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Domestic and International Climate Migration from Rural Mexico

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Abstract

Evidence is increasing that climate change and variability may influence human migration patterns. However, there is less agreement regarding the type of migration streams most strongly impacted. This study tests whether climate change more strongly impacted international compared to domestic migration from rural Mexico during 1986-99. We employ eight temperature and precipitation-based climate change indices linked to detailed migration histories obtained from the Mexican Migration Project. Results from multilevel discrete-time event-history models challenge the assumption that climate-related migration will be predominantly short distance and domestic, but instead show that climate change more strongly impacted international moves from rural Mexico. The stronger climate impact on international migration may be explained by the self-insurance function of international migration, the presence of strong migrant networks, and climate-related changes in wage difference. While a warming in temperature increased international outmigration, higher levels of precipitation declined the odds of an international move.

Keywords

Climate change; rural Mexico; domestic migration; international migration; environment

Introduction

Climate change has become an issue of global magnitude, with impacts ranging from sudden onset events (e.g., droughts, storms, flooding) to slow onset processes (e.g., sea level rise, desertification) (IPCC 2013). Particularly rural, agricultural-dependent populations in developing countries are sensitive to these climate impacts due to a lack of technological barriers to guard against weather extremes (Huq et al. 2003). Climate vulnerability emerges in a unique regional context and is influenced by socioeconomic factors, culture, politics,

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and institutions (Kelly and Adger 2000). Some highly publicized work, suggests that climate change and variability may lead to massive migration from developing countries to industrialized nations over the coming decades (Myers 2002; Stern 2007). In response to such claims, researchers have increased their efforts to answer the question: *Does climate change and variability impact human migration* (Hunter et al. 2015)?

For much of the global south, studies find that adverse climate conditions impact circular, short-distance migration but have only marginal influence on international moves (Bohra-Mishra et al. 2014; Henry et al. 2004; Mueller et al. 2014). Climate migration as a demographic phenomenon is contingent on the historical, cultural context and my differ by gender (Henry et al. 2004), physical capital (Gray and Bilsborrow 2013), and purpose of the move (Gray and Mueller 2012). Regarding the type of climate effects, these studies suggest greater influences of temperature compared to precipitation on migration patterns (Bohra-Mishra et al. 2014; Mueller et al. 2014).

Although many studies find stronger climate effects on short-distance mobility, studies from Latin America suggest that adverse climatic conditions can also increase international moves (Feng and Oppenheimer 2012; Gray and Bilsborrow 2013; Hunter et al. 2013). However, the climate – international migration relationship is often weak and emerges region specific for certain sub-populations. For example, adverse climate condition influence Mexico-U.S. migration predominantly in areas characterized as historically dry (Nawrotzki et al. 2013), mostly rural (Feng and Oppenheimer 2012; Nawrotzki et al. 2015a), with a long history of transnational labor migration (Hunter et al. 2013). The strong focus on international migration is the result of widespread fear surrounding uncontrollable flows of climate migrants and refugees, fleeing their countries to seek shelter in industrialized nations, which has prompted the intensification of research in international migrant flows (Kaenzig and Piguet 2014). While, for the Mexican case the relationship between climate and international migration is well established (Hunter et al. 2013; Nawrotzki et al. 2015b), we know little about the relationship between climate and domestic migration. This research paper is an attempt to begin filling this gap by asking: *Does climate change more strongly impact international compared to domestic migration from rural Mexico*?

Migration as Self-insurance Mechanism

Human migration is influenced by socioeconomic, cultural, political and demographic processes in combination with environmental factors (Castles 2010). As conceptually outlined by Black and colleagues (2011), climate change can influence migration indirectly through changes in these primary drivers and directly through increasing frequency and severity of environmental stresses including natural disasters.

For the Mexican case, econometric models suggest that climate change and variability most strongly impacts the agricultural sector (Boyd and Ibarraran 2009). In rural Mexico, agricultural income contributes between 23% and 67% to a household's income portfolio (de Janvry and Sadoulet 2001), leading to a high degree of dependence on the agricultural sector for income generation and sustenance (Winters et al. 2002). This dependence on the agricultural sector makes the livelihoods of rural Mexicans vulnerable to climate change and variability, given that little technological infrastructure exists to off-set negative climate effects (Endfield 2007). For example, only 23% of permanently cropped land was irrigated in Mexico during 2001 (Carr et al. 2009). Adverse climate change may have negative impacts on agriculture-related income and job availability and households may employ migration as a strategy to stabilize livelihoods (McLeman 2011).

This "agricultural pathway" (Nawrotzki and Bakhtsiyarava 2016) between migration and climate can be usefully situated within the New Economics of Labor Migration (NELM) theory (Taylor 1999). Within this framework, the migration of a household member functions as household-based informal insurance strategy to guard against market failures (Stark and Bloom 1985), that may be attributed to adverse environmental change. The decision to send a household member elsewhere as a risk diversification strategy is made jointly by the household unit (Massey et al. 1993; Taylor 1999). Resources are pooled, and perhaps borrowed, to finance the move and an implicit contract encourages remittances (Stark and Bloom 1985). The migrating household member is often strategically placed in a destination where climate and market conditions are uncorrelated to conditions at home (Massey et al. 1993; Stark and Bloom 1985).

International versus Domestic Climate Migration

While the NELM framework helps to explain the relationship between climate change and migration through the agricultural pathway, it does not distinguish between migration types. In our case, we are interested in examining the relative probabilities of international and domestic migration from rural Mexico as related to climate factors. For guidance on this dimension, we draw on the six principles of environmental migration proposed by Allan Findlay (2011).

The first principle suggests that most potential migrants actually prefer to stay in their current place of residence even if adverse environmental circumstances may undermine livelihoods and produce lower standards of living. This principle has been referred to as the immobility paradox (Fischer and Malmberg 2001). Such immobility could reflect a preference for *in situ* (in place) adaptation strategies in the face of environmental pressures (McLeman 2011). Strategies include changing farming patterns, seeking employment in non-agricultural sectors, selling assets, borrowing money from family and friends, and/or drawing on public assistance programs (Gray and Mueller 2012).

Yet, if *in situ* options become exhausted or insufficient, livelihood diversification through migration may be an option (McLeman 2011). Findlay's second and third principles note that short distance moves are more likely than long distances (principle 2), and long distance moves are more likely to be within country than international (principle 3) in the absence of social ties. Domestic moves have a number of benefits including positive returns on education investment, familiar cultural and linguistic environment, and lower travel costs (Lindstrom and Lauster 2001). This explains why domestic circular migration is a common migratory form in many developing countries (Henry et al. 2004).

However, Mexico is characterized by a unique historical context in which century-long labor migration to the U.S. has created a culture in which international migration is viewed as normative (Kandel and Massey 2002). Dense migrant networks connect Mexico and the U.S. (Fussell 2004), and such networks are known to operate as migration corridors that may facilitate climate-related migration (Bardsley and Hugo 2010). Accordingly, Findlay's fourth, fifth, and sixth principles suggest that international migration in response to climate factors may become a viable livelihood option in the presence of established historical social networks (principle 5), conditional on immigration policies (principle 4) and socioeconomic status (principle 6). International movement may have a number of advantages over domestic migration. First, the self-insurance function of migration, stressed by NELM theory, suggests that households ideally choose a destination where the environmental and market conditions are uncorrelated with those at the origin (Massey et al. 1993; Stark and Bloom 1985). A long distance move, particularly if to another country, may best assure the uncoupling of remittance income from local weather and market conditions (Rosenzweig and Stark 1989). Second, international migration may be particularly attractive given the substantially higher wages earned in the U.S. (Massey and Espinosa 1997). Moreover, the wage difference itself may be influenced by climate factors (Lilleor and Van den Broeck 2011) as climate impacts may stronger depress wages in Mexico compared to the U.S. due to different levels of technological infrastructure that can be used to guard against adverse climate impacts (Gutmann and Field 2010).

In summary, while domestic migration is usually the preferred migration type in response to environmental strains, international migration may be a viable option given the unique Mexican context of strong transnational migrant networks to the U.S. Making use of high-resolution climate data in combination with detailed migration histories, this study offers an empirical test whether rural Mexican households more strongly respond to climate change and variability with domestic or international migration.

Data and Methods

Data

For the investigation of the impact of climate change on migration, we draw on two data sources – the Mexican Migration Project and the Global Historical Climate Network – Daily data sets. We obtained socio-demographic characteristics and migration histories from the Mexican Migration Project (MMP). Since 1982, the MMP selects between four and six communities located throughout Mexico each year, and interviews a random sample of 200 households in each community (Massey 1987). The MMP collects detailed sociodemographic information of household members as well as year-by-year labor and migration histories and has been widely used for migration research (e.g., Fussell and Massey 2004; Hunter et al. 2013).

For the construction of climate measures, we obtained daily temperature and precipitation information for 214 weather stations across Mexico for the years 1961-98 from the Global Historical Climate Network – Daily (GHCN-D) data set. The GHCN-D data set is managed and released by the National Oceanic and Atmospheric Administration (NOAA) and undergoes rigorous data quality checks (for details see Menne et al. 2012).

Unit of Analysis

Informed by NELM theory, we understand migration as a household-level livelihood strategy (Massey et al. 1993). The household is the fundamental unit through which individuals create a sense of identity and through which status and prestige are obtained (Cohen 2004). It is against this backdrop that migration is considered embedded in a household's needs, desires, and aspirations, rather than as a strategy employed by an individual removed from their social context (Kanaiaupuni 2000). The climate information is linked to the household-level migration information at the municipality level. For this study we focus on 68 rural municipalities (Figure 1) since prior research has shown that the rural agricultural sector is strongest impacted by climate change (Boyd and Ibarraran 2009). Households in rural municipalities reside in towns (2,500 – 10,000 inhabitants) or villages (< 2,500 inhabitants).

In this study we investigate climate change and variability as a driver of migration during the years 1986-99. The year 1999 forms the upper limit because for later years the available weather stations within the GHCN-D data set drops to n=15, rendering interpolation methods for years after 1999 unstable. We chose 1986 as the lower limit of the study period because of the strong influence of the Immigration Reform and Control Act (IRCA), enacted in this year, on the socio-political context in which migration occurred (Orrenius and Zavodny 2003).

Variable Construction

Outcome variable—Separate measures of international (U.S.) and domestic (within Mexico) outmigration served as primary outcome variables for this study. Migration is defined as a move that involved a change in usual residence, excluding short visits for vacation, shopping, visits, and commuting (Fussell 2004). We generated a household-year data file in which the outcome variables were coded 0 for years during which no migration occurred and 1 if any household member moved. International and domestic migration are not mutually exclusive events, requiring the construction of migrant-type specific event history datasets and the estimation of separate models for each migrant type. The datasets comprise households that have no prior international or domestic migration experience. Household-years are included after the year that the household was formed (approximated by the year of marital union formation), and when the household head was at least 15 years of age. Household-years are removed from the data set after the year that the first move was performed, when the head turns 65, when the household was censored during the survey year, or when the end of the study period was reached in 1999. We also account for households' moves in and out of the study community and expose households to the risk of migration only during years when at least one core member (head or spouse) were present in the community.

For international migration, Figure 2 shows a higher migration hazard at the beginning and the end of the observation period with a dip during 1992-93. International migration rates are impacted by macro-economic conditions and Mexico experienced an economic crisis during the mid-1980s (Lustig 1990) and during 1994-96 (McKenzie 2006), which explains the elevated migration hazards. A factor contributing to the increase in migration after 1994 was the establishment of the North American Free Trade Agreement (NAFTA) (Sanchez Cohen et al. 2013), which negatively influenced agricultural employment opportunities in Mexico (Fussell 2004).

In contrast, domestic migration rates declined across the study period. The decline in domestic migration rates could be reflective of a deceleration of rural-urban migration due to industrial downturn and urban wage declines (cf., Perz 2000). Under conditions of economic crisis and economic restructuring (e.g., Sanchez Cohen et al. 2013), the incentive to migrate internationally may increase concurrently with a decline in the incentive to move to urban areas within Mexico.

Primary predictor variables—We employed a set of climate change indices, formalized by the Expert Team on Climate Change Detection and Indices (ETCCDI), as primary predictors in this research project. The ETCCDI indices were generated for the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and focus largely on temperature and precipitation extremes (Peterson et al. 2001). The indices were formalized with the goal to provide a standardized set of measures that would improve the comparability of studies on climate change and variability across time and space (Peterson and Manton 2008). For the purpose of this study we employ the IPCC's definition of climate change as “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties for an extended period, typically decades or longer” (IPCC 2014a. 120).

We assume a causal pathway in which climate change and variability influence migration through impacts on the agricultural sector (Nawrotzki and Bakhtsiyarava 2016). Prior research of climate effects on the agricultural sector shows that threshold effects have stronger impacts on yields than changes in average temperature and precipitation (Lobell et al. 2013; Schlenker and Roberts 2009). In addition, measures of the cumulated number of times that a certain thresholds was surpassed are better positioned to capture the distribution of weather outcomes than measures of one-time extremes (cf., Schlenker and Roberts 2009). As such, we employ a set of eight ETCCDI indices that capture the cumulated number of times that a percentile-based threshold was surpassed (Table 1).

We build on work by Nawrotzki et al. (2015b) and construct the climate indices using a four-step procedure involving missing data imputation, index construction, spatial interpolation, and computation of relative change measures. Although the GHCN-D data set undergoes careful quality checks (e.g., Menne et al. 2012), about 21% of the daily records in the 38-year time series (1961-98) were missing, because of non-recording, instrumentation problems, or data quality issues. We imputed missing records using a technique known as Multiple Imputation (MI) (Rubin 1987), which accounts for the uncertainty in the generated values through the addition of randomness during the imputation procedure (Allison 2002). MI was implemented using the R package *Amelia* (Honaker et al. 2011), which allows for the imputation of time-series data through the inclusion of polynomials for time. Inspecting density, overimputation, and overdispersion plots, suggested that the imputation model produced reliable results (Honaker et al. 2011). The imputed data set was then used as input to compute the ETCCDI climate indices using the R package *climdex.pcic* managed by the

Pacific Climate Impacts Consortium (Bronaugh 2014). The climate indices were computed for each weather station. In order to obtain estimates of climate change for the 68 rural MMP municipalities, we used the geostatistical method of cokriging that employs information on the local spatial autocorrelation, the spatial trend, and the spatially uncorrelated random noise to predict climate values at unknown locations (Bolstad 2012; Hevesi et al. 1992). We incorporated information from a digital elevation model (Danielson and Gesch 2011) in the cokriging interpolations, as temperature and precipitation patterns are correlated with altitude. From the interpolated surface we then extracted point estimates using a lattice of 700 × 700 meters and computed the average climate index for each municipality. To investigate the robustness of the cokriging estimates, we employed a bootstrap approach to estimate prediction errors. Plotting the error values revealed no systematic bias in the estimates over space and time, providing evidence for the credibility of the interpolation procedure.

As a final step, we computed the difference between the average of a three-year time period leading up to each observation year and a 30-year climate normal reference period (1961-90). For each municipality, the resulting difference was then divided by the standard deviation to generate z-scores that are comparable across measures (Table 2).

The observed trends in our climate measures are partially in line with anticipated future changes (IPCC 2013). While no clear trend in precipitation patterns can be discerned, a general trend in warming was evident.

Control variables—We group control variables into physical, financial, social, human, and natural capital to capture key livelihood capitals that shape the household context in which migration occurs (Scoones 1999). Variables were included as time varying whenever longitudinal information was available and as time-invariant when only cross-sectional information could be obtained (see Table 3). Variables available at a decadal scale (e.g., census based measures) were linearly interpolation to derive time-varying predictors as a common method in event history analysis (Allison 1984; Steele 2005).

At the household level, social capital is reflected by two dummy variables, the gender (female = 1) and the marital status of the household head (married = 1). Human capital was reflected by the number of young children (age < 5 years) in the household during a particular period, the education level of the household head measured in years of schooling, as well as the cumulative working experience measured as years employed. In addition, a set of dummy variables indicated whether the household head was employed in a blue-collar occupation, a white-collar occupation, or was unemployed/not in the labor force during a given period. To capture possession of physical capital, two dummy variables were included in the models, indicating whether a household owned property or a business. Social capital was approximated by measuring the proportion of adults in the municipality with domestic and international migration experience. As measures of municipality-level physical capital, we computed the Euclidean distance to the Mexico-U.S. border as well as the distance to the nearest urban center. For the computation of the distance measures, we used the World Administrative Divisions polygon layer and the World Cities polypoint layer from ESRI's spatial data library (ESRI 2012). To capture municipality-level affluence and overall development, we computed a standardized wealth index based on 10 variables, capturing the quality of the housing unit as well as access to services and infrastructure (Cronbach's alpha = 0.85). Natural capital was reflected as the area of land where corn or wheat were harvested, derived from the Terra Populus data extraction system (Kugler et al. 2015), as well as a measure of the percentage of farmland irrigated. In addition, general climatic conditions were captured by a measure of the average daily precipitation as well as the average daily temperature during the 30-year baseline period (1961-90). Finally, the percentage of the male labor force employed in the agricultural sector serves as an indicator of employment in climate sensitive sectors.

Estimation strategy

We employ discrete-time event-history models to investigate the impact of climate change on international and domestic migration patterns (Allison 1984; Singer and Willett 2003). Owing to the hierarchical data structure, we use a multi-level version of the traditional discrete-time event history model (Steele et al. 1996). These models allow for the inclusion of time-varying and time-constant predictors, operating both at the household level as well as the municipality level (Barber et al. 2000). To guard against endogeneity, all predictor variables were lagged by one year. The formal representation of the employed model is provided in Equation 1.

$$\text{logit}(h_{ijk})=\alpha+\beta_1(c_{ik})+\sum_{n=2}^{y}\beta_n(x_{nz})+u_k \quad (1)$$

Within the multi-level event-history model, we estimate the migration hazard h of a household j located in municipality k during each period i. The parameter α represents the baseline hazard and was included as a set of dummy variables, one variable for each year, to allow for the most flexible representation of time (Singer and Willett 2003). The parameter β_1 represents the effect of a generic climate change index c_{ik}, as primary analytical focus of this study. The subscript ik of the climate change index indicates that this variable constitutes a time-varying municipality-level predictor. The expression $\sum_{n=2}^{y}\beta_n(x_{nz})$ represents the effects ($\beta_2, \beta_3, \ldots, \beta_y$) of various control variables ($x_2, x_3, \ldots, x_y$) that are included as time-varying and time-constant predictors at the household and municipality level, as indicated by the generic subscript z. Although respondents usually remember the year of migration with considerable accuracy (Massey et al. 1987), we included a measure of the survey year in all models to account for residual recall bias. Finally, the parameter u_k represents the municipality random effects term, which helps to account for the clustering of households within municipalities. The multi-level models were estimated using the *lme4* package (Bates 2010; Bates et al. 2014) within the R statistical environment version 3.1 (RCoreTeam 2015). For improved speed and convergence properties, we adjusted the integer scalar settings (nAGQ=0) so that the random and fixed effects coefficients were optimized (optimizer="bobyqa") in the penalized iteratively reweighted least squares step (Bates et al. 2014).

Results and Discussion

Migration is determined by various sociodemographic factors (Brown and Bean 2006). As a first step in our analysis, we built a multivariate base model to account for the various migration drivers (Table 4). Due to a strong northwest to southeast climatic gradient, the measure for the distance to the U.S.-Mexico border is highly correlated with baseline temperature ($r = 0.70$) and to a lesser degree with baseline precipitation ($r = 0.37$). The distance-to-border measure was, therefore, removed from the set of predictors. With this adjustment, the variance inflation factor (VIF) remained below 2.8 for all predictors, suggesting that multi-collinearity did not influence the estimates.

We observed many similarities in the factors influencing international and domestic outmigration. An increase in the number of young children in a household reduces the odds of both international and domestic migration, a phenomenon that has been observed in previous research on Mexican migration (Massey and Riosmena 2010; Nawrotzki et al. 2013). A young child requires attention and care, which ties human capital to nurturing activities. Similar, an increase in working experience is associated with a decline in migration probability, in line with prior research suggesting that migration is frequently employed by young males (Fussell 2004; Massey et al. 1987).

Despite some similarities, a number of differences between international and domestic migration responses became apparent. For example, the gender of the household head more strongly influences international compared to domestic migration (Lindstrom and Lauster 2001). Similarly, marital status impacts the likelihood of domestic migration but not of international migration, perhaps due to the fact that domestic moves are more frequently related to family formation (White and Lindstrom 2006), while international moves are usually employment related (Cerrutti and Massey 2001). Property and business ownership significantly reduces the risks of migration only for international moves, likely due to the importance of international migration to overcome liquidity constraints to start a business or build a house (Massey and Parrado 1998). The percentage of adults with international migration experience significantly increases the odds of an international move as a result of the benefits from having access to established migrant networks (Fussell 2004). However, the presence of strong international migrant networks tends to deter domestic moves (Lindstrom and Lauster 2001). The likelihood of international migration but not domestic migration is related to baseline climatic conditions, reflective of the fact that most international migrants originate from the moderate south-central area of Mexico (Hamilton and Villarreal 2011). The results further suggest that domestic migration is more likely from agricultural dependent communities, but that primary crop production (e.g., corn) with irrigation support reduces the odds of a domestic move. Overall, the control variables display directionalities in line with prior research and anticipated by theoretical considerations, lending credibility to the base model.

In the next analytical step, we added one climate index at a time to the fully adjusted model (Table 5). A jack-knife type procedure was employed to test the robustness of the observed effects. During each permutation, one municipality was removed and the model was estimated using the reduced sample (Nawrotzki 2012; Ruiter and De Graaf 2006).

Regardless of which municipality was omitted from the sample, the estimates retained their significance, demonstrating a high degree of robustness of the observed climate effects.

Five out of eight (63%) coefficients showed a significant relationship between climate change and international migration. In contrast, only one out of eight (13%) climate change coefficients was significantly associated with domestic migration. However, for a more conservative evaluation, we performed a formal test of coefficient difference (Paternoster et al. 1998). The results show statistically significant differences in the coefficients only for precipitation during extremely wet days. When using only this measure as evaluation criterion, we again observe significant climate effects on international but not on domestic migration from rural Mexico. At first glance, this observation appears to contradict Findlay's (2011) second and third principles that short distance moves are more likely than long distances, and long distance moves are more likely to be within country than international. However, climate-related international migration in Mexico occurs in a unique cultural context, providing empirical evidence for Findlay's fifth principle, that climate related international migration is possible in the presence of established transnational networks.

In Mexico, a long history of labor migration has led to the creation of a unique culture in which international migration is viewed as normative (Kandel and Massey 2002). Dense migrant networks connect Mexico and the U.S. (Massey and Espinosa 1997), and may operate as “migration corridors” that ease the costs associated with international moves, strongly facilitating climate related migration (Bardsley and Hugo 2010, p. 249).

Another reason for the higher response with international migration may be related to climate impacts on the wage differential (Lilleor and Van den Broeck 2011). Climate/weather events were responsible for approximately 80% of economic losses in Mexico between 1980 and 2005 (Saldana-Zorrilla and Sandberg 2009). As such, climate change may have differentially depressed wages in Mexico, leading to a larger wage gap between Mexico and the U.S., and thereby increasing the attractiveness of an international move. In the light of climate related market failures, international migration to the U.S. may have been viewed as a promising strategy of self-insurance through the partial uncoupling of income streams from local environmental and market conditions (Stark and Bloom 1985). In short, the insurance function of migration, established migrant networks, and a climate related change in the wage differential help to explain why we observe stronger effects of climate change and variability on international compared to domestic migration from rural Mexico in line with Findlay's fifth principle of environmental migration.

When investigating the directionality of significant climate change coefficients, we observe effects in line with the agricultural pathway (cf., Feng and Oppenheimer 2012; Mueller et al. 2014; Nawrotzki and Bakhtsiyarava 2016). We find that an increase in temperature (warming) generally increases outmigration. For example, an increase in the warm spell duration by one standard deviation unit increases international migration by 22% (Odd Ratio [OR] = 1.22). Climate change-related warming trends have been shown to decline crop yields (Lobell and Field 2007). Major staple crops such as corn are particularly sensitive to heat stress during sensitive stages in the growing cycle including flowering and pollination (Sanchez et al. 2014). Following a heat stress related agricultural shock, households may employ migration to diversify their livelihood portfolio (cf., Mueller et al. 2014). The warm spell duration is the only climate change index that is also significantly associated with an increase in domestic migration, suggestive of the importance of temperature effects for livelihoods in rural Mexico (cf., Bohra-Mishra et al. 2014). Although less influential, a cooling in temperature (e.g., increase in % cool days) appears to benefit agricultural-dependent livelihoods, leading to a decline in the odds of international migration.

The precipitation measures generally suggest that an increase in precipitation extremes is beneficial for the agricultural sector, resulting in a decline in livelihood based migration responses. For example, an increase in precipitation during extremely wet days by one standard deviation decreased the odds of an international move by 22% (OR = 0.78). Sufficient precipitation is crucial for plant growth and crop yield (Steduto et al. 2012), especially in a country such as Mexico where little irrigation capacity exists (Carr et al. 2009). The observed trends mirror results using annual average precipitation measures (Hunter et al. 2013; Nawrotzki et al. 2013). Given that the 1990s were particularly dry years (Stahle et al. 2009), high precipitation events may have been important to meet water demands without surpassing thresholds to flooding.

Conclusions

This study contributes important empirical insights to the growing literature exploring whether climate change and variability influences human migration dynamics. We contribute to these larger research efforts by focusing on the important question of destination choice for climate migration from rural Mexico. Overall, we find that climate change more strongly influenced international compared to domestic migration. The stronger effects of climate change on international migration may be explained by the self-insurance function of international migration, the presence of transnational networks that operate as migration corridors, and wage differentials that may increase under adverse climate changes. In line with the agricultural pathway, a warming trend was associated with increased levels of international outmigration while higher levels of precipitation declined the odds of an international move.

A few limitations deserve mention. *First*, the detailed information on migration streams available within the MMP data comes at the cost of national generalizability. The findings predominantly apply to the study communities during 1986-99, although similarities with findings from nationally representative studies (e.g., Nawrotzki et al. 2013) suggest that the general trends may apply more broadly to Mexico. *Second*, the employed interpolation and imputation techniques may have resulted in data smoothing and may therefore underestimate the true variation in the climate variables. However, cross-validation tests provide evidence of the accuracy of the climate change measures. *Third*, although based on daily temperature and precipitation data, the ETCCDI climate indices represent annual aggregates that do not capture more nuanced temporal effects (e.g., growing season). However, the use of ETCCDI indices has the distinct advantage of facilitating the embedding of human ecology research in broader climate research endeavors and will make investigations of the social dimension of climate change more comparable across time and space. *Finally*, data limitations prevented us to account for the influence of broader contextual factors (e.g., structural and institutional). Future research may benefit from qualitative investigations (e.g., interviews and focus groups) to explore the significance of the political and institutional context as well as socio-psychological factors (e.g., risk perceptions and attitudes) for the climate change-migration relationship.

With these limitations in mind, the study has important theoretical and policy implications. Our results challenge the assumption that climate-related migration will be predominantly short distance and domestic as assumed by Findlay's (2011) second and third principles. In contrast, we provide empirical evidence that in some countries, such as Mexico, adverse climate change may strongly increase international migration but have only little impact on domestic moves. Likely the increased sensitivity of international mobility can be attributed to the presence of strong transnational ties. While Findlay's (2011) fifth principle acknowledges the existence of such a dynamic, this is the first study to provide empirical evidence that climate change has much stronger impacts on international compared to domestic migration in rural Mexico. It is important to acknowledge that well-established transnational networks are not unique to the Mexican case. Future research may explore whether international migration is more sensitive to climate factors than domestic migration in other developing countries with well-established transnational ties to industrialized nations.

Recent climate change projections suggest that over the 21st century temperatures will continue to increase while precipitation will decline leading to increased climate variability with adverse impacts on the agricultural sector (IPCC 2014b). Climate change adaptation programs may help stabilize the livelihoods of rural Mexican households and may prove a more cost effective way of reducing undocumented migration than expensive border fortification measures that have been shown to be of limited success in deterring undocumented migration (Massey and Riosmena 2010).

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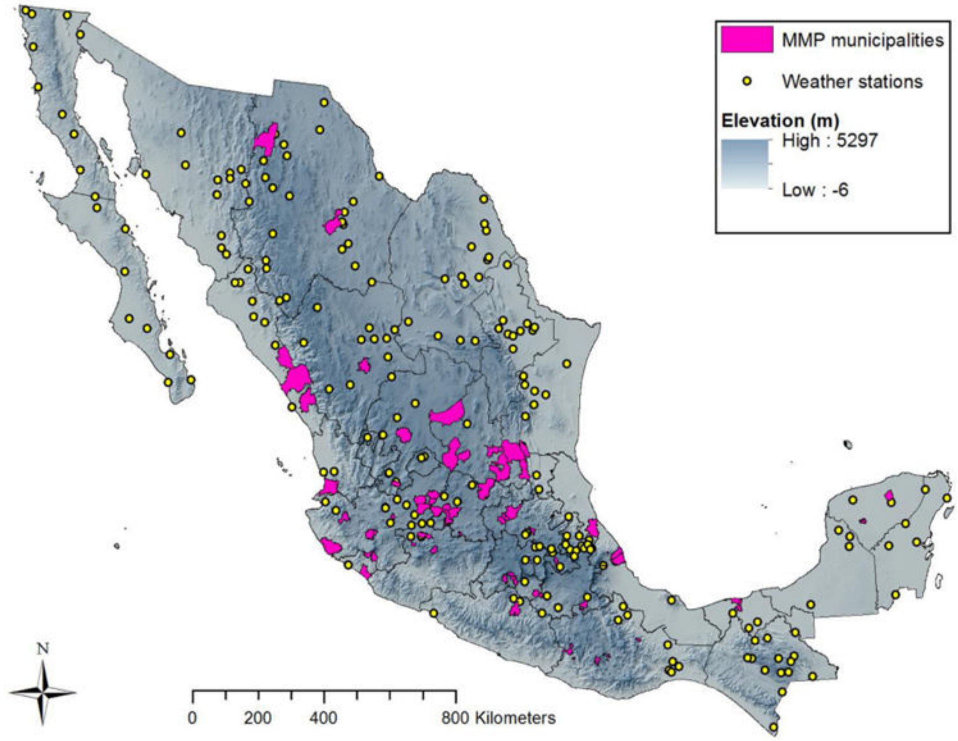

Figure 1. Map of location of rural MMP municipalities and weather stations in Mexico

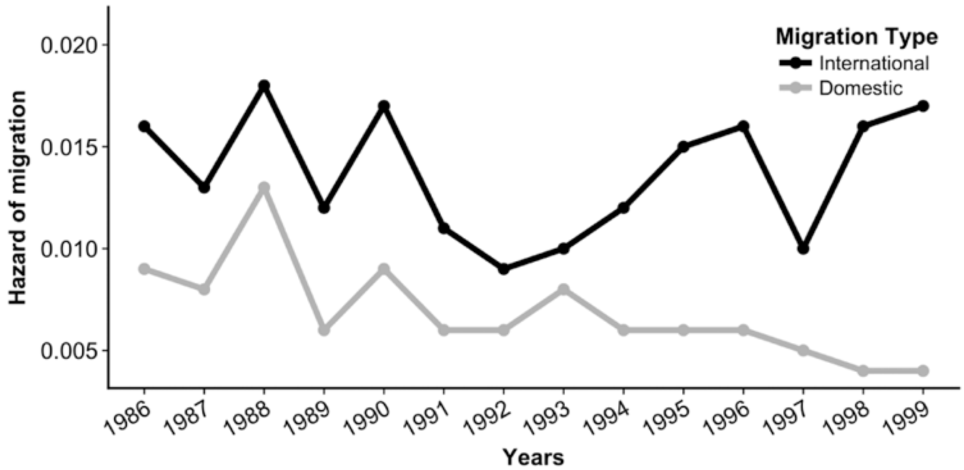

Figure 2. Hazard of international and domestic outmigration from rural Mexico, 1986-99

Table 1

Definition of percentile-based ETCCDI indices employed for the analysis of the impact of climate change on international and domestic migration from rural Mexico, 1986-99

Indicator Name	ID	Indicator definition	Unit
Temperature (high)			
Warm spell duration	wsdi	Annual count when at least six consecutive days of max temperature > 90th percentile	days
% warm nights	tn90p	Percentage of days per year when daily min temperature > 90th percentile	%
% warm days	tx90p	Percentage of days per year when daily max temperature > 90th percentile	%
Temperature (low)			
Cold spell duration	csdi	Annual count when at least six consecutive days of min temperature < 10th percentile	days
% cool nights	tn10p	Percentage of days per year when daily min temperature < 10th percentile	%
% cool days	tx10p	Percentage of days per year when daily max temperature < 10th percentile	%
Precipitation			
Precip very wet days	r95ptot	Annual total precip from days when precip > 95th percentile	mm
Precip extremely wet days	r99ptot	Annual total precip from days when precip > 99th percentile	mm

Note: A full description of the complete set of 27 ETCCDI climate change indices can be found at http://etccdi.pacificclimate.org/list_27_indices.shtml

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Table 2

Average values of ETCCDI climate change indices for selected years for rural Mexico

	SD	Mean		
		1986	1993	1999
Temperature (high)				
Warm spell duration	2.22	-0.21	2.09	6.32
% warm nights	1.16	-0.56	0.85	1.84
% warm days	1.12	-0.17	0.95	3.06
Temperature (low)				
Cold spell duration	1.52	0.01	0.98	3.96
% cool nights	0.75	0.41	0.24	1.60
% cool days	0.81	0.43	0.57	-0.23
Precipitation				
Precip very wet days	0.90	0.12	0.65	0.11
Precip extremely wet days	1.06	0.10	0.69	0.73

Notes: Standard Deviation (SD) was computed across the entire study period 1986-99. Climate change measures were lagged by one year.

Table 3

Summary statistics and source information of control variables employed in the study of international and domestic migration from rural Mexico, 1986-99

	Unit	TV	Source	Mean	SD
Household level (head)					
Social capital					
Female	1|0	No	MMP	0.11	0.32
Married	1|0	Yes	MMP	0.68	0.47
Human capital					
No. of children	Count	Yes	MMP	0.72	0.99
Education	Years	Yes	MMP	5.62	4.19
Working experience	Years	Yes	MMP	22.45	13.34
Occupation: not in labor force	1|0	Yes	MMP	0.09	0.29
Occupation: blue collar	1|0	Yes	MMP	0.83	0.37
Occupation: white collar	1|0	Yes	MMP	0.07	0.26
Physical capital					
Owns property	1|0	Yes	MMP	0.60	0.49
Owns business	1|0	Yes	MMP	0.14	0.35
Community/municipality level					
Social capital					
International migrants	%	Yes	MMP-C	15.53	14.66
Domestic migrants	%	Yes	IPUMS-I	5.11	7.64
Physical capital					
Distance border	100km	No	ESRI	7.28	1.88
Distance city	100km	No	ESRI	0.68	0.43
Financial capital					
Wealth index	z-values	Yes	IPUMS-I	-0.79	0.39
Natural capital					
Corn (area harvested)	sqm/10ha	No	TerraPop	1.26	1.10
Wheat (area harvested)	sqm/10ha	No	TerraPop	0.10	0.27
Farmland irrigated	%	No	INEGI	23.62	25.68

	Unit	TV	Source	Mean	SD
Base period precip (1961-90)	mm/day	No	GHCN-D	2.82	1.34
Base period temp (1961-90)	deg. C	No	GHCN-D	21.07	2.93
Economic environment					
Male labor in agriculture	%	Yes	MMP-C	55.97	17.67

Notes: TV = time varying; Source information: MMP = Mexican Migration Project data available from http://mmp.opr.princeton.edu/; MMP-C = COMMUN supplementary file of the MMP; IPUMS-I = Mexican census data (1% extract) obtained via Integrated Public Use Microdata Series – International (MPC 2013a); TerraPop = cropland type data obtained via Terra Populus (Kugler et al. 2015; MPC 2013b); INEGI = data obtained from Instituto Nacional de Estadística y Geografía (INEGI 2012); GHCN-D = data derived from the Global Historical Climate Network – Daily (Menne et al. 2012); ESRI = Spatial data library ArcGIS Online (ESRI 2012).

Table 4

Multi-level discrete-time event history models predicting the odds of international and domestic migration from rural Mexico, 1986-99

	International		Domestic	
	b	sig.	b	sig.
Household level (head)				
Female	0.54	***	0.78	
Married	0.98		0.65	***
No. of children	0.91	**	0.86	**
Education[a]	0.89		1.03	
Working experience[a]	0.74	***	0.82	***
Occupation: not in labor force	0.97		1.14	
Occupation: white collar	0.54	***	0.79	
Owns property	0.86	*	0.81	
Owns business	0.79	*	0.88	
Community/municipality level				
International migrants[a]	1.52	***	0.82	**
Domestic migrants[a]	1.09		1.08	
Distance city	0.85		0.60	*
Wealth index	1.11		1.05	
Corn (area harvested)	0.90		0.80	*
Wheat (area harvested)	0.98		1.34	
Farmland irrigated [a]	1.03		0.93	*
Base period precip (1961-90)	1.19	*	1.13	
Base period temp (1961-90)	0.90	**	0.98	
Male labor in agriculture [a]	1.05		1.11	*
Model statistics				
Var. Intercept (Mun)	0.269		0.166	
BIC	9371		5362	
N (HH-year)	67508		66220	
N (HH)	7062		6859	
N (Mun)	68		68	

Notes: Coefficients reflect odd ratios;

[a]coefficients reflect an incremental change of 10 units; baseline hazard of migration was controlled by a set of year dummies (not shown); all models control for the survey year to account for recall bias (not shown); Occupation: Blue collar used as reference; all predictors were lagged by one year;

[*]p<0.05;

[**]p<0.01;

[***]p<0.001.

Table 5

Impact of climate change on the odds of international and domestic migration from rural Mexico, 1986-99

	International		Domestic		
	b	**sig.**	**b**	**sig.**	**CoefDif**
Temperature (high)					
Warm spell duration	1.22	***	1.13	**	No
% warm nights	1.06		0.99		No
% warm days	1.30	***	1.19		No
Temperature (low)					
Cold spell duration	0.99		1.03		No
% cool nights	0.92		0.97		No
% cool days	0.84	*	0.95		No
Precipitation					
Precip very wet days	0.76	***	0.89		No
Precip extremely wet days	0.78	***	0.92		Yes

Notes: coefficients reported in odd ratios; each coefficient was estimated using the complete set of household and municipality control variables shown in Table 4; CoefDif = indicates whether coefficients of the international and domestic model are significantly ($p<0.05$) different based on Paternoster et al. (1998);

* $p<0.05$;

** $p<0.01$;

*** $p<0.001$.