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Undocumented migration in response to climate change

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Abstract

In the face of climate change induced economic uncertainty, households may employ migration as an adaptation strategy to diversify their livelihood portfolio through remittances. However, it is unclear whether such climate migration will be documented or undocumented. In this study we combine detailed migration histories with daily temperature and precipitation information for 214 weather stations to investigate whether climate change more strongly impacts undocumented or documented migration from 68 rural Mexican municipalities to the U.S. during the years 1986–1999. We employ two measures of climate change, the warm spell duration index (*WSDI*) and the precipitation during extremely wet days (*R99PTOT*). Results from multi-level event-history models demonstrate that climate-related international migration from rural Mexico was predominantly undocumented. We conclude that programs to facilitate climate change adaptation in rural Mexico may be more effective in reducing undocumented border crossings than increased border fortification.

Keywords

Climate change; environment; climate change adaptation; international migration; undocumented migration; documentation status; rural Mexico

Introduction

Climate change has the potential to strongly influence economic conditions through the agricultural sector (Boyd & Ibarraran, 2009). For example, in Mexico about 80% of

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Ethics Statement
The analyses described in this paper were performed using secondary data obtained from various publically available sources as outlined in the Data and Methods section.

economic losses between 1980 and 2000 have been attributed to climate and weather shocks (Saldana-Zorrilla & Sandberg, 2009). In rural areas of Mexico, households heavily depend on agricultural production for income and sustenance (de Janvry & Sadoulet, 2001; Winters et al., 2002). Similar to many households in various developing countries, rural Mexican households often lack the technological infrastructure to guard against adverse climate impacts (Gutmann & Field, 2010). For example, in Mexico only about 23% of arable land was irrigated in 2000 (Carr et al., 2009). As such, we assume an agricultural pathway in which climate change impacts agricultural production, leading to livelihood instabilities (Black et al., 2011a).

In response to livelihood uncertainties, households may employ migration as a household-level risk management strategy (Massey et al., 1993). A household may send a migrant to an international destination to access a stable income stream through remittances, which is independent of local climate and market conditions (Stark & Bloom, 1985). A number of studies have explored the relationship between climate and migration from Mexico and find a significant relationship between rainfall decline and international outmigration, largely from rural areas with established transnational networks (Feng & Oppenheimer, 2012; Hunter et al., 2013; Nawrotzki et al., 2013). However, no study to date has investigated whether climate change is associated with undocumented versus documented/legal migration.

Insights from related literatures suggest that climate change may influence undocumented migration in different ways than documented migration. If climatic shocks, such as droughts, impair the livelihoods of rural farmers, households may not have sufficient time for the formal process of visa application, which can take years to complete (Papademetrious & Terrazas, 2009), and may instead choose the more rapid path of undocumented border crossing. This assumption is in line with the literature on migratory responses to the impact of economic recessions. Historical evidence suggests that economic crises in Mexico have resulted in surges of undocumented migration to the U.S. (Hanson & Spilimbergo, 1999); likewise, unauthorized movement is also much more responsive to economic crisis in the U.S. than movement through legal immigration channels (Papademetrious & Terrazas, 2009). In a similar way, climate shocks may indirectly influence migration dynamics through their impacts on various economic sectors (Boyd & Ibarraran, 2009) and therefore disproportionately drive undocumented migration. To shed light on this unsolved puzzle, this research note investigates whether climate change and variability more strongly influences undocumented versus documented migration from rural Mexico to the U.S.

Data and Methods

Data

We combined detailed migration histories from the Mexican Migration Project (MMP) (Massey, 1987) with daily temperature and precipitation information obtained from the Global Historical Climate Network (GHCN) (Menne et al., 2012) for 214 weather stations across Mexico. Both data sets undergo rigorous quality checks and have been used in a wide range of published research (Alexander et al., 2006; Hunter et al., 2013; Massey et al., 2015; Wu, 2015). The MMP started collecting data in 1982 and selects between two and five communities each year, interviewing a random sample of 200 households in each community (Massey, 1987). For this study, we employed data from MMP waves 1987–2013, resulting in an analytical sample of 7,062 households located in 68 rural municipalities. Although not strictly nationally representative, validation exercises have demonstrated that the MMP very accurately reflects the characteristics and behavior of international migrants (Massey & Capoferro, 2004).

The MMP data contains a wealth of sociodemographic information on all household members and, most important for this study, asks about the year of the first move to the U.S. and the documentation status during that particular trip. This retrospective information on the date of the first move enabled us to construct an event-history file, indicating the household migration status for each observation year during the study period of 1986–1999. This period was chosen as a time of relatively stable migration policies following the enactment of the Immigration Reform and Control Act (IRCA) in 1986 (LoBreglio, 2004) and because Mexico experienced conditions of increased temperature and drought during the 1990s (Stahle et al., 2009) that resemble conditions expected under climate change (Collins et al., 2013; Wehner et al., 2011). A reduction in the weather stations available through GHCN after 1999 prevented the construction of the climate measures for later years.

Outcome variable

In the cultural context of Mexico, migration needs to be considered as a household-level strategy (Cohen, 2004). A household sends a migrant to an international destination as a self-insurance mechanism against local market failure, expecting the migrant to remit money to support the household in Mexico (Massey et al., 1993; Taylor, 1999). We therefore focus on the household as the unit of analysis in line with prior work (de Janvry et al., 1997; Hunter et al., 2013; Kanaiaupuni, 2000). We constructed an event history file (risk set), in which household-years are assigned a value of 0 when the household was at risk for international migration but no move occurred, a value of 1 if an undocumented international move occurred, or a value of 2 if a documented international move occurred. Households are at risk for migration if they did not send a member to the U.S. before 1986. Households were included in the data set for years after 1986 as long as the household head was at least 15 years of age, and after the date of the first union formation (household heads can get divorced, widowed, and remarry in later years). These criteria ensure that households were truly formed during years when they were exposed to the risk of migration. Households are removed from the data set following the year of the first move, when the household head turns 65, when the household is censored at the survey year, or at the end of the study period in 1999. Households may move in and out of the study community and are only exposed to the risk of migration if at least one core household member (head or spouse) was present during a given year.

Although other pathways are possible (e.g., Burke et al., 2009; Nawrotzki et al., 2009), we assume that climate effects lead to migration through negative impacts on the agricultural sector (Mueller et al., 2014). Rural households in Mexico heavily depend on agricultural production for income and sustenance (Conde et al., 2006; Wiggins et al., 2002; Winters et al., 2002). As such, we focus our analysis on 68 municipalities that contain rural MMP communities (population < 10,000) dispersed across the country. Figure 1 shows the location of the rural municipalities as well as the 214 weather stations for which daily temperature and precipitation data was available.

Primary predictors

Previous research shows that temperature and precipitation above and below certain thresholds have the strongest impact on agricultural production (Lobell et al., 2013; Schlenker & Roberts, 2009). As such, we employ two climate change indices that reflect percentile-based threshold effects, the warm spell duration index (*WSDI*) and the precipitation during extremely wet days (*R99PTOT*). The warm spell duration index was computed as the annual count of days when at least six consecutive days of maximum temperature were above the 90th percentile of the 30-year reference period (1961–1990). The 30-year period of 1961–1990 is known as "climate normal" and recommended by the World Meteorological Organization (WMO) as reference period for the study of climatological trends (Arguez & Vose, 2011). The precipitation during extremely wet days was computed as the annual total precipitation from days when precipitation was greater than the 99th percentile of the 30-year reference period (1961–1990). These climate change indices have been formalized by the Expert Team on Climate Change Detection and Indices (ETCCDI), sponsored by the World Meteorological Organization and the United Nations, to increase the comparability of climate change studies across time and space (Peterson & Manton, 2008).

Although the GHCN undergoes rigorous quality checks (Menne et al., 2012), about 21% of the records were missing, largely due to instrumentation errors. As recommended by the climatological literature (Auffhammer et al., 2013), we imputed missing data to generate a balanced panel of complete weather station records. We employed Multiple Imputation (MI) (Allison, 2002) using the R package *Amelia* (Honaker et al., 2011), which was designed for the imputation of time-series data by explicitly accounting for temporal trends. The complete time series of daily temperature and precipitation records was then used as input to construct the two climate change indices for each weather station for the years 1961–1999 using the R package *climdex.pcic,* maintained by the Pacific Climate Impact Consortium (Bronaugh, 2014).

We then employed cokriging as a geostatistical method of interpolation (Bolstad, 2012; Hevesi et al., 1992) to generate a surface of climate change index values across Mexico. Cokriging is a method frequently employed to interpolate climate measures and indices (Aznar et al., 2013; Rogelis & Werner, 2013), and it allowed us to account for the correlation between climate and elevation using a Digital Elevation Model (DEM) (Danielson & Gesch, 2011) as covariate in the interpolation model. We employed a bootstrap resampling procedure to cross-validate the interpolation results and found the local estimates to be robust. Using a lattice of 700×700 meters, we then extracted climate change values from the interpolation surface and assigned the respective area average to each MMP municipality for which migration histories were available.

Finally, we computed relative change measures as the standardized difference between the climate index value during the three-year window leading up to each observation year and a

30-year (1961–1990) long-term average. A three-year window was chosen to minimize the influence of short-term fluctuations and to account for lagged response patterns (McLeman, 2011). Figure 2 shows the hazard of migration as well as the climate change index values across the study period.

Figure 2 Panel A shows a certain degree of similarity between the trajectory of the hazard of documented and undocumented migration with higher values in the late 80s and late 90s. During these years Mexico experienced two economic recessions (Lustig, 1990; McKenzie, 2006) that may have influenced the decision to migrate with or without the proper documentation.

Figure 2 Panel B shows the change in the two climate change measures relative to the baseline period (1961–1990). In line with climatological reports (Stahle et al., 2009), the warm spell duration index shows an increase in the consecutive number of hot days over the study period. However, no clear trend could be discerned for precipitation during extremely wet days.

Control variables

We include various control variables, reflecting social, human, physical, financial, and natural capital; these variables have been shown to be important predictors of migration in prior research (e.g., Brown & Bean, 2006; Massey et al., 2010; Nawrotzki et al., 2013). Table 1 provides source information and summary statistics on all control variables employed in the analysis. Variables were included as time varying and time invariant and operate both at the household and municipality level. When information was available at decadal time steps (e.g. census data), we employed linear interpolation to derive semi time-varying measures, a common practice in event-history analysis (Allison, 1984).

Measures of *social capital* include gender (female =1) and marital status (married = 1) of the household head. In a patriarchal society such as Mexico, social status and access to social networks differs by gender and has been shown to significantly shape migration responses (Kanaiaupuni, 2000). Similarly, a marital union may expand a household's family and kin networks that may serve as an informal social security system in times of crisis (Abu et al., 2014). In addition, we employ a measure of the percent of adults within the community with migration experience as a proxy indicator of migrant network density, which has been shown to strongly determine the likelihood of a future move (Fussell & Massey, 2004).

We measure *human capital* by accounting for the number of young children (age < 5 years) in the household as well as the education (years of schooling), working experience (years employed), and occupation (blue collar, white collar, not in labor force) of the household head. The presence of young children ties human capital needed for nurturing activities to the household and has been shown to reduce the odds of an international move (Massey & Riosmena, 2010; Nawrotzki et al., 2013). We were unable to include a measure for age of the household head in the models due to high correlation with working experience ($r = 0.93$) and resulting multi-collinearity.

Financial capital is measured by a standardized wealth index at the municipality level that combines information from 10 variables on the quality of housing (material of floor, wall, roof, number of rooms and bedrooms, toilet type) as well as service and infrastructure access (water supply, electricity, sewage system, cooking fuel type) (Cronbach's alpha = 0.85). In the developing world migration is often used as a means to overcome liquidity constraints to purchase a home or start a business (Massey & Parrado, 1998; Taylor et al., 1996). To account for this relationship, we measure the level of *physical capital* in terms of business or property ownership (owner = 1) at the household level.

As a measure of *natural capital* we account for general agricultural dependence by using a measure of the corn area harvested. This measure was constructed by the Global Landscape Initiative (Monfreda et al., 2008) for the year 2000 and is available through the Terra Populus data extract system (Kugler et al., 2015; MPC, 2013b). Because the impact of climate effects on livelihoods may depend on the ability to employ technological infrastructure (Gutmann & Field, 2010), we account for access to irrigation systems through a measure of the percentage of farmland irrigated. This data was obtained from the Mexican agricultural census (INEGI, 2012) and averaged across the years 2003–2005. In addition, prior research has shown that the effect of climate variability on migration differs based on the general climatic context (Nawrotzki et al., 2013). To account for the general climatic background, we included measures of the average temperature and precipitation during the baseline years (1961–1990). Finally, we capture employment in climate sensitive sectors through a measure of the percentage of males in the labor force employed in agriculture.

Estimation Strategy

We employ event-history models for this analysis (Allison, 1984). The models were estimated within a competing risk framework, in which the household can either perform an undocumented or documented move (Singer & Willett, 2003). Owing to the hierarchical structure of our data, we employ a multi-level version of the event-history model that accounts for the nesting of households within municipalities (Steele et al., 1996; Steele et al., 2004). To guard against endogeneity, all predictors were lagged by one year (Gray, 2009, 2010).

$$\log\left(\frac{m_{\mathrm{ijk}}}{s_{\mathrm{ijk}}}\right)=\alpha+\beta_1(\mathrm{WSDI}_{ik})+\beta_2(R99\mathrm{PTOT}_{ik})+\sum_{n=3}^{y}\beta_n(x_{nz})+u_k \quad (1)$$

In equation 1, the multi-level event-history model is specified as the odds of experiencing a migration event of type *m* (undocumented or documented migration) relative to no mobility (event type *s*) for each household *j* located in municipality *k* during year *i*. The parameter α captures the baseline hazard and was included as a set of year dummies for the most flexible representation of time (Singer & Willett, 2003). This parameterization accounts for differences in the overall migration levels in each year, which can be attributed to various unmeasured factors such as changes in the macroeconomic conditions in the origin and destination countries. The parameters β_1 and β_2 reflect the effect of the two climate change indices (*WSDI* and *R99PTOT*), which were jointly included in the model to simultaneously account for temperature and precipitation changes (Auffhammer et al., 2013). The climate change variables constitute time-varying municipality-level predictors (indicated by subscript *ik*), and it has been shown that a two-level model structure is appropriate for such variables (Barber et al., 2000). All models control for the effect (β_n) of various sociodemographic factors (x_n) on the probability to migrate. These controls can operate both at the household and municipality level, indicated by the generic subscript *z*.

Although tests have shown that recall bias is of little concern for the MMP data (Massey et al., 1987), we include a measure for the survey year to account for residual recall error. Finally, the parameter u_k constitutes the municipality random effects term that accounts for the nesting of households within municipalities. The multi-level event history models were estimated using the package *lme4* (Bates, 2010; Bates et al., 2014) within the R statistical environment (RCoreTeam, 2015).

During the 1986–1999 study period, n=819 households reported an undocumented move while only n=95 households reported a documented move. Although a documented move constitutes a rare event, discrete-time event history models are specifically designed for small numbers. Simulation exercises have demonstrated that at least five events per predictor are necessary to produce unbiased and reliable estimates (Vittinghoff & McCulloch, 2007). The fitted models (Table 2) contain 19 substantive predictors, yielding an average of five events per predictor for the total of 95 documented migration events, which constitutes a sufficiently large number to produce valid and stable results.

Results

In line with prior work, the results from the multi-level event-history models (Table 2) reveal that undocumented migration most likely occurs from male headed households without young children in which the household head has little education and work experience, is employed in a blue collar occupation, and does not own a business or property (Fussell, 2004; Massey et al., 1987; Massey & Parrado, 1998; Nawrotzki et al., 2013; Woodruff & Zenteno, 2007). The presence of migrant networks strongly facilitates both documented and undocumented migration (Fussell & Massey, 2004; Massey & Espinosa, 1997). In contrast, documented migrants are usually better educated and come from areas less dependent on agricultural production (Fussell, 2004). As the primary analytical focus, the models also include the two climate change indices.

The results show that climate change significantly influenced international migration from rural Mexico to the U.S. but that this relationship exclusively emerged for undocumented moves. The significant temperature effect suggests that an increase in warm spell duration by one standard deviation unit increased undocumented international outmigration by 19% (Odd Ratio [OR] = 1.19). In contrast, an increase in precipitation during extremely wet days by one standard deviation reduced the odds of an undocumented international move to the U.S. by 18% (OR = 0.82).

Discussion and Conclusion

Combining detailed migration histories with two climate change indices based on daily temperature and precipitation information, this study provides evidence that rural Mexican households employed migration as an adaptation strategy in the face of adverse climate variability and change. However, the results show that while climate change significantly influenced undocumented migration, it had no impact on documented moves. Because it is often difficult to obtain a valid work visa given quotas, backlogs, and application costs (Papademetrious & Terrazas, 2009), households may resort to undocumented border crossing to stabilize livelihoods and access alternative income streams through remittances.

The directionality of significant climate change effects suggests a rise in undocumented international migration in response to a warming in temperatures. Heat waves and temperature increases are problematic for the agricultural sector and are associated with a decline in crop yield (Lobell et al., 2013). Adverse impacts on agricultural productivity may lead to a decline in income and employment opportunities to which households may respond with increased levels of migration (Bohra-Mishra et al., 2014; Mueller et al., 2014).

In contrast, increases in precipitation led to a decline in undocumented migration. Only a small proportion (23%) of the arable land in Mexico is irrigated (Carr et al., 2009), making agricultural production highly dependent on rainfall. In addition, Mexico experienced severe drought conditions during the study period (Stahle et al., 2009). Under such conditions, an increase in rainfall was likely beneficial, reducing households' need to employ migration as adaptation strategy (Feng & Oppenheimer, 2012; Nawrotzki et al., 2013).

Projections of future climate change suggest that for Mexico temperature will increase (Collins et al., 2013) while precipitation will decline (Christensen et al., 2013), potentially leading to an increase in frequency and severity of droughts (Wehner et al., 2011). When livelihoods of agricultural-dependent households are impacted by adverse climate variability and change, they may respond with an increase in migration rates (Black et al., 2011a); our study suggests that such migrants will be predominantly undocumented. To reduce the number of undocumented border crossings from Mexico, the U.S. government has substantially increased the budget for border control and fortification (Massey & Riosmena, 2010; Orrenius, 2004). However, an increase in border fortification has been shown to be of limited success in deterring undocumented migration (Massey & Riosmena, 2010). Livelihood-based support programs to assist rural Mexicans in local climate change adaptation efforts may serve as a cost-efficient alternative to boarder control in decreasing the number of climate related moves. Such programs may include agricultural extension services to disseminate knowledge about the availability and use of drought resistant crop varieties and alternative farming practices (Nawrotzki & Akeyo, 2009; Schroth et al., 2009), subsidize the construction of irrigation systems (Howden et al., 2007), or assist households in finding non-agricultural employment to reduce their dependency on climate-sensitive sectors (Macours et al., 2012).

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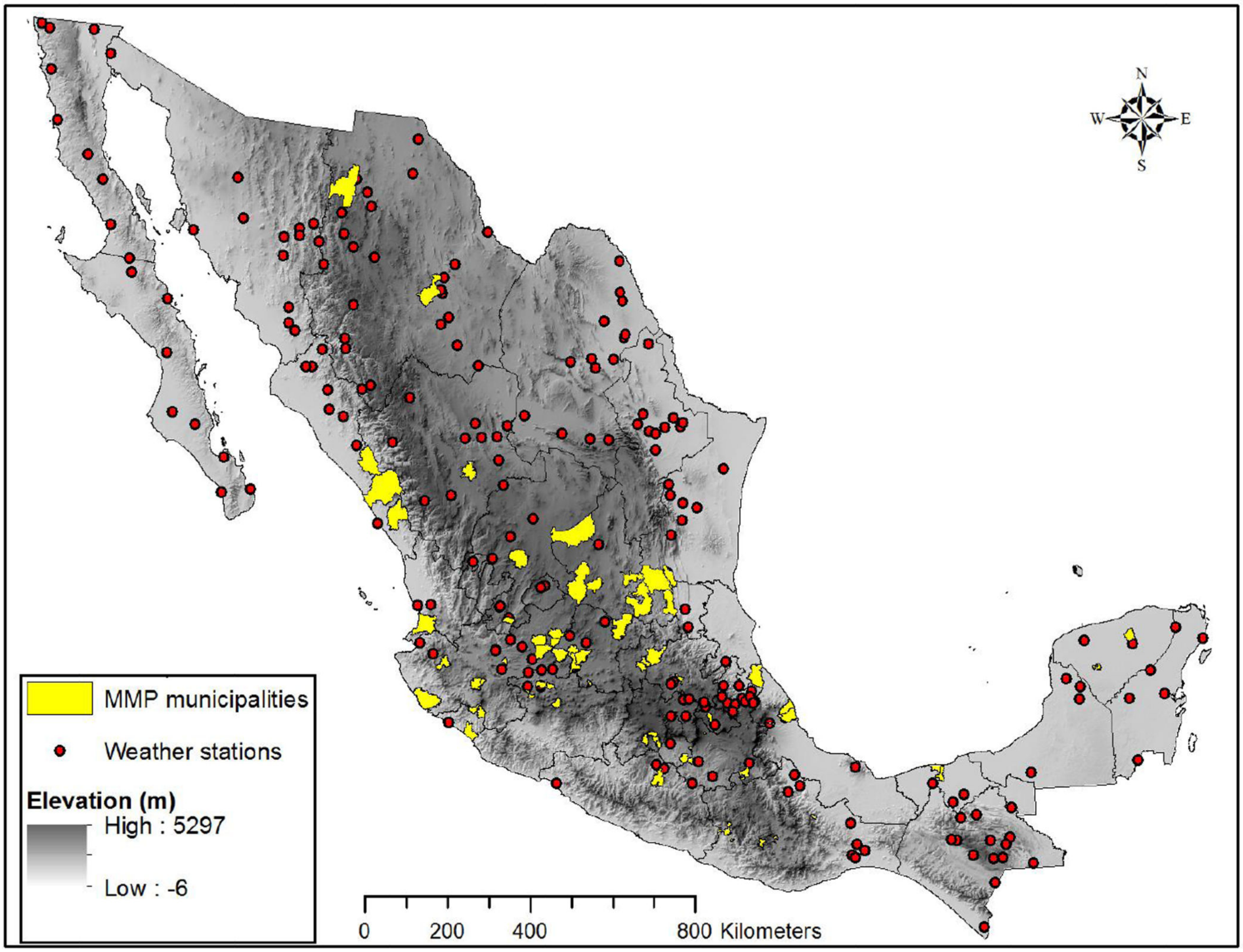

Figure 1.
Map of location of rural MMP municipalities and weather stations

Panel A: hazard of migration

Panel B: climate change

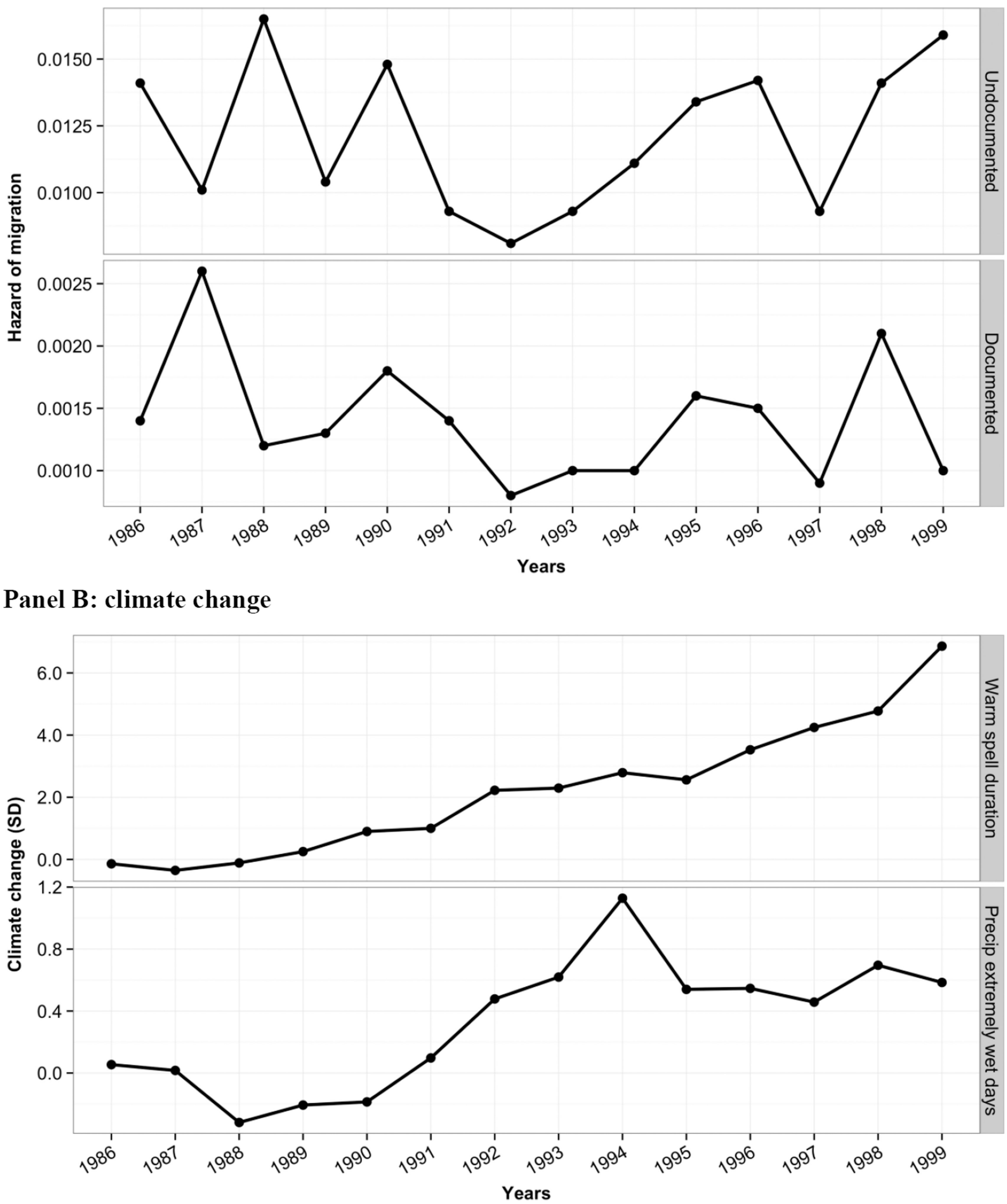

Figure 2.

Hazard of undocumented and documented international migration from rural Mexico as well as climate change values across the study period, 1986–1999

Table 1

Summary statistics and source information of variables employed in the study of undocumented and documented migration in response to climate change from rural Mexico, 1986–1999

	Unit	TV	Source	Mean	SD
Household level (head)					
Social capital					
Female	1|0	No	MMP	0.14	0.35
Married	1|0	Yes	MMP	0.80	0.40
Human capital					
No. of children	Count	Yes	MMP	0.85	1.04
Education	Years	Yes	MMP	5.34	4.28
Working experience	Years	Yes	MMP	24.94	12.34
Occupation: not in labor force	1|0	Yes	MMP	0.09	0.29
Occupation: blue collar	1|0	Yes	MMP	0.82	0.39
Occupation: white collar	1|0	Yes	MMP	0.09	0.29
Physical capital					
Owns property	1|0	Yes	MMP	0.70	0.46
Owns business	1|0	Yes	MMP	0.16	0.36
Community/municipality level					
Social capital					
Network density	%	Yes	MMP-C	15.18	14.51
Financial capital					
Wealth index	z-values	Yes	IPUMS-I	−0.79	0.39
Natural capital					
Corn(area harvested)	sqm/10ha	No	TerraPop	1.26	1.11
Farmland irrigated	%	No	INEGI	23.67	25.74
Base period precip (1961–90)	mm/day	No	GHCN-D	2.83	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	56.15	17.65
Climate change					

	Unit	TV	Source	Mean	SD
Warm spell duration	z-values	Yes	GHCN-D	1.79	2.22
Precip extremely wet days	z-values	Yes	GHCN-D	0.34	1.05

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; Ruggles et al., 2003); 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 2

Multi-level discrete-time event history models predicting the odds of undocumented and documented international migration from rural Mexico, 1986–1999

	Undocumented		Documented	
	b	sig.	b	sig.
Household level (head)				
Female	0.53	***	0.68	
Married	0.96		1.36	
No. of children	0.90	**	0.99	
Education [a]	0.74	**	3.29	***
Working experience [a]	0.71	***	1.00	
Occupation: not in labor force	0.91		1.45	
Occupation: white collar	0.50	***	0.63	
Owns property	0.83	*	1.14	
Owns business	0.77	*	1.03	
Community/municipality level				
Network density [a]	1.56	***	1.49	**
Wealth index	0.81		0.74	
Corn (area harvested)	0.94		0.68	*
Farmland irrigated [a]	1.04		0.93	
Base period precip (1961–90)	1.11		0.73	
Base period temp (1961–90)	0.91	**	0.98	
Male labor in agriculture [a]	1.01		0.88	
Climate change				
Warm spell duration	1.19	***	1.16	
Precip extremely wet days	0.82	***	0.98	
Model statistics				
Var. Intercept (Mun)	0.215		0.718	
BIC	8451		1703	
N (HH-year)	67511		67511	
N (HH)	7062		7062	
N (Mun)	68		68	

Notes: coefficients reflect odd ratios;

[a]coefficients relate to an incremental change of 10 units; baseline hazard of migration was included as a multi-part intercept using 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; low values on the Variance Inflation Factor (VIF) demonstrated that multi-collinearity does not bias the estimates; a jack-knife type procedure was performed, iteratively removing one municipality from the sample and re-estimating the model (Nawrotzki, 2012; Ruiter & De Graaf, 2006). The results show that the estimates for the climate change predictors are highly robust;

* $p<0.05$;

** $p<0.01$;

*** $p<0.001$