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Climate Variability and Inter-Provincial Migration in South America, 1970-2011

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Abstract

We examine the effect of climate variability on human migration in South America. Our analyses draw on over 21 million observations of adults aged 15-40 from 25 censuses conducted in eight South American countries. Addressing limitations associated with methodological diversity among prior studies, we apply a common analytic approach and uniform definitions of migration and climate across all countries. We estimate the effects of climate variability on migration overall and also investigate heterogeneity across sex, age, and socioeconomic groups, across countries, and across historical climate conditions. We also disaggregate migration by the rural/urban status of destination. We find that exposure to monthly temperature shocks has the most consistent effects on migration relative to monthly rainfall shocks and gradual changes in climate over multi-year periods. We also find evidence of heterogeneity across demographic groups and countries. Analyses that disaggregate migration by the rural/urban status of destination suggest that much of the climate-related inter-province migration is directed toward urban areas. Overall, our results underscore the complexity of environment-migration linkages and challenge simplistic narratives that envision a linear and monolithic migratory response to changing climates.

Keywords

Human migration; climate change; South America; vulnerability; urbanization

1. Introduction

The effects of catastrophic events (e.g., extreme drought and flooding) on migration in the developing world often draw the attention of the public and policymakers. However, human migration is also consistently linked to less visible but more pervasive forms of climate variability, such as increased temperature (Gray & Mueller, 2012; Marchiori et al., 2012;

Bohra-Mishra et al., 2014; Mueller et al., 2014). Although evidence of such effects is much more robust than it was only ten years ago, nearly all existing studies have been relatively narrow in geographic scope (for an exception see Gray & Wise, 2016). As well, diverse methodologies have been applied across these studies. As a result, the extent to which previous findings are generalizable across populations and contexts is an open question.

Our study addresses these limitations by quantifying human migration responses to climate variability using 25 rounds of census microdata from eight South American countries, and applying a common methodology and uniform definitions of migration and climate. This approach allows us to assess the extent to which climate change is affecting migration patterns across a very large geographic region—nearly an entire continent—and across multiple decades. We are also able to test for differences in climate effects according to affected individuals' sex, age, educational attainment, country of residence, and the type of destination (i.e., urban or rural). Attention to heterogeneity in climate effects is important for our understanding of behavioral responses to environmental change. Variations in response to similar changes in climate suggest systematic differences in the adaptation mechanisms that affected individuals are able or likely to use. Studying such patterns is merited since understanding the contours of how response patterns are distributed is a requisite for designing effective social protection policies vis-à-vis climate impacts. Evidence regarding the composition of climate-induced migration is also necessary to assess the likely social and economic consequences of these migration streams. Recent evidence shows that environmentally-induced migration in developing countries can bear negative consequences on the wages of residents in the receiving communities (Strobl & Valfort, 2015; Maystadt et al., forthcoming). Yet exactly who these migrants will affect depends on where they go and what skillset they bring to the destination, a question that has motivated large bodies of research on migration in general (Aydemir & Borjas 1994; Sjaastad, 1962; Todaro 1969). We begin to address this issue here by considering the characteristics of environmentally-induced migrants and the type of destinations they are moving to.

The remainder of the paper proceeds as follows. In the next section, we review existing evidence regarding climate effects on migration and identify key substantive and methodological limits to existing knowledge. We then outline our research objectives, data, and methodology. Next, we present our estimates of overall climate effects on inter-province migration, and test for heterogeneity across demographic groups. We then present estimates of climate effects on inter-province migration by the rural/urban status of destination using a subset of the data that includes information on destinations. As a final set of analyses, we assess whether the effects of climate variability on inter-province migration vary by country and historical climate conditions. We conclude by discussing our results and identifying implications for future research on this topic.

2. Climate and migration

As consensus formed around evidence of global anthropogenic climate change, concerns about climate-related migration—and so-called climate refugees—became increasingly widespread (Myers, 1997). While human migration continues to be one of the main expected social impacts of climate change, a more nuanced and evidence-based perspective has largely replaced predictions that climate change will uniformly cause large scale (and international) population movements (Black et al., 2011; Fussell et al., 2014; Hunter et al., 2015). The fundamental premise that climatic changes affect human migration patterns has largely not been disputed. The existence of such relationships has been shown across many studies (Bohra-Mishra et al., 2014; Gray & Mueller, 2012a; Hunter et al., 2013; Hunter et al., 2015; Mueller et al., 2014; Nawrotzki et al., 2015), and is consistent with prior work linking climate anomalies to short-term welfare losses in many developing countries (Paxson, 1992; Jalan & Ravallion, 1999; Dercon, 2004; Kazianga & Udry, 2006). However, recent research has underlined a number of complexities and contingencies with respect to climate effects on migration. These include differences according to the type of climatic change, the demographic characteristics and socioeconomic status of affected groups, and the distance and direction of migration.

Multiple types of climatic variability have been shown to affect migration. Key distinctions among climate measures include that between temperature and rainfall, and according to whether the measure captures short-term shocks or anomalous conditions over longer periods of time (e.g., multiple years). Some prior studies have found significant rainfall effects (Gray & Mueller, 2012a; Henry et al., 2004; Hunter et al., 2013), but recent findings suggest that temperature anomalies may also have consistent independent effects on migration (Bohra-Mishra et al., 2014; Gray & Wise, 2016; Mueller et al., 2014). Precipitation and temperature can plausibly affect mobility through a number of pathways or mechanisms, such as damaging housing and other physical infrastructure (De Waard et al., 2016; Fussell & Harris, 2014; Gray & Mueller, 2012b), causing physiological changes that shape household economic outcomes (e.g., lower productivity due to heat stress) (Graff Zivin et al. 2015; Hsiang, 2010), and through sector- or economy-wide impacts (Burke et al. 2015). Among this set of possible pathways, climate effects on migration have been most commonly hypothesized to occur via an agricultural mechanism in areas relying on subsistence agriculture (Kubik & Maurel, 2016; Nawrotzki & Bakhtsiyarava, 2016). In such a context, climate effects have been framed as first affecting agricultural production and then, through related effects on livelihoods, changing migration behavior (Gray & Mueller, 2012b; Mueller et al., 2014).

To this end, evidence regarding climate effects on agricultural production yields findings generally consistent with the migration literature. For example, evidence that abnormally high or low temperatures have adverse effects on agricultural production (Lobell & Asner, 2003; Lobell & Field, 2007; Peng et al., 2004) corresponds with findings showing strong temperature-migration links (Bohra-Mishra et al., 2014; Mueller et al., 2014). However, careful attention to the magnitude and direction of temperature anomalies appears warranted. As just one example, consider research that suggests that temperature effects on crop yields may be non-linear. In such cases, adverse climate effects on agriculture may only occur beyond certain temperature thresholds, with positive effects occurring as temperatures increase up to that critical value (Schlenker & Roberts, 2009). Likewise, other research has noted that abnormally low temperatures may also adversely affect agricultural production (Almaraz et al., 2008), suggesting the possibility of thresholds at both ends of an optimal temperature range for a given crop or crop system (Bardsley & Hugo, 2010; Bohra-Mishra et al., 2014). The complexity evident in this and other examples provide little in the way of clear hypotheses about the direction of climate effects on human mobility, since the effect of warming and cooling on livelihoods (and thus migration) may be contingent upon the magnitude of the change and the critical thresholds present in particular agro-ecological systems affected by climate change.

In addition to the distinction between temperature and rainfall effects, studies have shown significant climate effects on migration using measures of shocks at different time scales. Examples in the existing literature range from season-specific measures of climatic conditions (Mueller et al., 2014) to multi-year averages (Bohra-Mishra et al., 2014). The choice of measures has substantive implication since the behavioral responses to short-term shocks and slow-onset changes may be quite different. Responses to rapid-onset, short-duration shocks are largely framed in terms of *ex post* risk reduction: migration is a part of household strategies to mitigate the effects of adverse shocks on livelihoods, or to take advantage of a positive shock (Kleemans, 2014). Gradual changes in climatic conditions may also elicit behavioral changes—including migration— but the linkages are less clear since they may reflect differences in perceptions of change, ability to respond, and the availability of other *in situ* responses (Burke and Emerick, forthcoming; Nawrotzki & DeWaard, 2016).

The potential for heterogeneous outcomes according to individuals' ability to respond is consistent with expectations that climate-migration relationships are also shaped by social, economic, and political conditions in affected areas (Black et al., 2011; Hunter et al., 2015). Prior studies show that migratory responses to climatic variability differ according to demographic characteristics, socioeconomic status, and, in some cases, community-level variables such as migration networks (Nawrotzki et al., 2015). These characteristics are often viewed as correlates to vulnerability, determining both the severity of climate effects (e.g., on food security) and the set of possible responses to these changes. For example, in contexts with sex-segregated labor markets, male household members may be more likely to undertake labor-related migration in response to environmental changes (Gray, 2010). On the other hand, female-headed households may be in precarious economic situations that increase their likelihood of migration (Gray and Mueller, 2012b). Marriage-related migration is also common among women in some contexts. To the extent that marriage has economic implications for the affected households, one would expect these disproportionately female migration streams to be uniquely affected by weather shocks (Findley, 1994; Gray and Mueller, 2012a).

Beyond gender, the role of baseline (i.e., pre-shock) socioeconomic status has been posited to affect both households' need to move in response to shock, as well as their ability to do so (Kubik & Maurel, 2016). On the one hand, **i**ndividuals with limited resources commonly mitigate income risks through labor diversification, which often involves geographic mobility (Kochar, 1999; Rose, 2001; Jayachandran, 2006; Dillon et al., 2010). In other cases, however, climatic changes may have an immobilizing effect in which the change in environment negatively affects household resources needed to move (Black et al., 2011; Warner & Afifi, 2014). Such trapped population dynamics run contrary to arguments that conflate poverty with vulnerability to displacement. Other dimensions of socioeconomic status may also affect environment-migration dynamics. For example, education may not only moderate climate effects on migration by enabling *in situ* responses, but also by affecting individuals' baseline livelihoods (determining exposure to climatic change) and employment prospects in potential destinations (Deressa et al., 2009; Todaro, 1969).

Contextual factors may also moderate or mediate the relationship between climate and migration. Affected individuals are embedded in unique regional and national settings. These structural conditions affect the extent to which a given climatic change has a tangible effect on individuals, and shape individuals' ability and propensity to move. For example, prior research has demonstrated that the macroeconomic effects of temperature shocks have historically been limited to poor countries, and in some cases operate through a political mechanism (Dell et al., 2012). Other macroeconomic and political conditions—such as those shaping the availability of resources for climate mitigation programs and migration laws, for example,—may also affect climate-related migration (Adger, 2006; Kim & Wolinsky-Nahmias, 2014; Reuveny, 2007). Of course, environmental context also matters. Climate impacts are expected to be disproportionately concentrated in certain regions and agro-ecological systems (e.g., coastal communities, areas dependent upon rainfed agriculture), resulting in substantial spatial variation in climate-related risks (Jones & Thorton, 2003; Piontek et al., 2014; Thorton et al., 2009; Wheeler & von Braun, 2013). How these contextual factors interact to affect migration in a given particular setting is largely an empirical question, but the implication is clear: Factors above and beyond household characteristics may shape the effect of climate on migration.

The potential for both displacing and immobilizing effects underlines the somewhat ambiguous expectations regarding the direction of climate effects on migration. They also suggest the need to account for the type of move in question. For example, wealth—including so-called natural capital—may be particularly important for moves over longer distances (e.g., inter-region, inter-national) (Gray, 2009). This point is well established in the broader migration literature, which has shown that the economic and psychic costs of migration generally increase with distance (Sjaastad, 1962). Local mobility may therefore be relatively more available as a coping mechanism to the poor, leading to less selective climate effects on local moves than longer-distance migration. Perhaps unsurprisingly, then, rates of local movement have been shown to be more responsive to climatic variability than long-distance and international moves (Findley, 1994; Gray and Mueller, 2012b). That said, we also underline the possibility that in some cases longer-distance migration may be a more common, and indeed necessary response to environmental change. Local migration may not be an effective response to income risks driven by environmental changes that are common to a region (i.e., covariate shocks), making longer-distance migration the more effective risk-reduction strategy in these instances (Rosenzweig & Stark, 1989).

Climate effects on migration may also diverge with respect to the type of destination. While one could describe destinations according to a number of variables, the difference between rural and urban destinations is particularly salient. Evidence that climatic changes drive migration to rural areas may suggest that affected persons are adapting via simple geographic diversification (e.g., shifts from on-farm labor to agricultural wage labor in another region), but moves to urban areas would suggest both geographic and livelihood diversification (e.g., shifts out of agriculture entirely). The difference between such strategies has clear implications for integration and economic outcomes among migrants (including their ability to remit resources back to their origin), as well as for the impacts in receiving communities (Strobl & Valfort, 2015; Maystadt et al., forthcoming). Overall then, the existing literature on this topic has become increasingly sophisticated and robust in recent years, but existing results paint a complicated picture when considered as a whole. We attempt to better-understand the extent to which substantive or methodological considerations underpin this complexity in the current study.

3. Research objectives

Diversity among existing findings regarding whether and how climatic conditions affect migration reflects institutional and agro-ecological differences across the contexts in which prior studies have taken place. However, prior research has also employed different, and in most cases non-comparable, data and methods. Given that estimates of climate effects on migration are sensitive to how variability in conditions is conceptualized and measured (Auffhammer et al., 2013; Hsiang, 2016), it is difficult to distinguish between the substantive and methodological causes of observed diversity of existing findings. This state of existing evidence has limited researchers' ability to make generalizable claims about climate-induced migration, and to develop a clear understanding of why climate effects vary across contexts.

The fundamental goal of this paper is to assess the effect of climate variability on human migration patterns across a large multi-national region, and thereby provide more generalizable estimates than most existing studies. In advancing this objective, we address a number of specific questions and objectives. First, we ask how climatic variability affects the likelihood of inter-province migration in South America. Here, we focus on two aspects of climate variability that have received little attention to date. For one, we consider changes in climatic conditions measured over multi-year periods, which is intended to capture the effect of gradual changes in conditions. Understanding whether migration is employed as a part of strategies to adapt to slow-onset, long-term changes can add to emerging evidence regarding adaptation to long-term environmental change (versus short-term fluctuations) (Burke & Emerick, forthcoming; Koubi et al., 2016; Seo & Mendelsohn, 2008). Additionally, we examine the effect of exposure to repeated or prolonged climatic extremes. This avenue is of particular interest from a development standpoint concerned with understanding how to design resilience-enhancing social protection programs and lift households out of poverty traps (Barrett & Constas, 2014; Carter & Barrett, 2006). For both forms of climate variability, we consider 5- and 10-year periods to assess whether responses differ according to periodization. While we find some differences in the precision of our estimates according to the time frame, the main results are largely similar across models.

We proceed using the two 5-year climate measures from this initial analysis since they correspond directly with the migration interval. Using these measures, we examine whether climate effects on inter-province migration vary by individuals' age, sex, and primary school attainment (our second objective). Third, we ask whether climate affects inter-province migration to urban areas more than to rural destinations. The type of places that environmentally-induced migrants are moving to has implications for their personal outcomes (e.g., their likelihood of employment, wages; Harris & Todaro, 1970) and, depending on the size and composition of such migration streams, for the impacts in receiving communities (Strobl & Valfort, 2015; Maystadt et al., forthcoming). Evidence linking climate-induced population movements to urban growth and urbanization would unsettle assumptions that these are growth-driven processes, as a number of other studies from the African context have recently suggested (Barrios et al., 2006; Henderson et al, 2015; Poelhekke, 2011). Fourth, we test for differences in climate effects across countries. Although we are unable to identify specific country characteristics that moderate the effect of climate variability on migration, these tests provide a set of evidence as to whether national context—social, economic, and environmental—shapes the impacts of and responses to climatic variability. Fifth and finally, we assess whether the effects of climatic variability vary according to historical climate, with particular focus on average precipitation and temperature levels.

South America represents an appropriate region for investigating the influence of climatic variation on population mobility. For one, agriculture remains a major source of livelihood across the continent, particularly among vulnerable low-skilled workers and poor households (Vergara et al., 2014). As such, considerable shares of the population are directly exposed to the effects of climatic variability. Second, the historical precedence of internal and international migration in the region suggests that migration is commonly used as a means of adapting to changing material conditions (Cerrutti & Parrado, 2015). These observations suggest that migration is also likely to be used as a response to climate change and its second-order economic effects. Third, vulnerability and conditions for adaptation are heterogeneous across the continent, as evidenced by variation in overall levels of development, inequality, and the existence of social protection programs. Such diversity provides a unique environment for examining cross-national differences in climate effects on migration, the existence of which would suggest that macroeconomic and other structural factors may moderate adaptation to climate variability (Dell et al., 2012; Dell et al., 2014). Finally, as we describe in the next section, the availability of integrated data from across much of the continent and over many time periods also makes South America an advantageous context for studying climate effects on migration on a regional level.

4. Data

We use two secondary data sources for our analysis. First, we extracted multiple rounds of census data from the Integrated Public Use Microdata Series-International (IPUMS-International) (Minnesota Population Center, 2015). Using these data, we create a dataset that includes indicators of migration status, individual characteristics (age, sex, and primary school attainment) and location on census day and five years prior. All observations in our analytic sample include an indicator variable denoting whether an individual's province (or equivalent) of residence at the time of the census is different than their province of residence five years prior. This variable serves as our primary outcome of interest.

Our primary sample is drawn from eight countries in South America. Within the region, our data are limited to countries for which two or more censuses had collected information on individuals' 5-year migration status and their location of residence five years prior to the census at the first-order subnational level or below. We restrict our data to countries with two or more years of census data in order to estimate models with province-level fixed effects. These fixed effects reduce the potential of omitted variable bias driving the estimated coefficients on temperature and precipitation. This step is particularly important given limitations in data availability, which restrict us from including geographic variables that would be correlated both with climate and migration. We further restrict our sample to adults aged 20 to 45 at the time of the census, which corresponds with ages 15 to 40 at the beginning of the 5-year period for which we measure migration. Preliminary estimates of age-specific migration rates showed this age group to have the highest likelihood of mobility.

After these restrictions, our primary sample includes 21,344,711 observations from the following countries and census years: Argentina (1970, 1980, 2001), Bolivia (1976, 1992, 2001), Brazil (1991, 2000, 2010), Chile (1982, 1992, 2002), Colombia (1985, 1993, 2005), Ecuador (1990, 2001, 2010), Paraguay (1982, 1992, and 2002), and Uruguay (1975, 1985, 1996, 2011). Our analysis of inter-province migration by type of destination also defines migration according to whether an individual's province of residence on census day is different than their province of residence five years prior. Among migrants, however, this measure distinguishes according to whether individuals' census-day residence (i.e., their destination) is in a rural or urban area. The sample for this part of the analysis is restricted to the subset of the data for which information on destination type is available from two or more censuses for a given country. Since only three censuses in our original sample lack data on the rural/urban status of destination, our sample includes a total of 21,046,951 valid observations from eight countries, equivalent to 98.6% of our primary sample.

Second, we extracted monthly rainfall and temperature data for 1951-2013 from the Climatic Research Unit's (CRU) time series version 3.21 (Harris et al., 2014) at the province level using time-stable boundaries constructed by IPUMS. CRU is a global dataset of monthly weather conditions. These data are constructed at 0.5° resolution and are based on interpolations of data from over 4,000 weather stations. Using the CRU data, we constructed six sets of variables to measure exposure to climate variability at the province level. We extracted the data as spatial means to construct these province-level measures (Gray & Wise, 2016). The first two sets of variables represent temperature and rainfall averages over the 5- and 10-year periods from the month of the census backward, standardized to all other 5- and 10-year consecutive periods in the climate history of that province. We define these 5- and 10-year periods, respectively, as the 60 and 120 months from the month that the census day occurred in. As such, the 5-year period corresponds directly to the interval over which migration is measured.

A related pair of variables represents the standardized temperature and rainfall averages during the sixth through tenth years prior to each census, which allows us to capture potential lagged migratory responses to climate variation. Three additional sets of variables indicate the number of monthly temperature and rainfall z-scores (standardized to the full province history) exceeding two standard deviations (a) above and (b) below the mean during the 5- and 10-year period prior to the census, as well as the sixth through tenth years before each census. This two standard deviation criterion has been used in other climate and social science research to identify exceptional or severe temperature or precipitation levels, which contrast with the more typical variations that would be captured by a one standard deviation threshold (Hansen et al., 2012; Hunter et al., 2013; Rose, 2001; Twardosz & Kossowska-Cezak, 2015). Among these indicators of monthly shocks, however, we redefine negative rainfall shocks as any month when cumulative rainfall was less than 1 mm. This step is necessary because the z = (-)2 rainfall threshold falls below zero for provinces with low and/or highly variable historical rainfall patterns, making it an unobservable outcome for those places.

By merging the province-year climate dataset to the harmonized census data from IPUMS we are able to measure how exposure to climate variability affects the likelihood of inter-province migration, and determine if these relationships vary according to whether migrants moved to rural or urban destinations. Comparing results using different frames of reference allows for an explicit test of whether slow changes in climate affect mobility decisions. Contrasting findings produced from measures of changes in multi-year averages to cumulative exposure to extremes allows us to further assess whether migration is driven by gradual variations in climate or repeated or prolonged exposure to shocks in the medium run.

5. Empirical Strategy

We estimate a series of logistic regression models applied to our dataset to measure individual migration responses to climate variability. We control for exogenous individual characteristics (age, sex, and primary school attainment) and climate variability by including a set of variables $X_{i(t)p,t}$. We also include fixed effects for δ_p origin province and δ_d census-decade, with decades defined as ten year intervals starting from 1970. We control for common temporal changes on this ten-year basis since few censuses in our sample occurred on the same year, but our data include observations from two or more decades for each country. Since our analysis relies on repeated cross-sectional data, we adopt the convention of using t to reflect survey year and $i(t)$ to convey the observation is taken from individual i from survey year t below:

$$\log\left(\frac{\pi_{mi(t)p,t}}{\pi_{ni(t)p,t}}\right)=\alpha+\delta_d+\delta_p+\beta X_{i(t)p,t} \qquad (1)$$

Our primary analysis focuses on inter-province migration. Since our dependent variable is binary, we assume a logit specification for the model, where $\pi_{mi(t)p,t}$ signifies the odds of moving and $\pi_{ni(t)p,t}$ the odds of not moving for individual $i(t)$ from origin province p and in survey year t. We weight observations by the inverse probability of selection and cluster standard errors at the level of the origin province to allow for correlation in unobserved residential factors that influence migration outcomes. We take a similar approach when analyzing inter-province migration by the rural/urban status of destination, but given the categorical nature of this variable we use a multinomial specification in which m in equation 1 indicates migration to a specific type of destination (i.e., rural or urban).

Our first set of analyses focuses on estimating the respective overall effects of 5- and 10-year temperature and rainfall conditions and cumulative exposure to monthly shocks over those same periods. We also test for the presence of lagged effects by modeling migration as a function of rainfall during the sixth through tenth year prior to each census. Next, we focus on the effects of 5-year climatic conditions and cumulative exposure to monthly shocks over the 5-year periods from the time of each census, which correspond directly to the period for which individuals were at risk of migration. A focus on this time period is particularly appropriate for the analyses of heterogeneity, where a key question is whether the immediate responses to shocks differ systematically across groups and places. Using these two sets of measures, we examine whether inter-province migration is a more common adaptation behavior among particular subpopulations in each country by estimating a series of models that interact each climate variable with individuals' age, sex, and primary education attainment. The coefficient estimates of these interaction terms can be additively combined to estimate the net climate effect on the log odds of migration for a group of interest. To aid interpretation, throughout the text, we also present the corresponding net odds ratios (ORs) from these interaction models for groups of interest. We test for significant climate effects on migration for each group and conduct post-estimation tests of the joint interaction effects.

Next, we model climate effects on inter-province migration by the rural/urban status of destination using a multinomial framework. We then assess whether the effect of climate variability on inter-province migration varies across countries by estimating models that allow for interactions between country fixed-effects and our climate measures. As with our analyses of micro-level heterogeneity, we estimate climate effects for each group and evaluate the joint effect of all climate-country interactions. Finally, we estimate models that interact our 5-year climate measures with indicators of historical temperature and precipitation levels for each province.

6. Results

6.1. Descriptive statistics

We begin by describing key variables in our analysis (Table 1). Migration and climatic conditions are the primary variables of interest. The 5-year inter-province migration rate is 5.1 per 100. Our supplementary analyses also consider inter-province migration by the rural/urban status of destination. Less than one-fifth of inter-province moves for which we have information about the type of destination went to rural areas (rate = 0.9 per 100), with a large majority moving to urban areas (rate = 4.0 per 100).

Our summary statistics also reveal considerable variation in climatic conditions. The observed temperature and rainfall conditions over the years prior to each census in our data range from exceptionally low to exceptionally high relative to conditions in the historical record for each province. We also observe considerable variation in the observed number of monthly shocks during the 5- and 10-year periods prior to each census, although the ranges vary by the particular measure in question. For example, across all 5-year periods just prior to the censuses in our data, the number of positive monthly temperature shocks ranged from 0 to 15, while the number of negative temperature shocks ranged only from 0 to 7. The range of negative rainfall shocks over all 5-year periods prior to the censuses in our data is much higher (36), which in part reflects our definition of negative rainfall shocks as months with less than 1 mm of rainfall (regardless of historical climate).

Although we focus on deviations from province-specific historical conditions, understanding the range of actual climatic conditions aids interpretation. For example, the average historical reference points for the 5-year measures were 19.6°C and 7,015.8 mm for temperature and rainfall, respectively. Of course, these averages across the 139 province-level units in our analysis mask considerable variation in average conditions. As just one example, consider that the average historical temperature ranged from 4.9°C to 27.6 °C. This and other sources of variation have substantive implications for our analyses, since they suggest the possibility that both positive and negative deviations from average may have consequences that affect migration patterns.

6.2. Overall climate effects

Our first series of models estimate the effect of changes in multi-year climatic conditions and cumulative exposure to monthly shocks, considering 5- and 10-year periods and measures of climate variation for the sixth through tenth year prior to each census (Table 2). For reference, we present coefficient estimates from a baseline model that includes only control variables and decade and province fixed effects (Specification A). The results of the joint Wald test of climate variables shown for each subsequent model indicate whether the addition of the given climate variables offers an improved fit vis-à-vis this baseline.

The measures of multi-year climatic conditions represent the deviation of average temperature and total rainfall during that period from the long-term averages for each province, expressed in terms of province-specific z-scores. With respect to multi-year climate averages, we find that over 5-year periods, higher temperatures have a marginally significant ($p<0.10$) positive effect on the likelihood of inter-province migration (Specification B). The coefficient estimate of 0.061 (OR=1.063) is only statistically significant at marginal levels, with the estimate indicating that the odds of inter-province migration increases 6.3% for each standard deviation increase in the 5-year average temperature. Consistent with prior findings that temperature has stronger effects on migration than rainfall, the effect of changes in 5-year average rainfall is not significantly different from zero. Our estimates indicate no statistically significant associations between climate and inter-province migration when climate deviations are measured over a 10-year period (Specification C) or for years 6-10 prior to each census (Specification D). However, estimates show a significant positive association between changes in temperature during years 1-5 prior to each census and migration after controlling for climatic conditions during years 6-10 prior to the census (Specification E).

We also consider the effect of cumulative exposure to monthly shocks, which we measure with four variables that indicate the number of months that rainfall and temperature exceeded two standard deviations above or below the long-term average in a given period. Recall here that our measure of negative rainfall shocks simply captures months when total rainfall did not exceed 1 mm. A value of one for any of these variables represents a single one-off shock, while a value greater than one could indicate either repeated shocks throughout the period or a prolonged, multi-month period of extreme climatic conditions.

We find that both positive and negative temperature shocks have significant positive effects on the likelihood of inter-province migration when measured over the five years prior to each census (Specification F). For every additional month that temperatures were more than two standard deviations above the long-term average, the odds of inter-province migration increased by 3.4%. The effects were somewhat stronger for negative temperature shocks—which are less common in our data than positive shocks—with an 8.2% increase in migration odds for every month of exposure. These findings are consistent with evidence of non-linear climate effects (Burke et al., 2015). While prior research has tended to focus on the thresholds apparent at high temperatures, our findings also provide evidence of adverse effects at abnormally low temperatures. The implication is that deviations outside of an optimal temperature range (whether positive or negative) may disrupt local economies, with an apparent displacing effect. This result holds true whether temperature shocks are measured for 5- or 10-year periods (Specifications F and G, respectively). However, additional analyses show that temperature shocks during the sixth through tenth year prior to each census have non-significant effects on migration (Specification H), and that the estimated effects of shocks during years 1-5 before each census retain their significance when controlling for conditions during years 6-10 (Specification I). Together, these results indicate that temperatures during the five-year migration period, rather than before it, are most important for migration decisions as measured here.

Counts of positive rainfall shocks have a non-significant effect on migration when measured over the five years just prior to each census (Specification F), but have statistically significant, negative effects on migration when measured over 10-year periods (Specification G) and for years 6-10 prior to each census (Specification H). This result suggests that higher-than-average rainfall, and presumably good agricultural conditions, reduces pressures for out-migration through a lagged effect. Considered in the context of the estimated temperatures effects described above, our results suggest that adverse climatic conditions—temperatures outside of optimal levels—promote out-migration from affected areas. In contrast, exposure to higher-than-average rainfall—which in the absence of flooding may have positive effects (e.g., via increased crop production)—reduces migration, likely by lowering risk and other incentives for moving. Together, these findings are consistent with narratives that suggest out-migration is associated with adverse environmental conditions in the origin. That said, we also acknowledge the possibility that declines in migration associated with positive rainfall shocks represent an immobilization effect associated with flooding, which together with drought have been identified as key threats in the region (Dilley et al. 2005).

6.3. Between-group heterogeneity

We next assess the extent to which the effects of our 5-year climate measures vary across different demographic groups (Table 3). We proceed with these additional analyses using the 5-year measures that directly correspond with the interval used for our migration outcome, and for which our overall estimates suggest there are robust temperature effects. Here, we consider variation in climate effects by age, sex, and education, with the latter indicated by whether or not the individual completed primary school. We begin by interacting age with the standardized measure of 5-year temperature and rainfall conditions (Specification A).

Our results indicate that high rainfall diminishes the likelihood of migration at younger ages within our age range, but this negative effect is suppressed as respondents' age increases. For example, point estimates of rainfall effects range from as large (in absolute terms) as a 7.3% decline in migration odds per standard deviation increase in rainfall among those aged 20 at the time of the census (OR=0.932, β= -0.070, p=0.032) to statistically zero (OR=1.012, β=0.012, p=0.770) among those aged 45 at the time of the census (the upper end of our age range). Again assuming that increased rainfall is associated with improved agricultural conditions (in the absence of flooding), this finding suggests a dynamic whereby improved conditions increase demand for labor within households, with persons in the most active age affected most. For example, families might be less inclined to send their child to migrate under periods of high rainfall because they are less likely to need the income (Bandara et al. 2015; Beegle et al. 2006). The interaction between age and 5-year temperature averages are non-significant.

Considering the models that interact age with the number of monthly shocks per 5-year period (Specification B), we find that the effects of negative temperature shocks are moderated with age, but differences are only significant at marginal levels. Other climate shocks do not vary significantly with age.

We also examine whether climate effects vary by sex. Interacting sex with the 5-year rainfall and temperature averages reveals significant differences in temperature effects between men and women (Specification C). Higher-than-average-temperatures over 5-year periods increase the likelihood of inter-province migration among women only (OR=1.077). The effects among men are non-significant, as are the effects of the 5-year average rainfall measure among both men and women. Despite common assumptions—and evidence from some contexts (Halliday 2006)— that male labor migration is most responsive to shocks than migration among women, there is also evidence that female migrants are sometimes more likely to act in an insurance role (Rosenzwig & Stark, 1989; de la Briere et al., 2002). This finding may also reflect the fact that, in the region, migration among women related to livelihood diversification became common in only the latter parts of our study period (Cerrutti, 2009). If patterns of migration among men are relatively entrenched, then migration among women may be viewed as more flexible and thus disproportionately sensitive to even gradual changes in conditions. While speculative, this interpretation is consistent with research that has documented gender differences in migrant networks across the Americas, where men are more likely to be involved in dense, mature migrant networks than women (Hagan 1998).

With respect to the effect of exposure to monthly shocks (Specification D), positive and negative temperature shocks have positive effects for both men (OR=1.333, OR=1.096, respectively) and women (OR=1.035, OR=1.068, respectively). These estimates are consistent with prior models with respect to the effects of temperature versus rainfall shocks. Interaction terms indicate that the effect of negative temperature shocks is smaller in magnitude, but still positive, among women than men ($p<0.01$).

The final individual-level source of heterogeneity that we consider is education, which may also be interpreted as a rough proxy of socioeconomic status. We consider primary school completion because all adults in our analytic sample were beyond the typical primary school age at the beginning of the 5-year period used to measure migration and climate. Our first analysis considers the interaction between education and 5-year rainfall and temperature averages (Specification E). We find positive temperature effects (OR=1.104), but only among individuals who did not complete primary school. The effects of temperature are non-significant among persons who completed primary school, as are the effects of multi-year rainfall conditions for both groups. With respect to the effects of rainfall and temperature shocks measured at the monthly time scale (Specification F), we find consistent positive effects of positive and negative temperature anomalies among both those who did and did not complete primary school, with nonsignificant interaction terms. However, post-estimation tests reveal a significant joint effect of the education-climate interaction terms in this model. Overall, these results suggest a dynamic whereby those with low education (and lower socioeconomic status) are more likely to be displaced by gradual climatic changes than those who completed primary school, with exposure to anomalous temperatures driving these moves. In contrast, temperature shocks have significant effects on inter-province migration for all groups. A similar pattern was observed with respect to age- and gender-based differences, which were apparent in the effects of gradual changes over 5-year periods but not the effects of monthly shocks.

6.4. Climate effects on inter-province migration by destination type

The consequences of migration for both the individual migrant and the affected population as a whole may in part be contingent upon whether migrants are moving to rural or urban areas. To assess the extent to which climate-induced migration may be driving individuals disproportionately to rural or urban areas, we estimate multinomial logistic regression models of inter-province migration by the rural/urban status of destination (Table 4). Since the rural/urban status of residence is only available for a subset of the population, the estimates from these two models are not directly comparable to our prior analyses. We begin by examining the effect of period rainfall and temperature averages (Specification A). None of the estimates meet the standard threshold for statistical significance, and the negative effect of temperature on the likelihood of inter-province migration to rural destinations is the only estimate that is significant at a marginal level. The coefficient estimate indicates a negative temperature effect (relative risk ratio, RRR=0.932) on inter-province migration to rural areas, which may reflect a correlation between adverse conditions in the province of residence and those in surrounding provinces where individuals may be most likely to migrate. That such conditions would reduce moves to rural destinations—where climate effects on agriculture would be most concentrated—is consistent with proposed agricultural mechanisms.

When estimating the effect of monthly rainfall and temperature shocks (Specification B), we find that the positive effect of positive and negative temperature shocks observed in prior models is present with respect to inter-province moves to urban areas. Each month of exposure to negative temperature shocks is associated with a 9.9% increase in the odds of inter-province moves to urban destinations, with a corresponding positive effect of an approximately 3.6% for each month of exposure to positive temperature shocks. The observed climate effects on migration to urban areas may be of particular interest to demographers and policymakers concerned with urbanization, and the link between this process and global climate change. In line with recent evidence from the African context, our results suggest a potentially important climate-urbanization link (Barrios et al. 2006; Henderson et al. 2015; Poelhekke 2011). However, we underline the suggestive nature of our findings since we are not able to distinguish between rural-to-urban and urban-to-urban migrants in our data.

Climate effects on inter-province moves to rural areas are somewhat different. Our estimates suggest a negative (RRR=0.979), but marginally significant association between positive temperature shocks and inter-province moves to rural destinations. In line with the estimates of moves to urban areas, we find a positive and statistically significant effect of negative temperature shocks (RRR=1.050) on inter-province moves to rural destinations. Climate-related migration is not exclusively directed toward urban areas. This finding raises a number of important issues for future research to consider, including understanding whether the characteristics of rural- and urban-bound migrants are systematically different.

6.5. Between-country heterogeneity

As one way of examining whether climate effects on migration are shaped by the institutional or agro-ecological context in which they occur, we also analyze between-country differences in climate effects on inter-province migration (Table 5). Indeed, the considerable diversity in terms of agroecological conditions, reliance on agriculture, and wealth among the countries in South America is a key motivation for the geographic focus of this study. For example, across the geographically wide and topographically diverse area we consider here, the Food and Agricultural Organization (FAO) has identified at least ten major farming systems (Dixon et al. 2001). Also consider the diversity of income levels. Per capital gross domestic product (GDP, reported in 2005 U.S. dollars) in 2014 was $9,854 in Chile, $8,017 in Uruguay, $7,664 in Argentina, $5,881 in Brazil, $4,658 in Colombia, $3,809 in Ecuador, $2,094 in Paraguay, and $1,410 in Bolivia (World Bank 2016). In general, these income figures are inversely correlated with the shares of the population working in agriculture, where exposure to the effects of climatic change is expected to be greatest. For example, the share of total employment in agriculture is highest in the lowest income countries, such as Ecuador (29%), Paraguay (30%), and Bolivia (32%) and lowest in the region's wealthiest countries of Chile (13%), Uruguay (11%), and Argentina (1%) (World Bank 2016). Although we cannot identify the specific macro-level factors that moderate climate effects on migration in the current analysis, we expect the presence, direction, and magnitude of these effects to vary across the diverse contexts within our sample, as other multi-country studies have found (Gray & Wise, 2016; Neumann & Hermans, 2015).

We present the results in Table 5, which shows the net coefficient estimates of the climate variables of interest for each country. With respect to the 5-year rainfall and temperature averages, our results reveal two key patterns. First, changes in 5-year rainfall averages have little effect across the region: rainfall has a significant effect only in Columbia, where higher-than-average rainfall is associated with decreased likelihood of migration (OR=0.764). The effect of multi-year rainfall levels is non-significant in all other countries.

Second, the effects of changes in 5-year temperature averages are more widespread, but the direction, magnitude, and degree of confidence around these estimates vary considerably. The effects of multi-year temperature conditions are statistically significant at conventional levels in three of the eight countries. In one of those countries—Bolivia—the effect is negative (OR=0.847), while the effect is positive in the other two countries—Brazil and Uruguay. However, the magnitude of the effect varies considerably between those two countries. The estimated odds ratio for Uruguay (OR=2.446) is more than twice than that estimated for Brazil (OR=1.122). We also find a positive temperature effect in Chile (OR=1.364), but this estimate is only marginally significant ($p<0.10$). Post-estimation tests show that the joint effect of the country-specific interaction terms is statistically significant ($p<0.01$).

We next turn to our estimates of how exposure to monthly rainfall and temperature shocks affect the likelihood of inter-province migration across different counties. Our results indicate positive temperature effects in many countries, with exposure to anomalous temperatures increasing migration in all cases were there are non-zero effects. However, the magnitude and statistical significance of these estimates vary considerably across countries, as does the sensitivity of migration patterns to positive or negative temperature shocks. For example, exposure to months with abnormally higher temperatures is associated with statistically significant increases in inter-province migration odds in Argentina (OR=1.354) and Uruguay (OR=1.909), but negative temperature shocks did not have significant effects in either of these countries. In contrast, negative temperature shocks have positive effects on migration at marginal levels or greater in Bolivia (OR=1.063), Chile (OR=1.146), Colombia (OR=1.157), and Ecuador (OR=1.051).

Our estimates of models that allow climate effects to vary by country also suggest that negative rainfall shocks increase migration in some countries. Specifically, we find that each month of exposure to exceptionally dry conditions—when cumulative monthly rainfall does not exceed 1 mm—is associated with a 7.0% increase in the odds of inter-province in Chile, and a 68.4% increase in migration odds in Colombia. Together, our results in this section of the analyses highlight considerable macro-level variation in climate effects on migration, but nonetheless continue to support the argument that adverse conditions increase inter-province migration in the region. The one key exception to this pattern is the observed inverse association between multi-year temperature averages and migration in Bolivia. Under the assumption that higher temperatures are associated with adverse conditions, this inverse relationship suggests a trapped population dynamic whereby populations are immobilized by poor environmental conditions that may degrade the resources needed to migrate. That this dynamic is generally expected to be present among poorer populations is consistent with this observation in Bolivia, one of the poorest countries in the region.

6.6 Variation by historical climate

Migration patterns may be driven by threshold effects (Bohra-Mishra et al., 2014), such that shifts in migration occur only in response to changes associated with temperatures or rainfall above (below) a certain absolute level. Under such scenarios, one might observe differences in effects according to the absolute temperature and precipitation averages that deviations are measured from. As a final analysis, we therefore consider whether climate effects vary according to historical temperature and precipitation averages for each province (Table 6). We find little in the way of substantively important interactions, with one key exception: historical temperatures moderate the association between migration and multi-year average temperatures (Specification A). For example, point estimates suggest that populations in provinces with an average historical temperature of 5° C—near the bottom of the range observed in our sample—would experience a 22.6% increase in migration odds for every 1 SD increase in average temperatures (OR=1.226, β=0.204, p=0.031). The direction of this estimated effect is consistent with the overall model, but suggests a stronger relationship. This finding also means that cold snaps—which may be of most concern in places with cooler climates—have an immobilizing effect in such contexts. In contrast, the magnitude of this effect diminishes and approaches zero as average historical temperature increases. A similar calculation indicates that individuals in provinces with an average historical temperature of 27° C—near the top of the range observed in our sample—would experience no statistically significant change in the odds of inter-province migration given a 1 SD change in average temperatures (OR=0.915, β= -0.089, p=0.464). Higher average temperatures do not have a uniformly displacing or immobilizing effect.

7. Discussion and conclusion

In this paper, we evaluate the effects of climatic variability on human migration in eight South American countries, considering the effects of prolonged or repeated shocks and anomalous conditions over multi-year periods. The entirety of our results offers a complex picture of climate-migration linkages in the region, with impacts contingent upon the climate phenomenon in question, migration outcome examined, and national or demographic sub-population considered.

A number of notable patterns nonetheless emerge from these findings. First, changes in temperature tend to have more robust effects on migration than do changes in rainfall, a finding that is consistent with recent research. Second, overall estimates suggest that climatic variability increases the likelihood of inter-province migration across the region, rather than trapping vulnerable populations in place. Third and relatedly, these overall effects mask heterogeneity across groups, countries, and according to baseline climatic conditions (e.g., historical temperature and precipitation levels). The effect, or lack thereof, of some sources of climate variability is shown to be contingent upon affected persons' gender, age, and country of residence. For example, deviations in the average temperature over 5-year periods only have a significant effect on migration in Bolivia, Brazil, and Uruguay. In Bolivia increases in temperature have a negative effect on the likelihood of migration, but in the other two countries the effect is positive. The effects of temperature over 5-year periods is also shown to vary significantly according to the historical mean temperature, with the implication that temperature increases in certain places may have immobilizing effects on populations (versus migration-increasing effects elsewhere). Fourth and finally, much of the inter-province migration induced by temperature shocks measured at monthly intervals is directed toward urban destinations (i.e., rural-urban and urban-urban migration): Overall, each month of exposure to positive and negative temperature shocks increases the likelihood of migration to urban areas by 3.6% and 9.9%, respectively.

Our results also suggest a number of topics for future research, which we hope will build on our findings and address limitations to our study. For one, our evidence regarding cross-national heterogeneity in climate effects raises a number of lines for future inquiry. Chief among them is the need to identify the specific institutional or agro-ecological factors that explain such variation, which we were unable to do due to data limitations. Future work should endeavor to overcome these constraints such that researchers are able to measure time-varying determinants at sub-national scales to identify the conditions that moderate climate effects on migration. By identifying the how social, political, and economic context affects this relationship above and beyond individual characteristics, researchers can better inform the distribution of funding and design of interventions to target vulnerable populations and help them cope with climate variability.

A related limitation is our focus on internal migration. There are well-entrenched patterns of intra-regional migration in South America (Cerrutti & Parrado, 2015) such that our focus on inter-province migration within countries may miss substantial movement across international borders of neighboring or nearby countries. These international moves may be no further or more costly than inter-province moves within countries, making the internal-international dichotomy somewhat problematic. An implication is that such intra-regional migration is also likely to be used as a response to climate variability. While identifying such cross-border migration is not possible using the data analyzed in this study, future research using other data should address this question.

Our finding that much of the observed climate-induced migration is directed toward urban areas suggests the need to explore the consequences of such migration for the receiving communities and migrants themselves. In cases where affected migrants are moving from rural areas, then transitions to urban areas may represent a unique set of challenges. The use of migration to urban centers as a means of adapting to climate change will require many subsequent adaptations in livelihood for these rural populations, as well as the communities they settle in. That said, we were unable to identify whether urban-bound inter-province migrants originated in rural or urban areas, and data limitations also precluded comparable analyses of within-province migration directed toward urban areas. The implication is that we cannot make strong claims about climate and rural-to-urban migration in South America based on these findings. This is a clear limitation of the current analyses, and one that future research should address with other data. As we described above, existing literature on the link between climate and urbanization is quite limited, and to our knowledge currently restricted to studies of sub-Saharan Africa.

A final way that future work could build on the current study is to exploit data sources with finer-grained geographic identifiers. While a necessary limitation, the coarse, province-level measures used in our study may have obscured potentially important internal variation in climatic conditions, and did not account for the spatial distribution of the population at risk of migration. Likewise, our multi-year migration and climate measures may mask nuances with respect to time order and, in the case of our climate measures, seasonality.

Nonetheless, our use of an extremely large, multi-period and multi-national dataset to draw generalizable claims about climate-induced migration represents one of only a few recent studies to shift from country- and often time-specific analyses to broader scales (Gray & Wise, 2016). This is a task that should continue to be taken up in future research. The complexity of our findings also underlines the fact that the use of case studies (where fine-grained geographic identifiers are most likely to be available) should not be abandoned. Indeed, future research should work to more carefully integrate and compare large- and small-scale studies to better understand diverse patterns of climate effects on human migration.

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References

Adger WN. Vulnerability. Global Environmental Change. 2006; 16(3):268–281.

Almaraz JJ, Mabood F, Zhao X, Gregorich EG, Smith DL. Climate Change, Weather Variability, and Corn Yield at a Higher Latitude Locale: Southwestern Quebec. Climatic Change. 2008; 88(2):187–197.

Auffhammer M, Hsiang SM, Schlenker W, Sobel A. Using Weather Data and Climate Model Output in Economic Analyses of Climate Change. Review of Environmental Economics and Policy. 2013; 7(2):181–198.

Aydemir A, Borjas GJ. Cross-Country Variation in the Impact of International Migration: Canada, Mexico, and the United States. Journal of the European Economic Association. 2007; 5(4):663–708.

Bandara A, Dehejia R, Lavie-Rouse S. The Impact of Income and Non-Income Shocks on Child Labor: Evidence from a Panel Survey of Tanzania. World Development. 2015; 67:218–237.

Bardsley DK, Hugo GJ. Migration and Climate Change: Examining Thresholds of Change to Guide Effective Adaptation Decision-Making. Population and Environment. 2010; 32(2-3):238–262.

Barrett C, Constas M. Toward a Theory of Resilience for International Development Applications. Proceedings of the National Academy of Sciences. 2014; 111(40):14625–14630.

Barrios S, Bertinelli L, Strobl E. Climatic Change and Rural-Urban Migration: The Case of Sub-Saharan Africa. Journal of Urban Economics. 2006; 60(3):357–371.

Beegle K, Dehejia RH, Gatti R. Child Labor and Agricultural Shocks. Journal of Development Economics. 2006; 81(1):80–96.

Beegle K, De Weerdt J, Dercon S. Migration and Economic Mobility in Tanzania: Evidence from a Tracking Survey. The Review of Economics and Statistics. 2011; 93(3):1010–1033.

Black R, Adger WN, Arnell NW, Dercon S, Geddes A, Thomas D. The Effect of Environmental Change on Human Migration. Global Environmental Change. 2011; 21(S1):S3–S11.

Bohra-Mishra P, Oppenheimer M, Hsiang S. Nonlinear Permanent Migration Response to Climatic Variations But Minimal Response to Disasters. Proceedings of the National Academy of Sciences. 2014; 111(27):9780–9785.

Burke M, Hsiang SM, Miguel E. Global Non-Linear Effect of Temperature on Economic Production. Nature. 2015

Burke M, Emerick K. Adaptation to Climate Change: Evidence in US Agriculture. American Economic Journal: Economic Policy. Forthcoming.

Bryan G, Chowdhury S, Mobarak AM. Under-Investment in Profitable Technology: The Case of Seasonal Migration in Bangladesh. Econometrica. 2014; 83(5):1671–1748.

Carter MR, Barrett CB. The Economics of Poverty Traps and Persistent Poverty: An Asset-Based Approach. The Journal of Development Studies. 2006; 42(2):178–199.

Cerrutti M, Parrado E. Intraregional Migration in South America: Trends and a Research Agenda. Annual Review of Sociology. 2015; 41(1):399–421.

De la Briere B, Sadoulet E, De Janvry A, Lambert S. The Roles of Destination, Gender, and Household Composition in Explaining Remittances: An Analysis for the Dominican Sierra. Journal of Development Economics. 2002; 68(2):309–328.

Dell M, Jones B, Olken B. What Do We Learn from the Weather? The New Climate-Economy Literature. Journal of Economic Literature. 2014; 52(3):740–798.

Dell M, Jones B, Olken B. Temperature Shocks and Economic Growth: Evidence from the Last Half Century. American Economic Journal: Macroeconomics. 2012; 4(3):66–95.

Dercon S. Growth and Shocks: Evidence from Rural Ethiopia. Journal of Development Economics. 2004; 74(2):304–329.

Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M. Determinants of Farmers' Choice of Adaptation Methods to Climate Change in the Nile Basin of Ethiopia. Global Environmental Change. 2009; 19(2):248–255.

De Waard J, Curtis KJ, Fussell E. Population Recovery in New Orleans After Hurricane Katrina: Exploring the Potential Role of Stage Migration in Migration Systems. Population and Environment. 2016; 37(4):449–463. [PubMed: 27429504]

Dilley, M., Chen, R., Deichmann, U., Lerner-Lam, A., et al. Yetman, G. Natural Disaster Hotspots: A Global Risk Analysis. Washington, DC: World Bank; 2005. Disaster Risk Management Series No 5

Dillon A, Mueller V, Salau S. Migratory Responses to Agricultural Risk in Northern Nigeria. American Journal of Agricultural Economics. 2011; 93(4):1048–1061.

Dixon, JA., Gibbon, DP., Gulliver, A. Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Washington, D.C.: Food & Agriculture Organization; 2001.

Findley SE. Does Drought Increase Migration? A Study of Migration from Rural Mali during the 1983-1985 Drought. International Migration Review. 1994; 28(3):539–553. [PubMed: 12345794]

Fussell E, Harris E. Homeownership and Housing Displacement After Hurricane Katrina Among Low-Income African-American Mothers in New Orleans. Social Science Quarterly. 2014; 95(4):1086–1100. [PubMed: 26392638]

Fussell E, Hunter LM, Gray CL. Measuring the Environmental Dimensions of Human Migration: The Demographer's Toolkit. Global Environmental Change. 2014; 28:182–191. [PubMed: 25177108]

Graff Zivin, JS., Hsiang, SM., Neidell, MJ. Working Paper 21157. Cambridge, MA: National Bureau of Economic Research; 2015. Temperature and Human Capital in the Short-and Long-Run.

Gray CL. Environment, Land, and Rural Out-Migration in the Southern Ecuadorian Andes. World Development. 2009; 37(2):457–468.

Gray CL. Gender, Natural Capital, and Migration in the Southern Ecuadorian Andes. Environment and Planning A. 2010; 42(3):678–696.

Gray C, Mueller V. Drought and Population Mobility in Rural Ethiopia. World Development. 2012a; 40(1):134–145. [PubMed: 22523447]

Gray C, Mueller V. Natural Disaster and Population Mobility in Bangladesh. Proceedings of the National Academy of Sciences. 2012b; 109(16):6000–6005.

Gray C, Wise E. Country-Specific Effects of Climate Variability on Human Migration. Climatic Change. 2016 Forthcoming.

Hagan JM. Social Networks, Gender, and Immigrant Incorporation: Resources and Constraints. American Sociological Review. 1998; 63(1):55–67.

Halliday T. Migration, Risk, and Liquidity Constraints in El Salvador. Economic Development and Cultural Change. 2006; 54(4):893–925.

Hansen J, Sato M, Ruedy R. Perception of Climate Change. Proceedings of the National Academy of Sciences. 2012; 109(37):E2415–E2423.

Harris I, Jones PD, Osborn TJ, Lister DH. Updated High-Resolution Grids of Monthly Climatic Observations–the CRU TS3. 10 Dataset. International Journal of Climatology. 2014; 34(3):623–642.

Harris J, Todaro M. Migration, Unemployment and Development: A Two-Sector Analysis. American Economics Review. 1970; 60(1):126–142.

Henderson, V., Storeygard, A., Deichmann, U. Working paper. London School of Economics; 2015. Has Climate Change Driven Urbanization in Africa?.

Henry S, Schoumaker B, Beauchemin C. The Impact of Rainfall on the First Out-Migration: A Multi-Level Event-History Analysis in Burkina Faso. Population and Environment. 2004; 25(5):423–460.

Hsiang SM. Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America. Proceedings of the National Academy of Sciences of the United States of America. 2010; 107(35):15367–15372. [PubMed: 20713696]

Hsiang SM. Econometric Approaches to Causal Impacts of Climate Change. Annual Review of Resource Economics. 2016; 8(1) Forthcoming.

Hunter LM, Luna JK, Norton RM. Environmental Dimensions of Migration. Annual Review of Sociology. 2015; 41(1):377–397.

Hunter LM, Murray S, Riosmena F. Rainfall Patterns and U.S. Migration from Rural Mexico. International Migration Review. 2013; 47(4):874–909. [PubMed: 25473143]

Jalan J, Ravallion M. Are the Poor Less Well Insured? Evidence on Vulnerability to Income Risk in Rural China. Journal of Development Economics. 1999; 58(1):61–81.

Jones PG, Thornton PK. The Potential Impacts of Climate Change on Maize Production in Africa and Latin America in 2055. Global Environmental Change. 2003; 13(1):51–59.

Kazianga H, Udry C. Consumption Smoothing? Livestock, Insurance, and Drought in Rural Burkina Faso. Journal of Development Economics. 2006; 79(2):413–446.

Kim SY, Wolinsky-Nahmias Y. Cross-National Public Opinion on Climate Change: The Effects of Affluence and Vulnerability. Global Environmental Politics. 2014; 14(1):79–106.

Kleemans M. Migration Choice Under Risk and Liquidity Constraints. 2014 Unpublished manuscript.

Koubi V, Spilker G, Schaffer L, öhmelt TB. The Role of Environmental Perceptions in Migration Decision-Making: Evidence from Both Migrants and Non-Migrants in Five Developing Countries. Population and Environment. 2016

Kubik Z, Maurel M. Weather Shocks, Agricultural Production and Migration: Evidence from Tanzania. The Journal of Development Studies. 2016 Forthcoming.

Lobell DB, Asner GP. Climate and Management Contributions to Recent Trends in US Agricultural Yields. Science. 2003; 299(5609):1032. [PubMed: 12586935]

Lobell DB, Field CB. Global Scale Climate-Crop Yield Relationships and the Impacts of Recent Warming. Environmental Research Letters. 2007; 2(1):1–7.

Marchiori L, Maystadt JF, Schumacher I. The Impact of Weather Anomalies on Migration in Sub-Saharan Africa. Journal of Environmental Economics and Management. 2012; 63(3):355–374.

Maystadt JF, Mueller V, Sebastian A. Environmental Migration and Labor Markets in Nepal. Journal of the Association of Environmental and Resource Economists. Forthcoming.

Minnesota Population Center. Integrated Public Use Microdata Series, International: Version 6.4 [Machine-readable database]. Minneapolis: University of Minnesota; 2015.

Mueller V, Gray C, Kosec K. Heat Stress Increases Long-term Human Migration in Rural Pakistan. Nature Climate Change. 2014; 4(3):182–185.

Myers N. Environmental Refugees. Population and Environment. 1997; 19(2):167–182.

Nawrotzki RJ, Bakhtsiyarava M. International Climate Migration: Evidence for the Climate Inhibitor Mechanism and the Agricultural Pathway. Population, Space and Place. 2016

Nawrotzki RJ, De Waard J. Climate Shocks and the Timing of Migration from Mexico. Population and Environment. 2016

Nawrotzki RJ, Riosmena F, Hunter LM, Runfola DM. Amplification or Suppression: Social Networks and the Climate Change-Migration Association in Rural Mexico. Global Environmental Change. 2015; 35:463–474. [PubMed: 26692656]

Neumann, Kathleen, Hermans, Frans. What Drives Human Migration in Sahelian Countries? A Meta-analysis. Population, Space and Place. 2015

Paxson C. Using Weather Variability to Estimate the Response of Saving to Transitory Income in Thailand. American Economic Review. 1992; 82(1):15–33.

Peng S, Huang J, Sheehy JE, Laza RC, Visperas RM, Zhong X, Centeno GS, Khush GS, Cassman KG. Rice Yields Decline with Higher Night Temperature from Global Warming. Proceedings of the National Academy of Sciences of the United States of America. 2004; 101(27):9971–9975. [PubMed: 15226500]

Piontek F, Müller C, Pugh TA, Clark DB, Deryng D, Elliott J, et al. Frieler K. Multisectoral Climate Impact Hotspots in a Warming World. Proceedings of the National Academy of Sciences. 2014; 111(9):3233–3238.

Poelhekke S. Urban Growth and Uninsured Rural Risk: Booming Towns in Bust Times. Journal of Development Economics. 2011; 96:461–475.

Reuveny R. Climate Change-Induced Migration and Violent Conflict. Political Geography. 2007; 26(6):656–673.

Rose E. Ex Ante and Ex Post Labor Supply Response to Risk in a Low-Income Area. Journal of Development Economics. 2001; 64(2):371–388.

Rosenzweig MR, Stark O. Consumption Smoothing, Migration, and Marriage: Evidence from Rural India. The Journal of Political Economy. 1989; 97(4):905–926.

Schlenker W, Roberts MJ. Nonlinear Temperature Effects Indicate Severe Damages to US Crop Yields Under Climate Change. Proceedings of the National Academy of Sciences. 2009; 106(37):15594–15598.

Sea SN, Mendelsohn R. An Analysis of Crop Choice: Adapting to Climate Change in South American Farms. Ecological Economics. 2008; 67(1):109–116.

Sjaastad LA. The Costs and Returns of Human Migration. Journal of Political Economy. 1962; 70(5): 80–93.

Stoney, S., Batalova, J., Russell, J. [Access 11 September 2015] South American Immigrants in the United States. 2013. Available at: www.migrationpolicy.org/article/south-american-immigrants-united-states

Strobl E, Valfort MA. The Effect of Weather-Induced Internal Migration on Local Labor Markets: Evidence from Uganda. World Bank Economic Review. 2015; 29(2):385–412.

Thornton PK, Jones PG, Alagarswamy G, Andresen J. Spatial Variation of Crop Yield Response to Climate Change in East Africa. Global Environmental Change. 2009; 19(1):54–65.

Todaro MP. A Model of Labor Migration and Urban Unemployment in Less Developed Countries. The American Economic Review. 1969; 59(1):138–148.

Twardosz R, Kossowska-Cezak U. Exceptionally Cold and Mild Winters in Europe (1951–2010). Theoretical and Applied Climatology. 2015; 125(1):1–13.

Vergara, W., Rios, AR., Trapido, P., Malarín, H. IDB Discussion Paper 329. Washington, DC: Inter-American Development Bank; 2014. Agriculture and Future Climate in Latin America and the Caribbean: Systemic Impacts and Potential Responses.

Warner K, Afifi T. Where the Rain Falls: Evidence from 8 Countries on How Vulnerable Households Use Migration to Manage the Risk of Rainfall Variability and Food Insecurity. Climate and Development. 2014; 6(1):1–17.

Wheeler T, Von Braun J. Climate Change Impacts on Global Food Security. Science. 2013; 341(6145): 508–513. [PubMed: 23908229]

World Bank. World Development Indicators. Washington, D.C.: The World Bank; 2016. Available at: http://databank.worldbank.org/data/home.aspx

Highlights

- Extreme monthly temperatures have the most consistent effects on migration in the region
- Much of the climate-related inter-province migration is directed toward urban areas
- Climate effects on migration vary by country and historical climate conditions

Table 1

Summary of variables

Variable	N	Mean (Proportion)	SD	Min	Max
Age at census	2,13,44,711	31.329	7.417	20	45
Sex					
Male	1,05,08,001	(0.492)	-	-	-
Female	1,08,36,710	(0.508)	-	-	-
Educational attainment					
Did not complete primary school	76,71,289	(0.359)	-	-	-
Completed primary school	1,34,00,210	(0.628)	-	-	-
Unknown	2,73,212	(0.013)	-	-	-
Inter-province migration					
Did not migrate	2,02,58,265	(0.949)	-	-	-
Migrated	10,86,446	(0.051)	-	-	-
Inter-province migration status, by destination type					
Did no migrate	2,00,17,755	(0.951)	-	-	-
Migrated to rural destination	1,78,899	(0.009)	-	-	-
Migrated to urban destination	8,50,297	(0.040)	-	-	-
Climate measures, years 1-5 prior to census					
Temperature, standardized	445	0.226	0.879	-2.684	2.064
Rainfall, standardized	445	0.127	1.046	-2.622	2.684
Count, monthly temperature > 2 SD	445	1.888	2.308	0	15
Count, monthly temperature < (-)2SD	445	0.867	1.314	0	7
Count, monthly rainfall > 2 SD	445	2.789	2.031	0	10
Count, monthly rainfall <1mm	445	0.969	3.641	0	36
Climate measures, years 6-10 prior to census					
Temperature, standardized	445	0.061	0.954	-2.452	2.242
Rainfall, standardized	445	0.019	0.948	-2.334	3.221
Count, monthly temperature > 2 SD	445	1.546	1.989	0	12
Count, monthly temperature < (-)2SD	445	0.951	1.448	0	11
Count, monthly rainfall > 2 SD	445	2.544	1.873	0	9

Variable	N	Mean (Proportion)	SD	Min	Max
Count, monthly rainfall <1mm	445	0.951	3.598	0	38
Climate measures, years 1-10 prior to census					
Temperature, standardized	445	0.173	0.951	-2.269	2.477
Rainfall, standardized	445	0.105	1.054	-2.671	2.833
Count, monthly temperature > 2 SD	445	3.434	3.056	0	18
Count, monthly temperature < (-)2SD	445	1.818	2.045	0	11
Count, monthly rainfall > 2 SD	445	5.333	2.698	0	15
Count, monthly rainfall <1mm	445	1.919	7.166	0	73
Climate measures, historical[a]					
Temperature (°C), mean	139	19.557	5.482	4.943	27.608
Rainfall (mm), mean	139	7,015.828	3,881.386	267.737	25,250.960

[a] Historical measures represent the average temperature and rainfall over all consecutive 60-month (5-year) periods between 1951-2013.

Table 2

Coefficient estimates, logistic regression models predicting inter-province migration

	Spec. A	Spec. B	Spec. C	Spec. D	Spec. E	Spec. F	Spec. G	Spec. H	Spec. I
Climate variables, years 1-5 prior to census									
Temperature, standardized		0.061 +			0.087 *				
Rainfall, standardized		-0.039			-0.030				
Count, monthly temperature > 2 SD						0.034 **			0.028 **
Count, monthly temperature < (-)2SD						0.079 **			0.054 *
Count, monthly rainfall > 2 SD						-0.007			-0.009
Count, monthly rainfall <1mm						0.045			0.039
Climate variables, years 6-10 prior to census									
Temperature, standardized				-0.005	-0.048				
Rainfall, standardized				-0.045	-0.044				
Count, monthly temperature > 2 SD								-0.015	-0.011
Count, monthly temperature < (-)2SD								0.040	0.039
Count, monthly rainfall > 2 SD								-0.050 **	-0.043 *
Count, monthly rainfall <1mm								-0.061 +	-0.046
Climate variables, years 1-10 prior to census									
Temperature, standardized			0.032						
Rainfall, standardized			-0.031						
Count, monthly temperature > 2 SD							0.011 *		
Count, monthly temperature < (-)2SD							0.045 *		
Count, monthly rainfall > 2 SD							-0.026 **		
Count, monthly rainfall <1mm							-0.002		
Controls									
Age	-0.031 **	-0.031 **	-0.031 **	-0.031 **	-0.031 **	-0.031 **	-0.031 **	-0.031 **	-0.031 **
Sex									
Male	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)
Female	-0.119 **	-0.119 **	-0.119 **	-0.119 **	-0.119 **	-0.119 **	-0.119 **	-0.119 **	-0.119 **
Educational attainment									
Did not complete primary school	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)	(ref)

	Spec. A	Spec. B	Spec. C	Spec. D	Spec. E	Spec. F	Spec. G	Spec. H	Spec. I
Completed primary school	0.205 **	0.205 **	0.205 **	0.206 **	0.206 **	0.204 **	0.205 **	0.207 **	0.206 **
Unknown	-0.154 **	-0.158 **	-0.155 **	-0.150 **	-0.152 **	-0.145 **	-0.140 **	-0.138 **	-0.135 *
Pseduo R^2		0.0468	0.0467	0.0467	0.0469	0.0473	0.0472	0.0475	0.0478
Joint test, climate variables		*			**	**	*	**	**
N		2,13,44,711							

+ p<0.10,

* p<0.05,

** p<0.01

Models include constant and province and decade fixed effects

Table 3

Coefficient estimates, logistic regression models predicting inter-province migration, climate measures for years 1-5 prior to census

	Spec. A	Spec. B	Spec. C	Spec. D	Spec. E	Spec. F
Climate variables, years 1-5 prior to census						
Temperature, standardized	0.003		0.049		0.099 *	
Rainfall, standardized	-0.136 **		-0.037		-0.035	
Count, monthly temperature > 2 SD		0.053 *		0.033 **		0.036 *
Count, monthly temperature < (-)2SD		0.158 **		0.091 **		0.075 *
Count, monthly rainfall > 2 SD		-0.014		-0.003		-0.011
Count, monthly rainfall < 1 mm		0.041		0.048		0.041
Climate * control interactions						
Age * temperature, standardized	0.002					
Age * rainfall, standardized	0.003 **					
Age * count, monthly temperature > 2 SD		-0.001				
Age * count, monthly temperature < (-)2SD		-0.003 +				
Age * count, monthly rainfall > 2 SD		0.000				
Age * count, monthly rainfall < 1 mm		0.000				
Female * temperature, standardized			0.026 **			
Female * rainfall, standardized			-0.004			
Female * count, monthly temperature > 2 SD				0.002		
Female * count, monthly temperature < (-)2SD				-0.026 **		
Female * count, monthly rainfall > 2 SD				-0.009 +		
Female * count, monthly rainfall < 1 mm				-0.006 *		
Primary ed(=1) * temperature, standardized					-0.054	
Primary ed(=1) * rainfall, standardized					-0.003	
Primary ed(=1) * count, monthly temperature > 2 SD						-0.004
Primary ed(=1) * count, monthly temperature < (-)2SD						0.005
Primary ed(=1) * count, monthly rainfall > 2 SD						0.006

	Spec. A		Spec. B		Spec. C		Spec. D		Spec. E		Spec. F	
Primary ed(=1) * count, monthly rainfall < 1 mm											0.005	
Controls												
Age	-0.032	**	-0.029	**	-0.031	**	-0.031	**	-0.031	**	-0.031	**
Sex												
Male	(ref)		(ref)		(ref)		(ref)		(ref)		(ref)	
Female	-0.119	**	-0.119	**	-0.132	**	-0.083	**	-0.118	**	-0.118	**
Educational attainment												
Did not complete primary school	(ref)		(ref)		(ref)		(ref)		(ref)		(ref)	
Completed primary school	0.204	**	0.205	**	0.204	**	0.203	**	0.232	**	0.193	*
Unknown	-0.162	**	-0.145	**	-0.157	**	-0.145	**	-0.242	*	-0.241	+
Pseduo R^2	0.0469		0.0473		0.0468		0.0473		0.0469		0.0473	
Joint test, interaction effects	**				*		**		+		*	
N	2,13,44,711											

[+] p<0.10,

[*] p<0.05,

[**] p<0.01

Models include constant and province and decade fixed effects

Table 4

Coefficient estimates, multinomial logistic regression model predicting inter-province migration by destination type, climate measures for years 1-5 prior to census

	Specification A		Specification B	
	Rural destination	**Urban destination**	**Rural destination**	**Urban destination**
Temperature, standardized	-0.070 [+]	0.056		
Rainfall, standardized	-0.036	-0.010		
Count, monthly temperature > 2 SD			-0.021 [+]	0.035 [**]
Count, monthly temperature < (-)2SD			0.049 [*]	0.094 [**]
Count, monthly rainfall > 2 SD			-0.005	0.000
Count, monthly rainfall < 1 mm			0.079	0.047
Pseduo R^2	0.0474		0.0479	
Joint test, climate variables			[**]	[**]
N	2,10,46,951			

[+] p<0.10,

[*] p<0.05,

[**] p<0.01

Models include control variables and province and decade fixed effects

Table 5

Net coefficient estimates, derived from logistic regression models predicting inter-province migration with country-climate interaction terms, climate measures for years 1-5 prior to census

Country	Temperature, standardized	Rainfall, standardized	Count, monthly temperature > 2 SD	Count, monthly temperature < (-)2SD	Count, monthly rainfall > 2 SD	Count, monthly rainfall < 1 mm
Argentina	0.108	-0.131	0.303 **	0.057	0.004	0.060
Bolivia	-0.166 **	0.049	0.117	0.061 +	-0.004	-0.141 +
Brazil	0.115 *	0.016	0.009	0.052	0.015	0.018
Chile	0.311 +	-0.017	0.032	0.136 +	0.038 +	0.068 **
Colombia	0.005	-0.269 **	0.081	0.146 *	-0.056	0.521 **
Ecuador	-0.098	0.058	0.022	0.050 +	-0.017	-0.138
Paraguay	0.044	0.086	-0.032	-0.050	0.004	-0.138
Uruguay	0.894 **	0.220	0.646 **	0.144	-0.184	-0.138

[+] p<0.10,

[*] p<0.05,

[**] p<0.01

N=21,344,711; joint test of climate * country interactions X^2=287.50**

Models include control variables and province and decade fixed effects

Joint tests of interaction terms are statistically significant at p<0.01 for both models

Table 6

Coefficient estimates, logistic regression models predicting inter-province migration, climate measures for years 1-5 prior to census

	Spec. A		Spec. B	
Temperature, standardized	0.270	*		
Rainfall, standardized	-0.062			
Count, monthly temperature > 2 SD			0.080	
Count, monthly temperature < (-)2SD			-0.051	
Count, monthly rainfall > 2 SD			-0.042	
Count, monthly rainfall < 1 mm			0.082	+
Historical temperature * temperature, standardized	-0.013	*		
Historical rainfall * temperature, standardized	0.000			
Historical temperature * rainfall, standardized	0.000			
Historical rainfall * rainfall, standardized	0.000			
Historical temperature * count, monthly temperature > 2 SD			-0.001	
Historical rainfall * count, monthly temperature > 2 SD			0.000	
Historical temperature * count, monthly temperature < (-)2SD			0.008	
Historical rainfall * count, monthly temperature < (-)2SD			0.000	
Historical temperature * count, monthly rainfall > 2 SD			0.000	
Historical rainfall * count, monthly rainfall > 2 SD			0.000	
Historical temperature * count, monthly rainfall < 1 mm			-0.010	*
Historical rainfall * count, monthly rainfall < 1 mm			0.000	+
	0.046		0.047	
Pseduo R^2	9		5	
Joint test, climate variables			**	
Joint test, interaction efects				
N	2,13,44,711			

+ p<0.10,

* p<0.05,

** p<0.01

Models include control variables and province and decade fixed effects