0.173	(0.205)		
Hot + wet X temperature	-0.313	(0.235)		
Hot + wet X precipitation	0.332 †	(0.170)		
Hot + wet X temperature X precipitation	0.211	(0.155)		
Hot + dry X temperature	0.263	(0.215)		
Hot + dry X precipitation	0.171	(0.151)		
Hot + dry X temperature X precipitation	0.110	(0.179)		
W. + C. Africa X temperature			-0.255	(0.289)
W. + C. Africa X precipitation			0.324	(0.327)
W. + C. Africa X temperature X precipitation			0.175	(0.330)
S. America X temperature			-0.121	(0.257)
S. America X precipitation			0.041	(0.242)
S. America X temperature X precipitation			0.164	(0.243)
C. America + Carr. X temperature			-0.180	(0.309)
C. America + Carr. X precipitation			0.247	(0.240)
C. America + Carr. X temperature X precipitation			0.307	(0.256)
S.E. Asia X temperature			-0.679 †	(0.350)
S.E. Asia X precipitation			0.421	(0.283)
S.E. Asia X temperature X precipitation			0.414	(0.265)
Joint test, interaction terms	11.18		26.21**	
Joint test, climate variables	33.27***		65.04***	

†p<0.10, **p<0.05, ***p<0.01

Note: Control variables not shown. Standard errors clustered on birth province.

Table 5. Logistic regression models of lifetime migration

	Alternative climate		Alternative climate		Standard errors clustered on country		Country-specific linear time trend		Excludes education control		Ages 20-29		Ages 25-34	
	Model 8		Model 9		Model 10		Model 11		Model 12		Model 13		Model 14	
Climate, ages -1 to 4	β	(SE)	β	(SE)	β	(SE)	β	(SE)	β	(SE)	β	(SE)	β	(SE)
Temperature					-0.125	(0.127)	-0.154	(0.113)	-0.138	(0.097)	-0.072	(0.074)	-0.043	(0.078)
Precipitation					0.172 †	(0.102)	0.208 **	(0.090)	0.170 **	(0.077)	0.073	(0.094)	0.126 †	(0.076)
Temperature X precipitation					0.294 **	(0.115)	0.315 ***	(0.072)	0.290 ***	(0.077)	0.161 **	(0.075)	0.218 **	(0.088)
Climate, ages -1 to 9														
Temperature	-0.148	(0.110)												
Precipitation	0.164	(0.126)												
Temperature X precipitation	0.300	(0.228)												
Climate, ages 0 to 4														
Temperature			-0.110	(0.087)										
Precipitation			0.160 †	(0.091)										
Temperature X precipitation			0.348 ***	(0.107)										
Joint test, climate variables	2.77		21.59***		31.27***		24.99***		19.53***		13.91**		7.34†	

†p<0.10, **p<0.05, ***p<0.01

Note: Control variables not shown. Standard errors clustered on birth province.

Figures

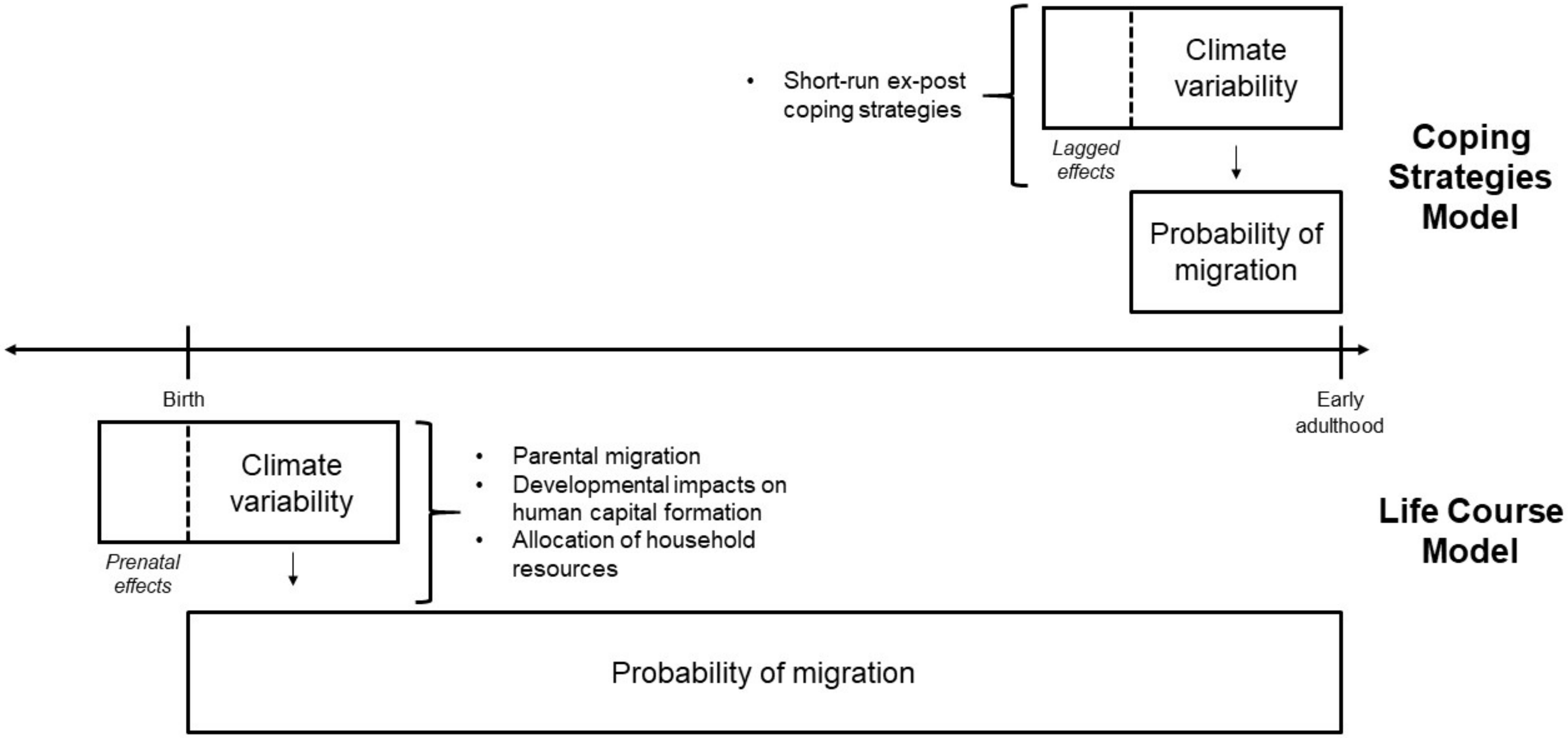

Figure 1 Conceptual framework of climate-related migration

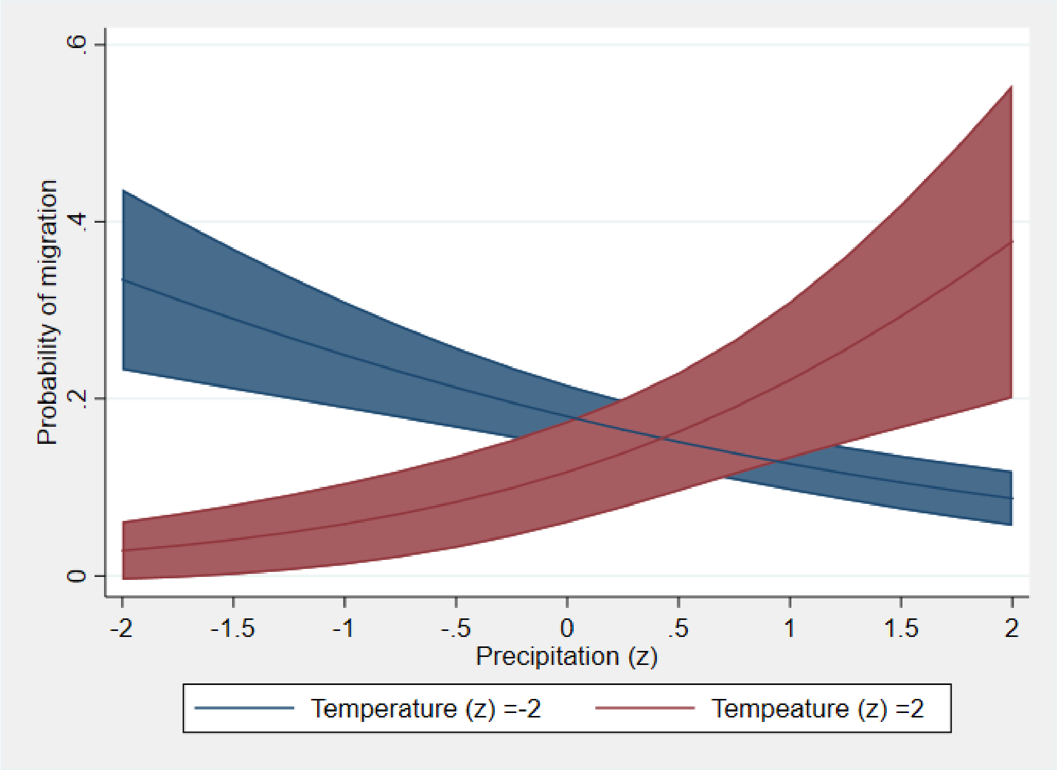

Figure 2 Predicted probability of migration by early-life precipitation and temperature (Model 3)