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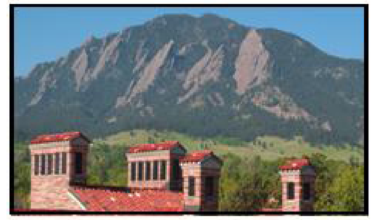

WORKING PAPER

Internal and International Mobility as Adaptation to Climatic Variability in Contemporary Mexico: Evidence from the Integration of Census Data with Satellite Imagery

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Internal and International Mobility as Adaptation to Climatic Variability in Contemporary Mexico: Evidence from the Integration of Census Data with Satellite Imagery

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ABSTRACT

Both internal and international migration are strategies used by rural Mexican households to cope with, or adapt to, weather events, climatic variability, and economic restructuring. Yet prior studies on "environmental migration" in this context have either not discriminated between internal and international movement or have focused exclusively on international movement. In addition, much prior work relied on very coarse spatial scales to operationalize the natural environment. To overcome this limitation, we use fine-grain rainfall estimates derived from NASA's Tropical Rainfall Measuring Mission (TRMM) satellite. The rainfall estimates are combined with other Mexican climate data as well as Population and Agricultural Census information to examine associations between environmental changes and municipal rates of domestic and international migration 2005-2010. Our findings suggest that municipal-level rainfall deficits relative to historical levels are an important predictor of both international and domestic migration, especially in areas dependent on seasonal rainfall for crop productivity. Although our results do not negate results of prior studies using coarse spatial resolution, they offer a more spatially nuanced examination of migration as related to social and environmental vulnerability.

Keywords: Environment, Climate Change, International Migration, Internal Migration Precipitation, Rainfall, Drought, Mexico, TRMM data, Remote Sensing

1 Introduction

Migration and other forms of spatial mobility have historically been deployed by households in order to cope with, or adapt to, the direct and indirect impact of weather events (e.g., damage to property and crops or changing local economic structures, see Hunter 2005; McLeman and Hunter 2010; McLeman and Smit 2006; López-Carr 2012). Because of likely increases in the frequency and severity of weather events with continued climate change in the future (Hoerling and Kumar 2003; IPCC 2007; McGranahan, Balk, and Anderson 2007),[1] migration may become a common coping mechanism in response to environmental change (Cutter, Boruff et al. 2003; Hunter 2005; Pielke and Sarewitz 2005; Cutter and Finch 2008; Finch, Emrich et al. 2010; Gilbert and McLeman 2010; McLeman and Hunter 2010; Wood, Burton et al. 2010).

Scholarship on migration and the environment mostly suggests that mobility within national borders (i.e., domestic migration) is a more common response to environmental change relative to international movements (e.g., Bardsley and Hugo 2010; Henry et al. 2003). Yet recent evidence from Mexico suggests international movement can be a viable adaptation strategy (Feng and Oppenheimer 2012) particularly for households and communities experiencing rainfall deficits (i.e., droughts, see Nawrotzki et al. 2013; Riosmena et al. 2013), or with well-established transnational connections (Hunter et al. forthcoming; Riosmena et al. 2013).

By exclusively focusing on international movement, these prior studies on Mexico migration cannot assess the relative importance of international migration vis-à-vis internal migration as a coping strategy in the face of environmental stress. This gap is a reflection of a

[1] Exacerbating the issue is the unabated emission of carbon dioxide, which is expected to increase the effects of climate change, extending them farther into the future Parry, M. L., Ed. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability: Working Group I Contribution to the Fourth Assessment Report of the IPCC, Cambridge University Press..

broader disconnect between the study of these two forms of migration (King and Skeldon 2010). The gap also signals a lack of deeper, more systematic understanding of the factors leading to different forms of adaptation to climate change. Understanding the nuances of migratory patterns relationship to environmental change is a topic of particular concern in Mexico, as many regions of the country are likely to experience increasingly negative impacts from climate change due to both physiographic conditions and anticipated socio-economic and demographic developments (c.f. Pielke and Sarewitz 2005; Boyd and Ibarrarán 2009).

We build on prior studies by examining the association between international and inter-municipal outmigration and rainfall deficits in Mexico, a country with large levels of internal and international migration out of rural areas and medium-sized towns with high levels of primary sector dependency (Garza 2003; Riosmena and Massey 2012). Further, we advance the state of the literature by employing satellite-derived weather information at the municipal scale - prior scholarship has used weather data aggregated at the state level. Employing this fine grain weather information mitigates the challenges posed by large intra-state variation in weather conditions. We thus improve on prior studies by examining both internal and international movement and by using high resolution satellite-derived weather estimates.

2 Prior Research

To date there is not a migration theory or framework that fully and explicitly incorporates the response of individuals to extreme weather events (Hunter 2005; Gemenne 2011), though it is an area of evolving scholarship (see Black, Kniveton et al. 2011). Nevertheless, many traditional migration frameworks are able to integrate weather-related correlates (Hunter 2005) as location-specific disamenities (Harris and Todaro 1970; DaVanzo 1981; Graves 1983), push factors (Petersen 1958), or stressors (Wolpert 1966). Further, there are clear parallels between migration theories and other frameworks better equipped to understand responses to environmental change. As such, we draw from literatures on rural livelihoods (Scoones 1998), vulnerability and adaptation to climate change (Adger 2006), the new economics of labor migration (Stark and Bloom 1985), and social capital theory (Portes 1998) to conceptualize the potential ways in which increasing climatic variability may have begun to play out in patterns of migration from rural Mexico.[2]

Rural livelihoods are deeply contingent on different forms of human, financial, social, and – in particular – natural capitals (i.e., access to natural resources and/or services, Scoones 1998). Environmental stress can impact natural capital (and rural livelihoods) through both slow[3] and fast[4] onset weather events. The response of households and communities to either class of weather event is shaped by structural conditions and social, economic, and demographic factors (Carney and Britain 2003; Myers, Slack et al. 2008; Raleigh, Jordan et al. 2008). In particular, the vulnerability of socioecological systems (SES) to stress, including environmental, depends on their degree of exposure (e.g., the intensity, frequency, and duration of negative weather events) and two additional factors (Adger 2006; Smit and Wandel 2006).

First, different communities may be differently affected by the same amount of environmental stress according to their degree of sensitivity. In terms of droughts, this could include a community's level of agriculture dependency, irrigation infrastructure availability, and pre-drought water table levels. This suggests that environmental stress may have different effects on households and communities with differing physiographic conditions (e.g., the impact of

[2] De Hass (2010) draws parallels between the Rural Livelihoods and New Economics of Labor Migration frameworks while McLeman and Smit (2006) discuss several commonalities between the New Economics of Labor Migration and the literature on vulnerability and adaptation.
[3] For example, slow onset events are those which occur over months to years, and can include salination of irrigation water due to sea level rise (Adamo 2011), increased rates of soil erosion due to changing rainfall patterns (Nearing et al. 2004), or lower crop yields due to drought (Liverman 1990).
[4] Fast onset events – for example, crop losses related to hailstorms (Klimowski 1998) – occur over days or hours.

precipitation deficits will be relative to long-run conditions and will depend on prior water table levels) and infrastructure (e.g., irrigation) levels. Second, vulnerability is contingent on adaptive capacity, “the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope.” (Adger 2006: p. 270). Household and community adaptive capacity is determined by entitlements not only from the individual financial and human capital but also from the actual and potential resources available from access to market or institutional aid mechanisms (e.g., capital or insurance markets, government programs) coupled with more or less stable networks of exchange and reciprocity (e.g., Goldman and Riosmena 2013).

Migration may also represent an adaptation strategy. For instance, consistent with the New Economics of Labor Migration framework (Stark and Bloom 1985; Massey et al. 1993), migration can be a response to inexistent, inefficient, or malfunctioning credit/capital or crop insurance markets and institutional mechanisms, thus suggesting that mobility is an *ex situ* form of adaptation stemming from a lack of local capacity. However, consistent with Social Capital Theory (e.g., Portes 1998; Massey et al. 1993), mobility facilitated by migrant networks can also be seen as a form of adaption derived from translocal adaptive capacity.

Recent scholarship has highlighted the influence of (deficits in) natural capital on migratory patterns in a manner consistent with movement being used as a form of adaptation to environmental stress (e.g., Gray and 2011; Henry et al. 2004; Massey et al. 2010; Meze-Hausken 2000)(Bilsborrow and DeLargy 1990; Hugo 1996; Curran 2002; Gray 2009; Massey, Axinn et al. 2010; Hunter, Leyk et al. 2012; Nawrotzki, Riosmena et al. 2013). However, just as in the literature on other forms of migration at-large, most of these studies have not fully integrated, conceptualized or tested the conditions that favor internal vs. international movement (for a conceptual exposition see King and Skeldon 2010; for an exception in the empirical study of environmentally-induced migration, see Henry et al. 2004).

Demographically, Mexico represents an interesting case for understanding the interrelation of these mechanisms (or those leading to a pattern of concentration in one particular type of destination) given the large and sustained tradition of both international and internal migration from rural areas (cf. Durand et al. 2001; Garza 2003).[5] Climatologically, rural Mexico is also likely to be particularly sensitive to impacts associated with climate change, attributable to the large changes expected in sub-tropical areas (Boyd and Ibarrarán 2009). There is growing evidence that the country may already be experiencing some effects of climate change, including sea level rise and changes in precipitation patterns (Hopp and Foley 2003; Burke and Maidens 2004; Lesser 2007; Sachs and Redlener 2010). Hernandez et al. (2003) suggest that further increases in carbon emissions could cause up to 39 percent of the Mexican territory to be under persistent drought conditions. With an ongoing lack of international action in reducing carbon emissions, these changes are likely to either become permanent or exacerbated over time (Parry 2007). Some climate scenarios project that areas in southern Mexico will effectively become unsuitable for rain-fed agriculture (Adamo and de Sherbinin 2011).

Environmental stress for Mexican residents – especially in poor rural households – has become increasingly evident (Eakin 2005; Gay, Estrada et al. 2006; Eakin and Wehbe 2009). With only 23% of cropped land irrigated in 2001(Carr, Lopez et al. 2009), many rural farmers in Mexico are strongly dependent on rainfall and thus are highly vulnerable to shifts in climatologic patterns. These households and communities have also had traditionally low adaptive capacity

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[5] For instance, between 2005 and 2010, 1.1 million Mexicans emigrated internationally. Although this number is large, it represents a slowdown relative to the 1995-2000 census window, during which approximately 1.6 million migrants were identified as migrating internationally. On the other hand, domestic migration has seen an uptick over the same time interval, increasing from 5.8 million recorded migrants between 1995 and 2000 to 6.3 million in 2005-2010.

given their chronic underdevelopment, a situation that has generally worsened in recent years with agricultural commodity market liberalization (Eakin 2005)(Janvry and Sadoulet 2001)(Zepeda et al. 2009).

Some research has focused on examining the conditions under which U.S.-bound migration is a likely response to weather events and, more broadly, a changing climate (Hunter et al Forthcoming; Feng, 2012 ;Munshi, 2003; Nawrotzki, 2013; Riosmena et al., 2013). Using econometric techniques on state-level data, Feng and Oppenheimer (2012) find that Mexican states experiencing climate-induced reductions in crop yields are associated with higher migration rates to the United States. Although these results suggest that international migration may be a common response to environmental change in rural Mexico, other work using migration data at finer scales (but state-scale rainfall) suggests this relationship is highly contingent on the exposure and sensitivity of communities as well as the available adaptive capacity portfolio. Using data from dozens of rural communities from the Mexican Migration Project, Hunter et al. (2013) only find an association between rainfall deficits and migration out of households located in Central-Western Mexico, the historical heartland of U.S. migration. They find no consistent relationship between rainfall and international migration in communities outside of the Central-West.[6] Further, Hunter and colleagues find that this relationship is stronger for households where the head has prior experience migrating internationally, suggesting that migration is a more likely adaptation strategy in places and households with higher levels of (migration-specific) social capital.

The general notion that international migration appears to be a common strategy in the wake of more extreme drought is consistent with other, broader-scope studies within Mexico.

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[6] Using a prior version of the MMP that by and large only included Central-Western communities, Munshi (2003) also finds a relationship between rainfall shocks and migration.

Using 2000 Census information on Mexican emigration from 1995-2000, Nawrotzki et al. (2013) find an association between climatic variability and rural Mexico-U.S. migration within historically drier regions. Using data from a decade later (2005-2010), Riosmena et al. (2013) also find a general association between rainfall deficits and migration but only in states experiencing below-average precipitation. These findings together suggest that international movement may be a more common response to more extended droughts. Further, Riosmena and colleagues also find the association stronger among households in municipalities with a substantial migration tradition, again suggesting international movement is used to cope with more severe environmental stress in places and households with the necessary social capital.

None of these studies examined the relationship between climatic variability and internal migration, thus leaving a gap in knowledge as to whether internal movement may be a more common response than international movement, particularly for less severe/prolonged rainfall deficits. Another alternative is that communities may "specializing" in internal relative to international movement because of historical-structural circumstances, and these historical patterns may shape response to environmental stress (see Lindstrom and Lauster 2001).

Data and Methods

Data

The analyses integrate data from all 2,455 Mexican municipalities, a spatial scale roughly analogous to U.S. counties (see Figures 1 and 2). Data sources are summarized in Table 1 and individual variables in Table 2. Our two main indicators of internal (i.e., inter-municipal) and international migration for each municipality of origin between 2005 and 2010 were calculated using a 10% extract from the Integrated Public Use Microdata Series (IPUMS) made available by the Minnesota Population Center (2011) off the original long form sample data collected by the Mexican National Institute of Statistics and Geography (INEGI). From this extract, we also calculated basic sociodemographic information such as age, employment status, remittances received (as a proxy for the intensity of migrant networks) and income. In addition, we obtained official population estimates from INEGI derived from the 2005 Population Count data, a mid-decade census-like enumeration, which we use as an offset (i.e., estimates of exposure to the risk of emigrating) in our Poisson models.

Places more dependent on agriculture, particularly those without irrigation systems (i.e., more dependent on rainfall) are likely more sensitive to climate variability. To examine this relationship, we use information on crop output as well as how much of this output was produced in rainfed lands in each municipality using data from the Mexican Agricultural Census (2007), also carried out by INEGI.

In line with prior work, we construct a measure of precipitation relative to long-term conditions as a proxy for levels of climatic variability. First, we obtained short-term (2005-2009) rainfall averages calculated based on Tropical Rainfall Measuring Mission (TRMM) satellite observations to estimate rainfall deviations from long term records[7]. Because TRMM's Precipitation Radar has only been online since 1998, we lack data from the same source to estimate our long-term baseline. For this purpose, we use a classification of dryness-wetness developed by INEGI personnel (based on a modified Koeppen classification system), who used this classification scheme to create climate microregions based on dryness and temperature. We

[7] The TRMM data was retrieved processed by the NASA Goddard Space Flight Center using version 7 of algorithm 3B42 (see http://trmm.gsfc.nasa.gov/3b42.html), which translates High Quality Microwave Estimates (HQ) and Infrared estimates from the National Climatic Data Center (NCDC) and Climate Prediction Center (CPC) into estimates of 3-hourly precipitation. The quality of HQ is known to vary over time as additional data sources have been introduced, leading to inaccuracies over small time steps (though at the monthly scale these are believed to be corrected). Efforts are currently underway to replace the 3B42 algorithm with an updated approach – the Global Precipitation Measurement IMERG algorithm (see Huffman 2012).

use the dryness classification (in Mexico, ranging from very dry, dry, semi-dry, sub-humid, and semi-humid) to estimate the baseline. The contemporary dryness of each municipality is estimated by dividing the TRMM estimates into quintiles, and compared to historic classifications to construct a binary indicator of if each municipality had more or less than expected rainfall during the 2005-2009 period.

2.2 Methods

To assess the influence of changes in precipitation on migration we utilize the sustainable livelihoods (Scoones 1998; Carney and Britain 2003) and vulnerability and adaptation frameworks to aid in the identification of five types of independent variables representing human, physical, financial, social, and natural capital (see table 2). Utilizing this framework, we broadly follow a two step procedure:

1) We aggregate satellite weather (0.25 degree raster grid) and IPUMS (individual or person-scale microdata) data to the municipality scale,
2) Global, stratified Poisson models for outmigration are fit to the data.

2.2.1. Aggregation of Data

Because both the social and biophysical data used in this study are produced at different scales, they must be aggregated to relevant spatial units for analysis. This is done using two different approaches, one for tabular data (IPUMS) and one for spatial data (TRMM precipitation data). In the case of IPUMS-sourced tabular data, using the 10% sample, migratory and sociodemographic characteristics were estimated by calculating a weighted average of all households within each municipality. Weights for each person (and household) were provided by IPUMS, and are calculated to allow representation of the full population from the limited IPUMS sample. The final municipality-level estimates are joined to spatial data layers delineating municipalities obtained from INEGI. Both long term climate and agricultural census information were provided by INEGI at the municipality scale, and thus required no aggregation.

The TRMM precipitation data were generalized to the municipality scale following the piecewise approximation procedure detailed in Goodchild et al. (1993):

$$V_t = \sum_{s=1}^{S} U_s \left(\frac{a_{st}}{\sum_{t=1}^{T} a_{st}}\right) \qquad \textbf{eq. 1}$$

where *t* is an identifier for the zone one is aggregating to (the municipality), *s* is an identifier for the zone one is aggregating from (i.e., a TRMM pixel), *T* and *S* represent the total of all zones *t* and s, U_s represented the value of interest at zone s (in our case, precipitation measured in mm/hour), a_{st} is the area of overlap between the two zones, and V_t is the estimated value for the zone one is estimating. In our application, this procedure weights each pixel of the TRMM dataset according to its overlap with each municipality – TRMM pixels that fall entirely inside of a municipality will have their entire value utilized when calculating the overall average, while those that fall on the border will be assigned a smaller weight according to the area of overlap.

2.2.2 Modeling

We use Poisson regression models to examine the influence of changes in precipitation on both international and domestic out-migration between 2005 and 2010. We chose a Poisson specification due to both the left-skewed distribution of the count data (counts of migrants in a municipality) as well as because the variance approximately equals the conditional mean. The models take the general form:

$$\log(y_i) = P + \beta_0 + x_n\beta \qquad \textbf{eq. 2}$$

where y is the count of migrants (either domestic or international) that left municipality i between 2005 and 2010. Given that differences in the number of migrants could be a simple reflection of place size, each model is fit with an offset term, P, also known as exposure, in our case the municipality's total population. By constraining the coefficient of P to an implicit value of 1, we effectively model the rate of out-migration as opposed to migration flows. In addition, β_0 is the constant (i.e., the mean municipality migration rate with all covariates equal to zero), while β denotes a vector of k coefficients for each independent variable.

Two separate models are fit, one for international and one for domestic migration (see table 2). Each model is stratified into two groups according to their degree of sensitivity to environmental stress associated with rainfall deficits. First, we define municipalities where more than 50% of crops are rainfed to have a more direct, higher level dependence on rainfall for agriculture (>50% rainfed). Those municipalities at or below the 50% threshold are defined as less directly reliant on rainfall[8].

3 Results

A total of four models were fit – two for municipalities with a low reliance on rainfed agriculture (a separate model for both domestic and international migration), and two for municipalities with a high reliance on rainfed agriculture. Final model selection was conducted using an iterative, deductive process in which a variety of factors including model fit, variable significance, and interpretability were considered. During the modeling process, two measures of

[8] The 50% rainfed value was chosen to build strata that differentiate municipalities of low and high rainfall dependence, as we hypothesize that the relationship between outmigration and rainfall will be different across these two groups. Because this 50% threshold is somewhat arbitrary, we tested the robustness of our model by systematically altering the threshold to 60, 70, 80 and 90 percent. Regardless of the threshold chosen, the directionality of our variable of interest (rainfall) remained the same.

human capital (the percent of individuals disabled and the percent of individuals that were female) were omitted in both models due to multicollinearity with other independent variables.

3.1 Rainfall-Reliant Municipalities (>50% Rainfed)

The results of the analysis are presented in table 3. Goodness of fit (pseudo r^2) for the model explaining international migration in rainfall-reliant municipalities is 0.51. All variables are significant (alpha = .05). In municipalities that are highly reliant on rainfall for agricultural purposes (>50% rainfed), more rainfall is associated with less international migration. This effect was particularly strong for municipalities that experienced less-than-usual rainfall.

With regard to control variables, international migration has a negative relationship with income in rainfall reliant areas – municipalities with higher levels of household income tend to experience lower levels of international migration. There is a positive relationship between remittances and international outmigration, and a negative relationship between the historic number of domestic migrants (1995-200) and contemporary (2005-2010) international migration. In highly rainfall-dependent municipalities, an older age tended to reduce the number of migrants. Larger agricultural areas resulted in less migration in rainfall-dependent municipalities.

For domestic migration, the goodness of fit (pseudo r^2) for our model examining rainfall-reliant municipalities is 0.33. All variables are significant (alpha = .05). In municipalities that are highly reliant on rainfall for agricultural purposes (>50% rainfed), additional rainfall resulted in fewer domestic migrants. This effect was even stronger in municipalities that experienced less-than-usual rainfall.

In municipalities with high levels of reliance on rainfall there is a negative relationship between domestic migration and remittances, as well as the total agricultural area. Historic domestic migration (1995 – 2000) had a positive correlation with domestic migration during the study period (2005-2010). Increasing age also tended to increase the number of migrants.

3.2 Low Rain Reliance

In terms of international migration, the goodness of fit (pseudo r^2) is 0.65 for municipalities with low (≤50%) rain reliance. All variables are significant (alpha = .05). More rainfall is associated with higher levels of international migration. International migration retains a negative relationship with income, a positive relationship between remittances and outmigration, and a negative relationship between the historic number of domestic migrants (1995-200) and contemporary (2005-2010) international migration. In low rainfall reliance municipalities an older age tended to increase the number of migrants. Larger agricultural areas resulted in more migration in low reliance areas.

For the model examining domestic migration in low rainfall reliance municipalities, goodness of fit (pseudo r^2) was 0.33. All variables – except agricultural surface size - are significant (alpha = .05). In low rain reliance municipalities (<50% rainfed) that experienced less rainfall than was historically usual, additional rainfall also decreased the number of domestic outmigrants.

In areas with low reliance on rainfall fed agriculture, domestic migration exhibits a negative relationship with remittances. Historic domestic migration (1995 – 2000) retained a positive correlation with domestic migration during the study period (2005-2010). Increasing age tended to decrease the number of domestic migrants.

4 Discussion

4.1 International Migration: Control Variables

The results from the model for international outmigration are mediated by the unique migratory situation in Mexico. With nearly a hundred years of history of migration to the United States, social networks are critical for individuals seeking to use migration as an adaptive strategy. This is represented in our model as captured by the percentage of households receiving remittances (REMIT), making the assumption that a larger number of individuals sending remittances also likely represents a larger number of individuals a community has access to. The results for this variable are as we theoretically expected – a positive, significant coefficient indicating that more households receiving remittances also results in additional migration. Further, this coefficient was both significant and showed the same direction irrespective of the rain fed threshold chosen for stratification (see table 3, panel B).

Also interesting with regard to international migration is the change in direction for the AGE coefficient between strata. For municipalities with low rain reliance, age had a small but positive and significant coefficient, whereas for rainfed municipalities the inverse was true. This could be indicative of the mobility of each population – individuals likely to work at or own farms with extensive irrigation may have access to funds and social networks later in life than those that work or own rain-fed farms. It could also indicate a preference of age groups for certain types of migration.

The negative coefficient on income for international migration is unique, and is in contrast with findings in other countries. This coefficient is also robust, having a negative value regardless of the threshold chosen to define “high rain dependence”. Again, the unique setting of Mexico is likely shaping this association – on the one hand, social networks are dominating the flows, while on the other hand the physical proximity of Mexico to the U.S. will reduce the costs of international migration. Further, the lack of detailed information on education structure within municipalities could be mediating this relationship, with higher income groups tending to be more educated and thus less likely to move.

4.2 Domestic Migration: Control Variables

In the case of domestic migration, the relationship between income and migration was positive, as expected, in both strata. While the REMIT variable is negative for domestic migration, this does not indicate that social networks are less important. Rather, domestic networks are captured by the HIST_MIG variable, which records the number of migrants a municipality sent to other domestic destinations between 1995 and 2000. For both our initial 50% strata and all robustness strata, the coefficient for HIST_MIG is both positive and large. This suggests that domestic social networks are key in determining migratory strategies.

Domestically, AGE has a positive coefficient in rainfall dependent areas and a negative coefficient in areas with low rain reliance. This is the inverse relationship seen for international migration. Similarly to the international case, this could be indicative of broad preferences of age groups for different types of migration – in this case elderly populations choosing domestic over international migration.

4.2 Comparing International and Domestic Migration as associated with Rainfall

In our models we utilize three terms to capture the impact of rainfall on migration: LESS_RAIN, RAINFALL, and an interaction term between these two. LESS_RAIN, a binary value in which a one indicates the municipality received less rainfall than usual, always had a positive relationship with migration. This suggests that, for both domestic and international migration, areas that received less rainfall than usual also sent more migrants than usual. As shown in the robustness test (figure 4; table 3, panel A), this relationship is always true for rain-dependent municipalities.

RAINFALL and the interaction term with municipalities that had less-than-usual rainfall (LESS_RAIN*RAINFALL) both help to capture the absolute impact of rain on migration. In both the international and domestic case, municipalities that are heavily dependent on rainfed agriculture always exhibited a negative relationship between precipitation and outmigration, i.e. if it rained more in rainfed areas, fewer migrants left. In municipalities that are well irrigated this relationship varies between international and domestic migration. Internationally, we see a positive relationship between rainfall and migration (table 3, panel A), potentially reflecting flooding or other natural disasters. However, in municipalities where less rainfall than usual was received this relationship is reduced in magnitude, sending fewer migrants. Domestically, we see the same small positive relationship, but municipalities where less rainfall than usual was received ultimately have a negative relationship due to the incorporation of the interaction term.

4.3 Comparison to past analysis using state resolution information:

The overall findings, reported in this paper, mirror those observed in prior research endeavors using coarser spatial resolution (e.g., state level). Two studies (Munshi, 2003; Hunter, Murray, and Riosmena, 2013) have used a non-random subsample of 7 and 12 Mexican states, respectively, and find that a decline in state-level precipitation was associated with international out-migration. Due to the non-random selection of states and the different nature of the sample (ethnosurvey), these studies can, however, only be used to confirm the general trend observed in the present study. Two studies (Feng and Oppenheimer, 2012; Nawrotzki, Riosmena, and

Hunter, 2013) employed census data for all 32 Mexican States and are therefore better positioned for a comparison of findings. Feng and Oppenheimer (2012) employed an instrumental variable approach that uses temperature and precipitation to predict crop yield, which in turn was used to estimate international outmigration. Due to this difference in measurement the results of Feng and Oppenheimer (2012) can, however, only be used to confirm the general trend that adverse climatic conditions increase international outmigration.

The study by Nawrotzki et al. (2013) is best positioned for comparison due to the use of a comparable measure of short term change in precipitation levels. Similarly to the present study, Nawrotzki et al. (2013) find that a rainfall decline was associated with an increase in international out-migration but only for states that were historically considered as “dry.” In contrast, the present analysis at the municipality level, paints a picture of heightened population sensitivity towards adverse environmental conditions, where a decline in rainfall spurs international outmigration at accelerated rates for historically dry areas. While the four prior published works have investigated the rainfall – migration association for the years prior to 2000, this study extends the generalizability of the broader trend by demonstrating a significant association between weather patterns and international outmigration one decade later under largely different political (e.g., increased border enforcement, (Angelucci 2005)) regimes.

5 Conclusions

This paper examines the relationship between migration and precipitation at the municipality scale in Mexico. We utilize fine-grain satellite-retrieved precipitation information in conjunction with INEGI census information, and examine international and domestic migration separately. We find that for municipalities that are highly reliant on rainfall for agricultural purposes, additional rainfall reduces the number of outmigrants. Further, we highlight the importance of disaggregating international and domestic migration, finding that age structure, agricultural base size, and migrant networks operate differently between these types of migration.

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Table 1. Data sources used in the analysis.

Dataset	Description	Source
Integrated Public Use Microdata Series (IPUMS)	Internationally harmonized micro-census data. Includes sociodemographic, migration, household, and geographic information in Mexico.	Preprocessed data was retrieved from the Minnesota Population Center (2011). Original data from National Institute of Statistics and Geography, Mexico
Tropical Rainfall Measuring Mission (TRMM)	High resolution, satellite-derived estimates of precipitation available since circa 1998.	(NASA-JAXA 2013)
Remittance Data	Provides information on the amount, in dollars, each household received for remittances.	2000 Census (INEGI)
Koeppen Classifications	Long-term climate classifications for different biomes across Mexico	INEGI

Table 2: Variables used in this analysis.

Variable			Description	Source	Expected Sign INT	Expected Sign DOM
Response variables	**Migration**	INT_MIG	Proportion of the population that migrated out of a municipality to an international destination, 2005-2010.	IPUMS	N/A	N/A
		DOM_MIG	Proportion of the population that migrated out of a municipality to a domestic destination, 2005-2010.	IPUMS	N/A	N/A
Explanatory variables	**Physical Capital**	IRRIG	% of Crop Units Irrigated within a Municipality	INEGI	+	+
	Financial Capital	INCOME	The average peso's earned by households within a municipality, 2010.	IPUMS	+	+
	Human Capital	DISAB	Proportion of individuals within the municipality who are disabled, 2010.	IPUMS	-	-
		AGE	Average age of individuals within the municipality, 2010.	IPUMS	-	-
		SEX	Proportion of individuals within the municipality who are female, 2010.	IPUMS	+	+
	Social Capital	REMIT	The proportion of households within a municipality that received at least some remittances.	INEGI	+/-	+/-
		HIST_MIG	The proportion of the population that migrated domestically from a municipality from 1995 to 2000.	IPUMS	+/-	+/-
	Natural Capital	RAINFALL	The amount of rainfall (in average mm / hour) each municipality received from 2005 to 2009.	TRMM	-	-
		LESS_RAIN	A binary 1 or 0, in which a 1 indicates the region received more rainfall than was historically usual.	TRMM / INEGI	-	-
		TOTALAGSURFACE	The total surface area of agricultural land within each municipality.	INEGI	+/-	+/-

Table 3: Poisson regression coefficients modeling municipal rate of international and internal migration in 2005-2010 according to level of rainfall reliance in the municipality.

	(A) International migration		(B) Internal migration	
	More Direct Rain Reliance (>50% rain fed)	Less Direct Rain Reliance (≤50% rain fed)	More Direct Rain Reliance (>50% rain fed)	Less Direct Rain Reliance (≤50% rain fed)
INCOME	-0.0002	-0.00009	0.0001	0.0001
AGE	-0.012	0.02035	-0.02	-0.03
REMIT	0.054	0.065	0.02	0.23
LESS_RAIN	0.28	0.065	-1.9	0.48
RAINFALL	-0.53	7.7	-0.398	-2.7
LESS_RAIN*RAINFALL	-0.811	-2.1	-0.000003	-0.000002º
TOTALAGSURFACE	-0.00000062	7.58E-08	4.98	4.06
HIST_MIG	-5.04	-6.98	-4.5	-2.16
Constant	-3.8	-5.23	**2121**	**247**
N	2092	242	0.54	0.33
Pseudo R^2	0.51	0.65		

Notes: All variables marked with a º are insignificant (p > .05).
Municipalities with greater than 50% of crops that are rain fed are placed into the "High Rain Reliance" group.

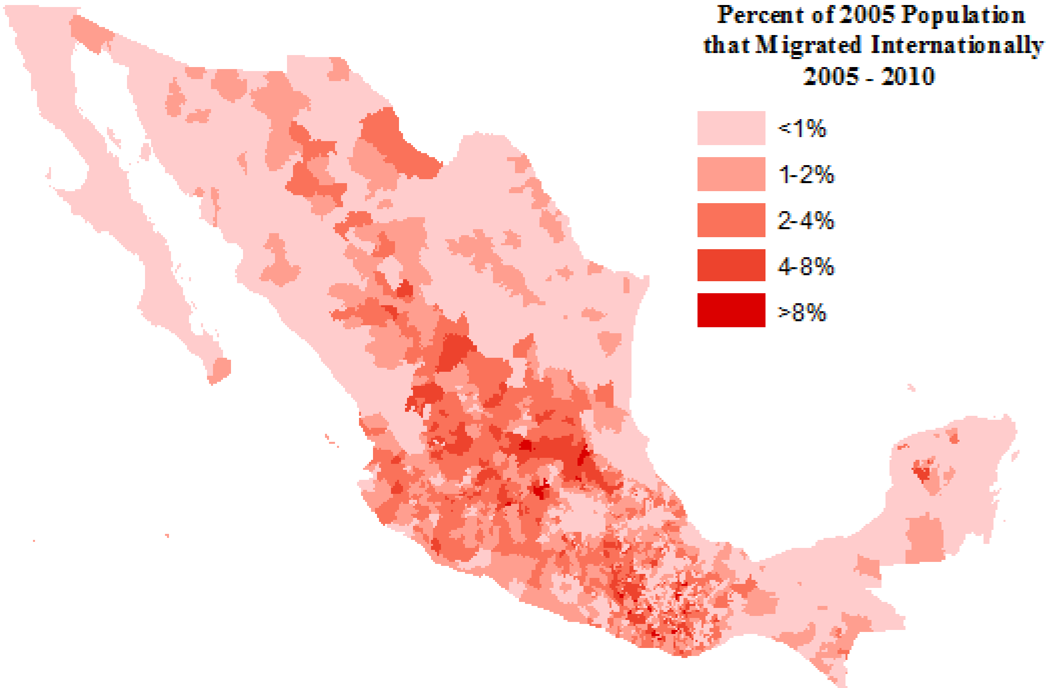

Figure 1. Municipal international migration rate in 2005-2010

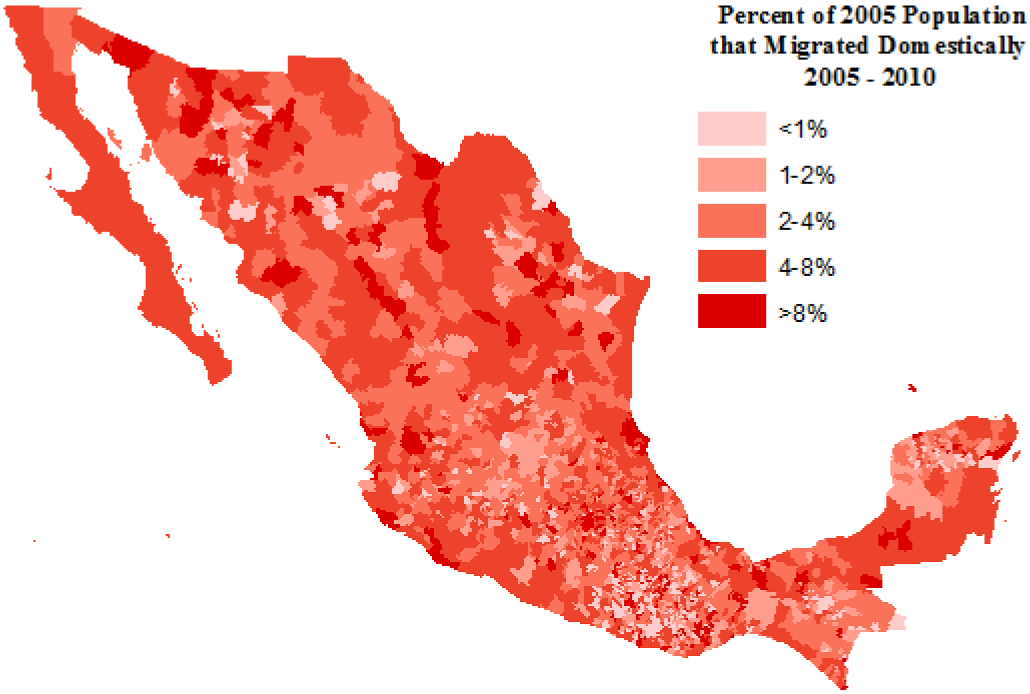

Figure 2. Municipal domestic migration rate in 2005-2010

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