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## Climatic Stresses and Rural Emigration in Guatemala\*

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### Abstract

International migration is a recurrent and growing phenomenon and a large share of emigrants originate from rural areas. This study examines the association between climatic stresses and rural emigration in Guatemala. We exploit variations on climatic stress situations and emigration flows at the subnational level and over time to examine whether the observed migration dynamics can be explained by the occurrence of specific adverse weather events. We find that drought periods affect emigration positively the following year, especially among men, while periods of high temperatures and low soil moisture affect male and female emigration negatively. The results are generally not much sensitive to alternative model specifications and estimations. The apparent mixed findings point to both direct effects where climatic stresses may encourage people to migrate in search of better opportunities, as well as indirect effects in the sense that climatic stresses affect agricultural productivity and household liquidity, which may prevent people from migrating despite their willingness to emigrate.

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\* Braulio Britos and Manuel A. Hernandez gratefully acknowledge financial support from the CGIAR Regional Initiative AgriLAC Resiliente. Estefania Puricelli and Ritvik Sahajpal gratefully acknowledge financial support from the NASA Applied Sciences Program (80NSSC18M0039). The authors would like to thank FEWS NET Guatemala and Foundation for the Development of Guatemala (FUNDESA) for facilitating part of the data used in the analysis.

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## 1. Introduction

International migration is a recurrent phenomenon that has grown rapidly over the past two decades, from 173 million people in 2000 to 281 million in 2020 (IOM, 2022), with a large share of emigrants originating from rural areas (FAO, 2016; IOM, 2020). Migration is driven by a wide set of factors that include both “push” factors that encourage or force people to move from their current location and “pull” factors that attract people to a new location (Rubenstein, 2017; The World Bank, 2018). In developing countries, migration mainly results from people’s vulnerability to varying triggering factors and shocks, but it also constitutes an important adaptation strategy to support livelihoods, build resilience, and protect against fragility (Hernandez et al., 2023). In particular, individuals or households migrate for multiple reasons, including being forced to leave their homes due to climatic shocks, conflict, violence, or economic motives, which are not necessarily mutually exclusive and may act as compound shocks that could further lead to threat-multiplying effects (Piguet et al., 2011; Josephson and Shively, 2021). Recent estimates indicate that about 80% of the people forcibly displaced worldwide had experienced acute food insecurity and high levels of malnutrition (Barchfield et al., 2021; USAID, 2021). In addition, emigration often involves irregular migration where people, especially vulnerable and food insecure households in rural areas, take treacherous routes to flee their home country.<sup>1</sup>

In the case of Guatemala, net emigration was close to 856,000 people between 2002 and 2021.<sup>2</sup> Most people emigrate to the United States (US), where apprehensions of Guatemalans at US borders have significantly increased from 17,338 in 2007 to 265,129 in 2019 (USCBP, 2022).<sup>3</sup> This trend is in line with the patterns observed in the most recent census data (INE, 2020), which show a continuous increase in the number of reported emigrants between 2002 and 2018. As shown in **Figure 1**, most of the increase in recent years is mainly originated from rural areas (Panel A) and while three of every four rural migrants are men, both the number of men and women emigrating have sustainably increased over the past years (Panel B).<sup>4</sup> Similarly, **Figure 2** reveals that most migrants concentrate in certain regions of the country, especially in the Western Highlands and Dry Corridor (Eastern side) that are areas with high poverty rates, malnutrition, and climate vulnerability (INE, 2015; Bouroncle et al., 2015; Bouroncle et al., 2017; MSPAS-INE-ICF, 2017). Family-related remittances, in turn, reached over 15 billion US dollars in 2021, representing around 18% of the Gross Domestic Product (GDP) in Guatemala (Maldonado and Harris, 2022).

We focus in this study on adverse climatic events as a major triggering factor of migration and evaluate the association between climatic stresses, including drought, excessive rain, heat, and lack of soil moisture, and emigration from rural areas in Guatemala. The estimation approach exploits variations over

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<sup>1</sup> Irregular migration refers to the movement of people that occurs outside of the laws and regulations of the sending, transit, and receiving countries (IOM, 2019). According to the Missing Migrants Project of the International Organization for Migration (IOM), over 50,000 people have lost their lives during migratory movements since 2014 (Black and Sigman, 2022).

<sup>2</sup> <https://population.un.org/wpp/Download/Standard/MostUsed/> (accessed September 2023).

<sup>3</sup> The COVID-19 pandemic led to a general decrease in apprehensions in 2020 but crossings resumed in 2021 and 2022 (USCBP, <https://crsreports.congress.gov/product/pdf/R/R47343> , accessed September 2023).

<sup>4</sup> More recent data from IOM show that after a decline in the number of returnees in Guatemala in 2020 and 2021 due to the pandemic, in 2022 the number was close to 100 thousand (similar to pre-pandemic levels) with an important increase of women 18 years and older (<https://infounitnca.iom.int/descargas/retornos/>, accessed September 2023).

time and across municipalities on climatic stress situations and emigration flows to assess whether the observed migration dynamics in a municipality can be explained by specific climatic circumstances. We rely on a fixed-effects regression model using annual municipality data, including Census and remote sensing data, for the period 2011 through 2018. We evaluate the sensitivity of our results to alternative model specifications and data samples. For a subperiod of the analysis, we further account for the possible influence of other factors, such as crime activity and economic conditions.

The estimation results show that periods of low to no precipitation affect migration positively, while both periods of high temperatures and low soil moisture affect migration negatively. An additional 5-day period with low precipitation increases the municipal rural migration rate by 1.4% the following year. Meanwhile, an increase in 10 days above 86F/30C and an additional 3-day interval of low soil moisture decreases the municipal yearly rural migration rate by 3.9% and 1.5%, respectively. The positive association between droughts and emigration is mainly observed among men, while the negative association between heat and low soil moisture and emigration is observed among men and women. We similarly find that the occurrence of several climatic events at the same time within a year tends to induce individuals to emigrate, although marginally. The results are generally not much sensitive to alternative model specifications and additional estimations performed. The findings suggest two apparent opposing effects that could be explained by likely direct and indirect effects of climatic stresses on migration decisions in rural areas. On one hand, climatic events, especially extreme ones, affect the quality of life and future expectations of production (agricultural) activities, encouraging and/or forcing people to migrate in search of better opportunities. On the other hand, adverse climate events affect agricultural productivity and household liquidity, which prevents potential migrants from covering the cost of migration, especially in a context of low liquidity, high credit restrictions, and high costs of emigrating irregularly, and therefore limits migration. When rainfall is low, for example, the expectations of crop yields and farm profits decrease, making farmers consider migrating in search of better opportunities; in contrast, prolonged days of heat and low soil moisture may result in higher liquidity or financial constraints that prevent people from migrating, despite their willingness to emigrate.

Our study contributes to the empirical literature on climate displacement, i.e., the displacement of people that is at least partially driven by the impacts of climate change, which has received special attention in recent years among academic and policy forums.<sup>5</sup> Quantitative evidence on the relationship between climatic shocks and permanent migration, whether internal or external, is still growing and the results are mixed.<sup>6</sup> Some related studies include Feng et al. (2010) who find a significant effect of climate-driven changes in crop yields in Mexico on the rate of emigration to the US. Dillon et al. (2011), in turn, find suggestive evidence that households engage in internal migration in Nigeria in response to agricultural risks captured by temperature degree days. Gray and Mueller (2012a) find that men's labor migration increases with drought in rural Ethiopia while marriage-related moves by women decrease. In rural Bangladesh, the same authors find that flooding has modest effects on mobility whereas crop failures unrelated to flooding have stronger effects (Gray and Mueller, 2012b). Marchiori et al. (2012) show that

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<sup>5</sup> The United Nations General Assembly adopted in 2016 the New York Declaration for Refugees and Migrants, which explicitly recognizes that people move "in response to the adverse effects of climate change, natural disasters (some of which may be linked to climate change), or other environmental factors" (UNGA, 2016).

<sup>6</sup> See Milan-Garcia et al. (2021) for a bibliometric review on climate change-induced migration. Huber et al. (2023) also provide a recent review of climate-related migration in the Central American Dry Corridor region that include part of the territory of Guatemala.

temperature and rainfall anomalies increase internal and international migration in sub-Saharan Africa. Gray and Blisborrow (2013) find that adverse environmental conditions do not consistently increase rural out-migration in Ecuador. Mueller et al. (2014) provide evidence that flooding has limited impacts on migration in rural Pakistan as opposed to heat stress that consistently increases long-term migration of men. More recently, Grecequet et al. (2017) find that people, on average, move from high to low vulnerability countries, while Jessoe et al. (2018) show that extreme heat increases migration domestically in Mexico from rural to urban areas and internationally to the US, and Mahajan and Yang (2020) find that hurricanes increase migration to the US where migrant networks in the host country play an important role. This paper contributes to this increasing literature focusing on the association between climatic stresses and international migration over an 8-year period in a context (country) of recurrent weather anomalies and emigration.<sup>7</sup>

More broadly, the study contributes to the discussion about the root causes of emigration in Central America.<sup>8</sup> As pointed out by Pons (2021), there is growing evidence that weather anomalies are having a devastating negative impact on agriculture in the region, affecting the livelihood of many smallholder farmers and serving as a migration driver, but it is difficult to precisely determine the role of climate variability in emigration decisions as there are other factors at play including crime and insecurity, economic crises, and family reunification. The literature on this regard, particularly from the Northern Triangle (El Salvador, Guatemala, and Honduras) to the US, is generally limited to studies and assessments based on cross-sectional surveys and interviews that allow to approximate correlations rather than causality (e.g., Cohn et al., 2017; Congressional Research Service, 2019a & 2019b; Creative Associates International, 2019; National Immigration Forum, 2019; Ruiz Soto et al., 2021). Formally identifying potential migration-triggering factors requires longitudinal data to better account for the timing of migration decisions and the occurrence of specific factors or events, which could also be interrelated and are not necessarily all observed (Ceballos and Hernandez, 2020). One exception that we are aware of for the case of Guatemala is a recent study by Bermeo et al. (2022) that examines migration drivers to the US using time-series data at the department level for the period 2012-2019. The authors find that agricultural stress (measured through an index that serves as an early indicator of high likelihood of drought) is positively associated with the number of apprehensions in the US southern border the following year. In the analysis below, we exploit more disaggregated subnational migration and remote sensing data at the municipality level to perform a detailed assessment of the relationship between climatic stresses, including drought, excessive rain, heat, and lack of soil moisture, and emigration in rural Guatemala, while controlling for (time-invariant) unobservable factors and other time-variant observable factors (when available). We similarly discuss the direction and possible channels through which the weather anomalies could be influencing the observed emigration dynamics.

The remainder of the paper is organized as follows. Section 2 describes the data and Section 3 the methodology used for the analysis. Section 4 presents and discusses the estimation results. Section 5 provides some concluding remarks.

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<sup>7</sup> Guatemala is ranked 16 in the Global Climate Risk Index that measures the level of exposure and vulnerability of a country to extreme events (Eckstein et al., 2021).

<sup>8</sup> See Hanson et al. (2023) for a historical perspective of US immigration from Latin America.

## 2. Data

The main dataset used for our analysis is the microdata from the last national census in Guatemala “XII National Population and VII Housing Census,” corresponding to 2018 and collected by the National Statistical Institute (INE). The census comprises information on the number of international migrants that left their households at some point during the 2002-2018 period. The dataset includes the location of the household (municipality and whether located in an urban or rural area) and the country the migrant emigrated to, which allows us to obtain international emigration flows from each municipality and area.

The annual municipality migration rate is calculated as the sum of international migrants per year reported by all rural households in each municipality divided by the rural population of the municipality in 2018 times 10,000 (i.e., it is annual the number of rural emigrants per 10,000 people in the municipality). This measure of migration is certainly an underreport as it does not include entire households (families) that had already migrated when the data was collected, although external migration flows in Guatemala are typically performed on an individual basis (or sequentially over an extended time period when involving several household members or an entire household).<sup>9</sup> Similarly, the measure of migration could be affected by recall bias as respondents may not necessarily recall the exact year when the household member migrated, particularly for extended recall periods.<sup>10</sup> Keeping this in mind, we limit the study to the period 2011-2018 and assess the sensitivity of our results to further restricting the years of analysis.<sup>11</sup>

The weather satellite data is obtained from different sources. Precipitation is sourced from USGS/FEWS NET CHIRPS data, facilitated by FEWS NET Guatemala. The data corresponds to cumulative rainfall in millimeters (mm) over 5-day intervals based on 0.05° resolution satellite imagery with in-situ station data. Hourly land temperature data (in degrees Celsius) is obtained from Copernicus Climate Change Service (2019). Soil moisture data is obtained from NASA-USDA SMAP (Sazib et al., 2021) and has a frequency of every 3 days; soil moisture is measured in millimeters and represents the aggregated surface and subsurface soil moisture. The spatial resolution of the satellite imagery for the temperature and the soil moisture datasets is approximately 0.1° by 0.1° (roughly equivalent to areas of 11 by 11 kilometers at equator).

Since our migration data is at the municipality level, we need to aggregate the weather satellite data at the same level. To achieve this, we compute the municipal weighted average of our weather variables.<sup>12</sup> The weight attributed to each raster is determined by its land coverage within each municipality. We further adjust each raster's weight based on the percentage of physical area cultivated with maize, utilizing the GEOGLAM-BACS crop mask (Becker-Reshef et al., 2023). This mask operates at a resolution

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<sup>9</sup> In several instances, emigration tends to be predominantly male led (Ruiz Soto et al., 2021); men often migrate first, leaving their spouses behind, who later can join them with their children.

<sup>10</sup> Recall error in household surveys has been recognized in the literature for decades (see, e.g., Evans and Leighton, 1995; Sudman et al., 1996).

<sup>11</sup> Given that most of the emigration in Guatemala is irregular, any migration variable used is by construction subject to misreporting. We considered alternatively using the rate of returnees that is based on apprehensions in the US southern border (compiled by the United States Customs and Border Protection), but this variable presents additional restrictions that become more acute if we are interested in disaggregating the information by location and is only available for a very reduced number of years at the municipality level.

<sup>12</sup> Computations correspond to temperature and soil moisture data. The precipitation data was facilitated by FEWS NET Guatemala at municipality level.

of 0.05° by 0.05°, which helps to exclude areas with no crop production when averaging the weather variables at the municipality level.

Based on these aggregated weather data, we construct annual indicators to capture climatic events such as droughts, excessive rain, heat, and low soil moisture. The drought variable measures the number of 5-day periods in a year with cumulative precipitation below 1mm; excessive rain is defined as the number of 5-day periods in a year with cumulative precipitation above 100mm; heat is measured by the number of days where the maximum temperature is above 86 degrees Fahrenheit or 30 degrees Celsius (86F/30C); and low soil moisture is defined by the number of 3-day intervals where soil moisture is below 10mm. These thresholds are standard thresholds that reflect negative weather events or climatic stresses that may affect households' agricultural activities and influence their decision-making.<sup>13</sup>

We additionally gathered annual data at the municipality level on homicides and extortions available from 2015 collected by the Civil National Police (PNC) and compiled by Infosegura,<sup>14</sup> as well as per capita Gross Domestic Product (GDP) for the years 2017, 2019, 2020, and 2021 calculated by the Foundation for the Development of Guatemala (FUNDESA).<sup>15</sup> Since GDP data for 2015 and 2016 were not available, we impute data for the missing years using a linear extrapolation based on the yearly trend from the four available years. We examine the robustness of our main results to the inclusion of these additional controls for the corresponding subsample period (2016-2018).

**Table 1** presents summary statistics at the municipality level of the key migration and climatic indicators used in the analysis for the period 2011-2018. On average, annual rural emigration amounts to 17.6 migrants per 10,000 inhabitants. The highest emigration rate is observed in 2016 in Union Cantinil, located in the department of Huehuetenango that shares a border with Mexico and is an area characterized by high international migration. When we decompose migration rates by sex, we observe a significant gap. While rural female migration is less than 7 migrants per 10,000 inhabitants, the male migration rate is 4.2-fold the female counterpart, close to 30 migrants per 10,000 inhabitants. The highest male migration rate is similarly observed in 2016 in Union Cantinil, while the highest female migration rate is observed in 2017 in Petatan, also in the department of Huehuetenango.

The average number of 5-day periods of cumulative rain below 1mm is 6.3, amounting to approximately 32 days in a year with low precipitation, while the maximum number of periods with low precipitation is 23 (equivalent to 115 days) that is registered in the municipalities of Fraijanes (department of Guatemala) in 2015, Sipacate (Escuintla) in 2011 and 2018, Cuilco (Huehuetenango) in 2011, 2015, and 2016, San Manuel Chaparrón (Jalapa) in 2015, Monjas (Jalapa) in 2015, El Progreso (Jutiapa) in 2015, Santa Catarina Mita (Jutiapa) in 2015, and Asunción Mita (Jutiapa) in 2015. Turning to excessive rainfall, defined as the number of 5-day periods of cumulative rain above 100mm, the average is 2.3 periods, which is approximately 11 days in a year, while the highest number of periods with excessive rainfall is 20 that amounts to 100 days. This value is observed in 2011 in El Rodeo and Catarina, both in the department of San Marcos. For excessive heat, defined as the number of days above 86F/30C, the average is 43.9 days. The maximum number of days with temperatures above 86F/30C is 318 days registered in Champerico in

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<sup>13</sup> We considered including in the analysis the number of days with temperatures below 32F/0C but there were less than 5 cases over the full working sample. For a discussion on climate indices, see, for example, Sun et al. (2015).

<sup>14</sup> <https://infosegura.org/guatemala>.

<sup>15</sup> <https://www.fundesa.org.gt/>.

the department of Retalhuleu in 2015. Lastly, the average number of 3-day intervals with low soil moisture is 2.3 in a year, comprising 7 days in a year. The highest number of intervals registered is 42 (about 126 days) in Villa Canales in the department of Guatemala.

In **Figure 3**, we plot the average rural migration rate against each corresponding climatic stressor (panels A through D) by municipality. We include a quadratic fit represented by the red line and 95% confidence band denoted by the grey area. We observe a somewhat negative relationship across most of the panels, suggesting that municipalities with lower rural emigration rates tend to experience a greater number of adverse weather events. This inverse relationship between emigration and climatic stresses provides an initial glimpse into the regression analysis performed below, although we cannot conclude though that the observed patterns are statistically significant at the 95% confidence level.

### 3. Methodology

Climatic events such as extended periods of drought, excessive rain, elevated temperatures, and low soil moisture can influence migration flows, whether directly encouraging or forcing people to migrate in search of better opportunities or indirectly through impacts on agricultural productivity and household liquidity preventing people from migrating (despite their willingness to do so). Our estimation strategy consists in evaluating if municipalities with a higher prevalence of climatic stresses exhibit higher or lower rural emigration flows in the next period. The time and geographical richness of our data allow us to estimate the effect of climate stresses on emigration across 297 municipalities and 8 years. We implement a fixed-effects regression model that allows us to account for time-invariant unobservable municipality characteristics that can also influence migration decisions, such as accessibility, socioeconomics, and cultural factors, among others. We also include year fixed effects to account for aggregate shocks such as overall changes in migration policies and economic conditions specific to those years.

We estimate the following regression model using our full working sample for the period 2011-2018,

$$y_{mt} = \beta_0 + \beta_1 D_{mt-1} + \kappa_m + \eta_t + \varepsilon_{mt} \quad (1)$$

where  $y_{mt}$  is the rural emigration rate at municipality  $m$  in year  $t$ ,  $D_{mt-1}$  is the lag of each climatic stress indicator defined above (drought, excessive rain, heat, and low soil moisture),  $\kappa_m$  is the municipality fixed effect,  $\eta_t$  is the year fixed effect, and  $\varepsilon_{mt}$  is the error term.

Our parameter of interest is  $\beta_1$ . This parameter captures the effect of an increase in the number of periods of climatic stress on next year's emigration rate. We include the lag of the climatic stress indicator as the decision to emigrate can take some time before it materializes after a negative event (i.e., weather shocks can happen today, but the act of migrating will most likely happen over the next period).

As part of the robustness checks to evaluate the sensitivity of our results, we perform below several additional estimations. These include disaggregating the sample by gender, considering alternative model specifications that include interactions of the climatic variables to capture possible augmented effects, using annual population projections (instead of 2018 Census population) to calculate the emigration rate, using alternative climatic indicators, and including additional time-varying control variables such as crime and GDP variables available for a subsample period.

## 4. Results

This section presents and discusses the empirical results of our study. We first present our base regression results and then the multiple additional regressions and robustness checks performed to assess the sensitivity of our findings.

### 4.1 Base Results

The full base regression results are reported in Appendix **Table A.1** that include the estimated coefficients that approximate the association between the occurrence of different climatic stressor variables and rural emigration rate the following year. We model both the overall emigration rate as well as the rate by sex. Standard errors are reported in parentheses, which are heteroskedastic-robust across all estimated models.

**Figure 4** shows the percentage change in the average rural migration rate associated with an increase of one (5-day) period of drought and excessive rain, 10 days of heat, and one (3-day) interval of low soil moisture, based on the regression results reported in Appendix **Table A.1**. The figure includes both overall and gender-specific effects on the migration rate. We observe that an additional 5-day period with low precipitation increases the aggregate municipal rural emigration rate by 1.4% the following year, while an increase in 10 days above 86F/30C and an additional 3-day interval of low soil moisture decreases the municipal yearly rural emigration rate by 3.9% and 1.5%, respectively. An additional 5-day period of excessive rain also has a positive effect of 1.5% on the emigration rate, but the effect is not statistically significant at conventional levels.

Decomposing by sex, we note a higher effect on average migration rates for men on drought and excessive rain, as opposed to heat and low soil moisture where there are generally not much differences by gender. An increase in one period of drought increases the average migration rate in 1.7% for men and 0.4% for women, although the latter effect is not statistically significant. One more period of excessive rain, in turn, increases the migration rate by 1.6% and 0.9% for men and women, respectively, but both effects are equally not significant (as the overall effect). In the case of 10 additional days of heat, the decrease in the average migration rate is of 3.8% for men and 4.2% for women. For one more 3-day interval of low soil moisture, the decrease is of 1.4% for men and 2% for women.

The results, like most of the international literature, are mixed. While the effect of drought on emigration is positive, the effect of heat and low soil moisture are negative. This suggests that weather shocks could be affecting migration decisions in rural areas in different manners explained by potential direct and indirect effects of adverse climatic events. In our study framework, drought could be affecting migration decisions in a more direct fashion, particularly among men. Excessive droughts can impact their quality of life and expectations about future agricultural yields of farmers, compelling them to consider relocating in the near future in search of better opportunities. This finding is similarly in line with Bermeo et al. (2022) analysis at the department level that finds a positive association between agricultural stress periods driven by droughts and apprehensions of Guatemalans at the US southern border.

Meanwhile, the negative effect from heat and low soil moisture periods on both men and women emigration decisions could be connected to indirect effects of climatic stresses explained by borrowing constraints and agricultural productivity. External migration from Guatemala is costly and farmers are

typically financially constrained. In a world without financial frictions, households wanting to migrate would borrow money, pay the migration cost, and then repay their loan from abroad. But in the presence of liquidity constraints, there will be farmers that would only migrate if they had enough cash to pay the migration cost upfront; hence, farmers could be waiting for a good crop (weather) year to cash their crops and pay the migration cost. On the margin, for farmers that are looking to emigrate, whenever there is a bad weather shock, this affects their agricultural productivity negatively and decreases their profits, which prevents them from covering the migration cost, and thereby lowers the emigration flows in a given municipality. This phenomenon aligns well with the findings of Bazzi (2017) and is related to the findings of Cattaneo and Peri, (2016) and Gazeaud et al. (2023), who show that positive shocks to farming, as well as cash transfers, can lead to migration.

## 4.2 Additional Estimations

### *Joint effects of climatic stresses*

We examine possible combined impacts of different climatic stresses on emigration by augmenting equation (1) described in the methodology section with interaction terms of the climatic variables. The full estimation results are reported in Appendix **Table A.2** and summarized in **Figure 5**, which presents the percentage change in the average rural emigration rate exclusively associated with the combined increase of one period in each corresponding pair of climatic adverse indicators.<sup>16</sup>

We observe that the interactions of climatic events predominantly exhibit a positive association with emigration, except for heat combined with low soil moisture (that also have negative individual effects as discussed above). The magnitudes are though small and not always statistically significant. An increase in one period of drought combined with excessive rain increases the average rural migration rate by 0.28%, which is indicative of a larger variance in precipitation over the year that is not necessarily desirable for farmers due to likely frequent shifts between excessive and low precipitation. Hence, as rain is more volatile in an area, more people are emigrating the next period. A similar logic can be applied to the observed positive effect (0.13%) of an increase in excessive rain combined with low soil moisture on emigration. An additional period of excessive rain combined with 10 additional days of heat similarly increases the average emigration rate by 0.29%. The rest of the effects are not statistically significant. The results suggest that the occurrence of several climatic events at the same time within a year tends to affect individuals in rural areas in a more direct way (as many of them are devoted to agricultural activities), which compel them, although marginally, to emigrate.

### *Alternative definition of dependent and independent variables*

**Table A.3** in the Appendix presents the estimation results when separately considering alternative dependent and independent variables. In the first three columns of the table, we redefine our rural migration rate (i.e., our dependent variable) by changing the denominator. Rather than dividing the number of rural emigrants for a specific year by the official rural population of the municipality in 2018 (reported in the Census), we divide it by population projections for each respective year. These projections

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<sup>16</sup> For clarity of exposition, we only present effects on the overall emigration rate in the figure and not effects by sex.

were performed by the National Institute of Statistics (INE) in 2008 (covering the period 2008-2020). Given that these projections do not distinguish by area (urban and rural) or gender, we derive projections at the municipality-area-gender level by multiplying the municipal projections by the proportion of the rural population and male share in 2018 in every municipality. As observed, the drought variable continues to have a positive and statistically significant effect on emigration as in the base results, while the positive effect of excessive rain is now also significant. On the other hand, both heat and low soil moisture continue to have a negative effect on emigration.

In the last three columns of the table, we redefine our climatic (right-hand side) variables. Instead of considering the number of periods in a year that the climatic variable reaches a critical (given) threshold, we consider the maximum number of consecutive periods where this variable was consistently reaching the critical threshold. Given that uninterrupted periods of severe weather shocks are potentially worse than our baseline definition, we could expect the effects on migration rates to be larger. This only holds, however, for low consecutive intervals of soil moisture that have a larger negative effect on emigration the subsequent year, while extended heat periods have a similar effect as in our baseline model that considers the number of periods. In terms of rainfall, consecutive periods of drought have a lower effect than the base results but are not significant. Interestingly, prolonged heavy rainfall leads to a decrease in the rural migration rate for the total population as well as for both men and women.

#### *Alternative sample period and inclusion of control variables*

Our next exercise is to evaluate the sensitivity of our results to limiting the period of analysis and including time-varying control variables. In the first three columns of Appendix **Table A.4**, we report the results of limiting the study period to 2015-2018 (i.e., considering four instead of eight years of recall). As discussed above, the main two limitations of our data set are possible entire family migration and recall bias, such that reducing the study period can help to partially mitigate these concerns. From the table, we observe some variation in the magnitude of the coefficients for drought, excessive heat, and low soil moisture, relative to the base results, but their sign and significance level remains consistent. Drought particularly shows a larger positive effect in this case: an increase in one drought period is associated with a 3.7% increase in rural migration rate; an additional 3-day interval of low soil moisture is, turn, correlated with a 1% decrease in emigration.

In the remaining three columns of the table, we augment our base model defined in equation (1) with available municipality annual variables. While our main specification includes municipality and time fixed effects that permit to control for time-invariant unobservable differences across municipalities as well as by aggregate (national) shocks, there could be time-varying factors at the municipality level also influencing emigration decisions. In Central American countries, as noted earlier, some important push migration factors include violence and lack of economic opportunities that may vary across locations and years. More violence and crime activities in an area may encourage more people to emigrate, while more economic activity may have a dual effect: on one hand, it may increase the opportunity cost of a potential migrant, thereby reducing migration; on the other hand, income-constrained individuals experiencing an increase in their income, might boost migration. We accordingly add to our main specification lagged violence indicators (extortion and homicides rates) and per capita GDP available only from 2015 onwards such that we must limit the analysis to the 2016-2018 period and interpret the results accordingly (considering also that GDP values had to be extrapolated for some years as discussed above).

As observed in the table, violence and GDP are generally not statistically significant (except for the positive effect of GDP on men emigration). Regarding the weather variables, the positive effect of drought and negative effect of low soil moisture persist, and their magnitudes are somewhat comparable to the results when segmenting the study period to 2015-2018 (reported in the first three columns of the table). The effect of heat, however, loses significance, while excessive rain shows a positive and significant impact on rural emigration in this specification.

### *Effects on urban areas*

Lastly, we explore the potential effects of weather on the emigration rate in urban areas. The National Institute of Statistics (INE) of Guatemala broadly defines urban areas as cities, villages, towns, and populated places with more than 2,000 inhabitants, provided that 51% or more of the households have access to electric lighting and piped (tap) water in their dwellings. While adverse weather events should affect to a lower extent migration decisions in urban areas that typically rely on economic activities other than agriculture, certain urban areas, such as peri-urban areas and small population centers, may still depend to some extent on primary (agricultural) activities, making them exposed to climatic shocks.

Using the same specification as in our baseline model, the first three columns of Appendix **Table A.5** report the effect of climatic stresses on the urban emigration rate (analogously defined as the rural emigration rate). As in the case of rural areas, we observe a negative association between heat and low soil moisture and urban emigration the following year, although the magnitude of effects is somewhat lower (especially for soil moisture). Drought and excessive rain, on the other hand, do not seem to affect urban emigration flows.

As an additional robustness exercise and given the absence of data on the specific city or town of residence of the household, in the last three columns of Appendix **Table A.5** we further segment our sample to only include municipalities where all households are in urban areas. These are mostly municipalities that are administrative capitals of their departments (except for the departments of Alta Verapaz and Zacapa) plus the municipalities of San Pablo La Laguna (department of Solola), San Pedro La Laguna (Solola), and Cajola (Quetzaltenango). As observed in the table, we find that none of the climatic variables seem to have a significant effect on next year's migration rate, suggesting that in highly urbanized areas the effect of climatic stresses on emigration is almost negligible. These results provide additional support to our base results that exclusively focus on rural areas, although we acknowledge that this latter exercise may be influenced by lack of statistical power as the analysis is limited to 23 fully urban municipalities (over the period 2011-2018).

## **5. Concluding remarks**

International migration has surged by 62% during the past two decades and an important share of emigrants originate from rural areas in developing countries. This study evaluates the relationship between climatic stresses and rural emigration in Guatemala exploiting rich subnational data at the municipality level for the period 2011-2018. The estimation results show that drought periods are positively associated with emigration the following year, especially among men, while high temperature and low soil moisture periods are negatively associated with male and female emigration patterns.

Excessive rain periods are also positively correlated with emigration, but the effects are only statistically significant in a few model specifications. We similarly observe that the occurrence of several adverse weather situations at the same time within a year seems to contribute to emigration, although marginally. The apparent opposite effects of different adverse weather events point to both direct and indirect effects of climatic stresses on emigration decisions. On one hand, negative weather events, such as droughts, may translate into agricultural stress situations that may encourage people in rural areas to emigrate in search of better opportunities. On the other hand, in a context of high liquidity constraints and high costs of (irregular) migration, adverse weather conditions, such as prolonged days of heat and low soil moisture, may affect agricultural productivity and household liquidity that prevent people from eventually migrating, despite their willingness to emigrate.

These overall varying effects are in line with the related international literature and suggest that climate change is playing some role on emigration decisions in Guatemala, besides crime, lack of economic opportunities, and family reunification. The results remark the importance of performing additional studies, possibly using detailed microdata at the individual or household level, to fully understand the specific underlying mechanisms through which different weather anomalies operate directly or indirectly on emigration decisions. Besides gender, these decisions could vary, for example, by age, education, and region. This is key to develop better-tailored policies that align social protection, rural development, and climate action objectives and promote programs that mutually support food security and climate adaptation and mitigation. The seemingly mixed effects of weather anomalies on emigration flows indicate that it is critical to not only focus on public and private investments to increase agricultural resilience to climate change but also on investments that support sustainable development in rural areas beyond agriculture that can offer households alternative economic opportunities than emigrate.

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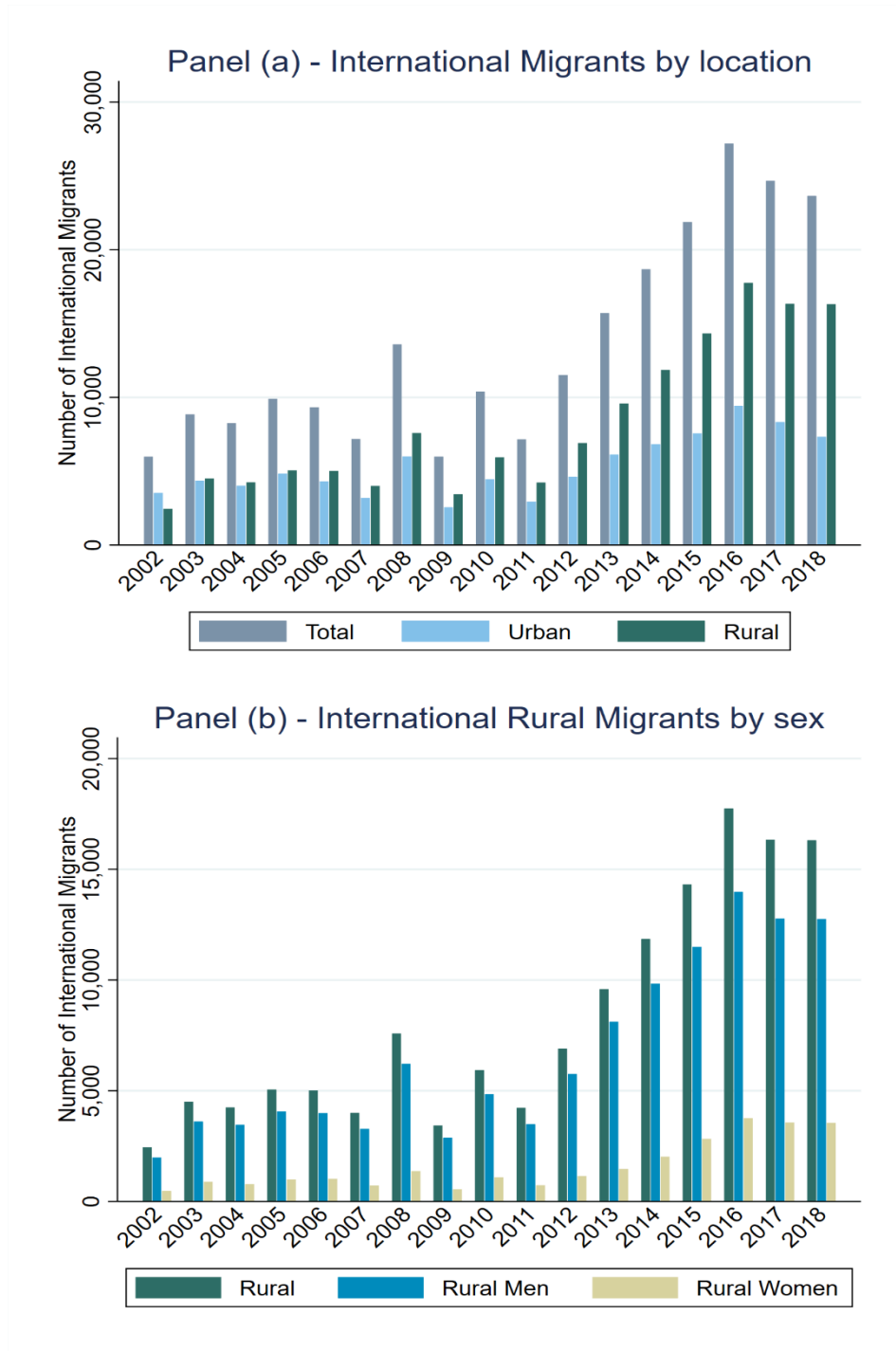
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Table 1. Summary statistics of migration and climatic variables at the municipality level, 2011-2018

Variable	N	Mean	SD	Min	Max
Rural emigration rate (per 10,000 inhabitants)	2,376	17.56	24.26	0	297.51
Rural male emigration rate (per 10,000 inhabitants)	2,376	29.28	41.25	0	527.66
Rural female emigration rate (per 10,000 inhabitants)	2,376	6.92	11.03	0	105.15
Number of 5-day periods of rain below 1 mm	2,376	6.30	6.73	0	23
Number of 5-day periods of rain above 100 mm	2,376	2.27	3.53	0	20
Number of days above 86F/30C	2,376	43.89	68.01	0	318
Number of 3-day intervals of soil moisture below 10 mm	2,376	2.25	7.11	0	42

Note: The unit of observation is a municipality-year. N = number of observations. SD = Standard deviation. Min = Minimum. Max = Maximum. mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.

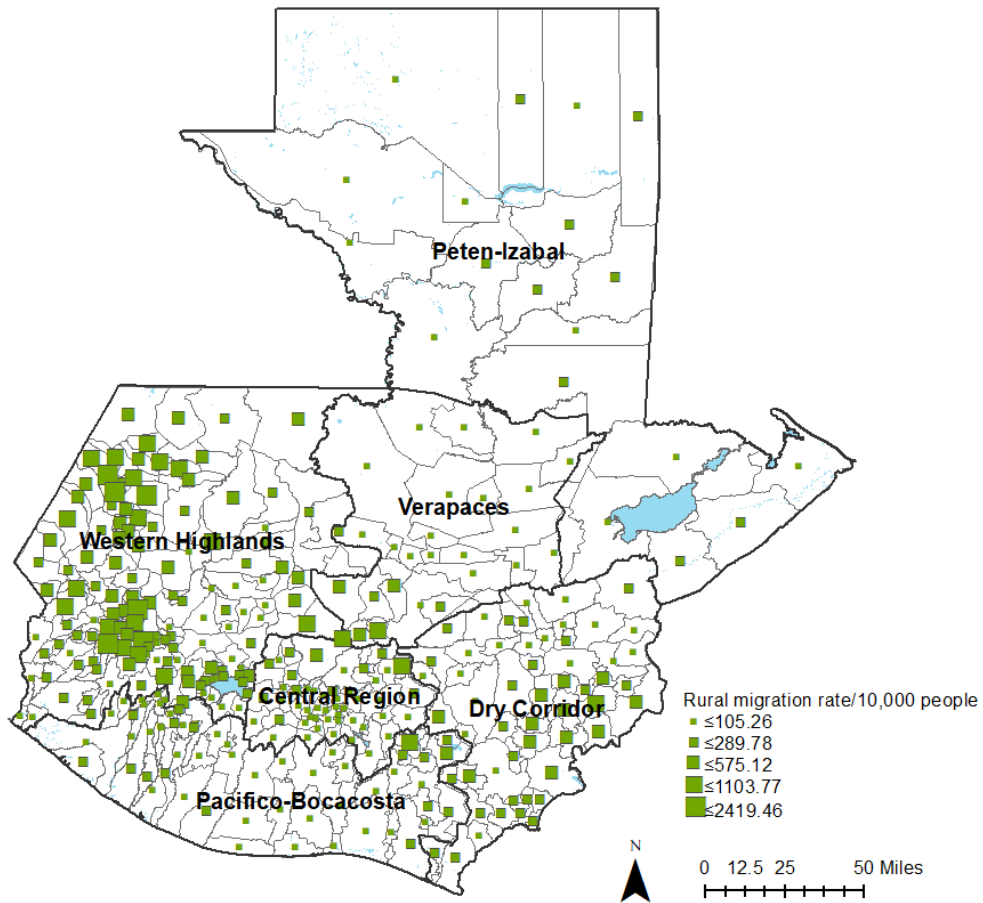
Figure 1. International Migration in Guatemala, 2002-2018



Source: 2018 Population and Housing Census (INE, 2020).

Note: The upper panel reports the annual number of international migrants by year and originating location (urban and rural), while the lower panel reports the annual number of international migrants from rural areas by year and gender.

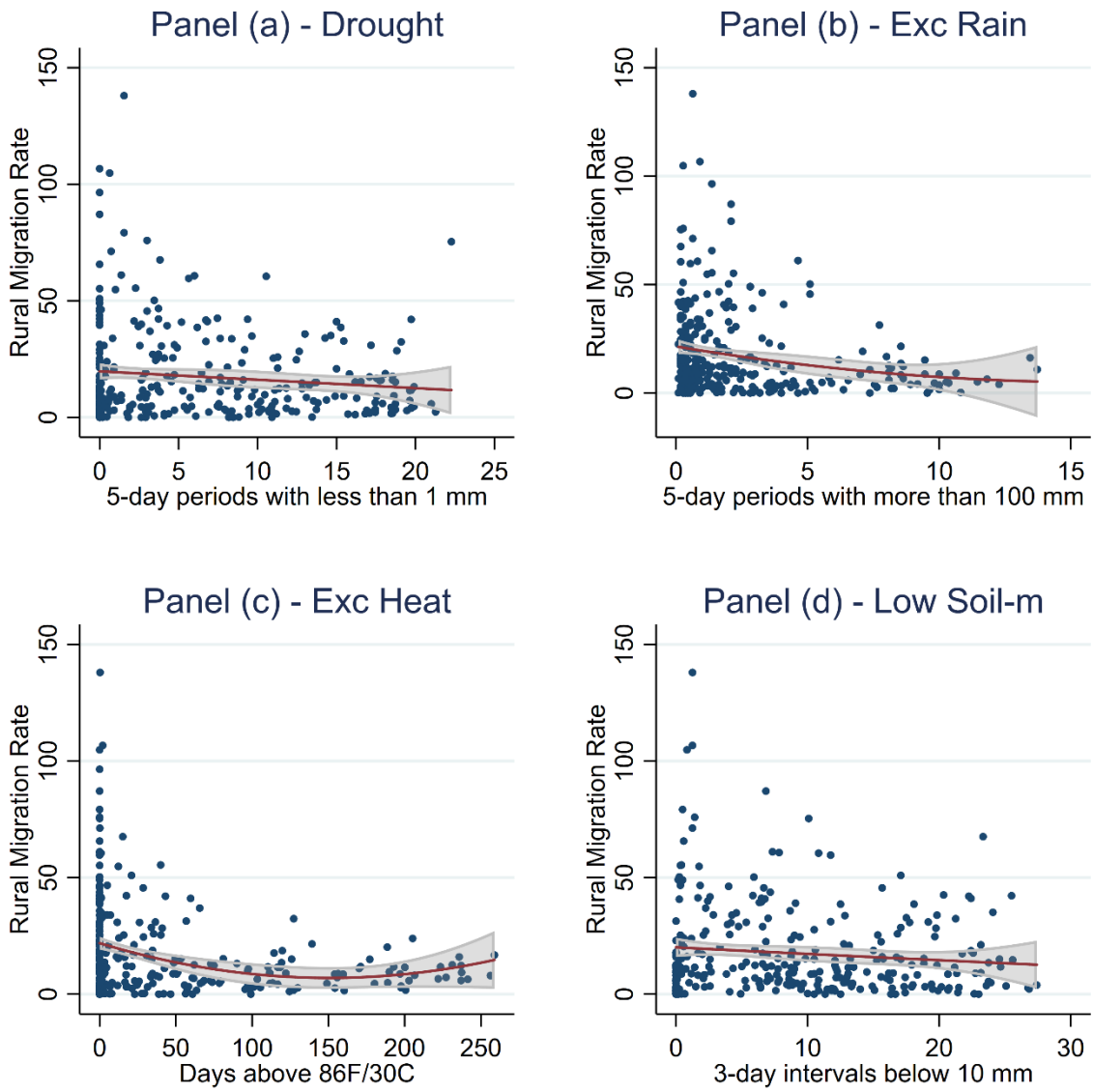
Figure 2. International Rural Migration Rate by Municipality, 2002-2018



Source: 2018 Population and Housing Census (INE, 2020).

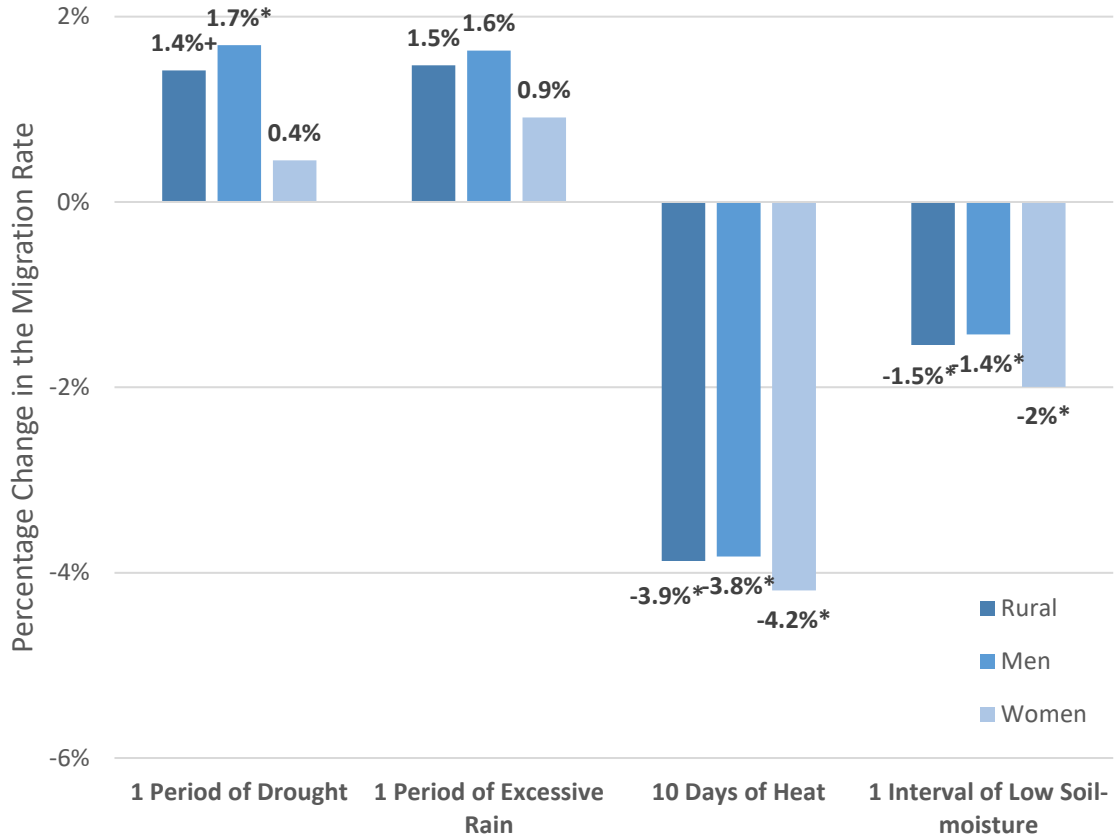
Note: The reported migration rate is based on the cumulative number of international rural migrants between 2002 and 2018 in each municipality, divided by the population of the municipality in 2018.

Figure 3. Average Rural Migration Rate by Municipality and Climatic Stresses, 2011-2018



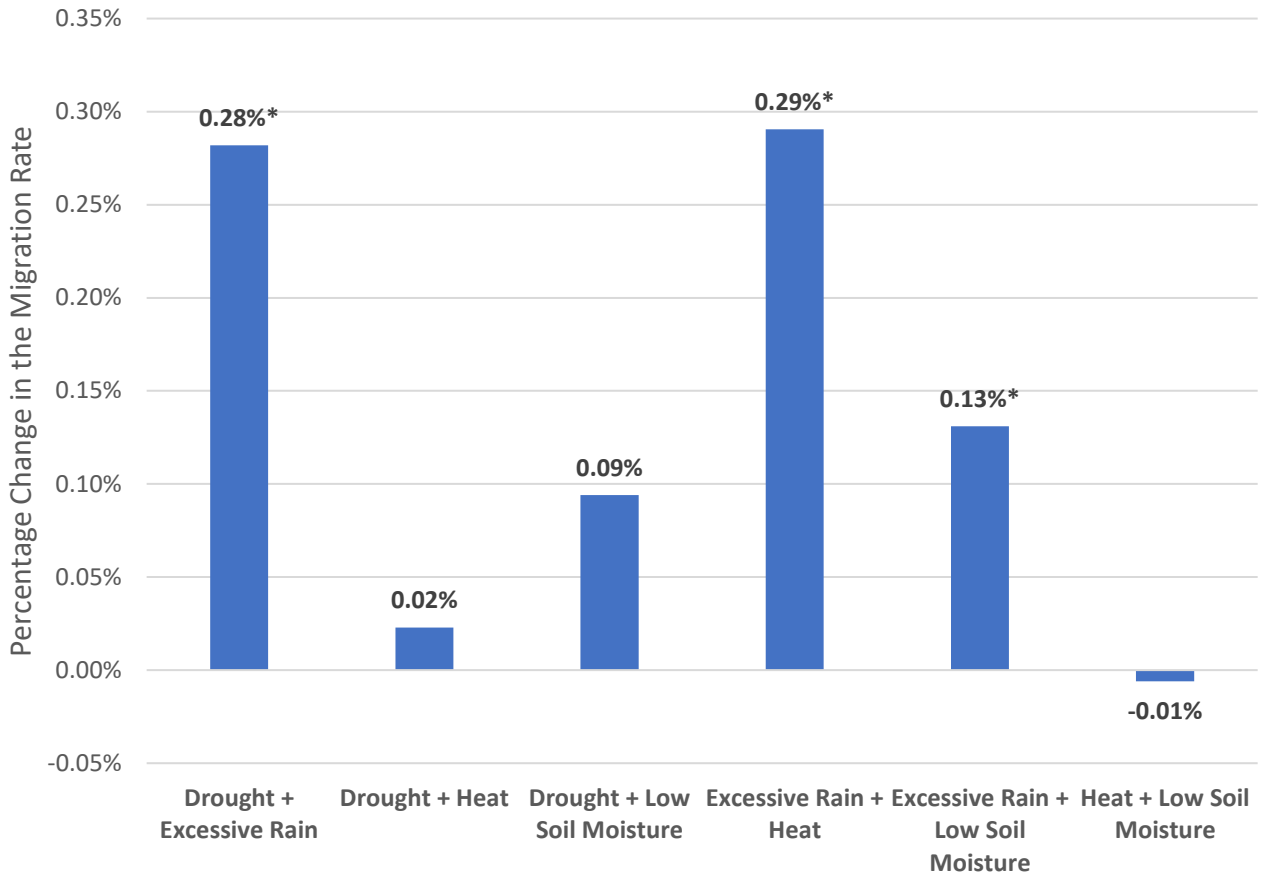
Note: The dots in the figures correspond to the average rural migration rate and climatic stressor variables by municipality over the period 2011-2018. The red line is the quadratic fit of the reported data and the grey area illustrates the 95% confidence band. mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.

Figure 4. Effect of Climatic Stresses on Rural Migration Rate, Total and by Sex



Note: This figure plots the percentage change in the average rural migration rate after an increase of one period or interval for our climatic variables (ten days for the case of heat), which are based on the estimation results reported in Appendix **Table A.1**. A period of drought and excessive rain corresponds to 5 consecutive days while one interval of low soil moisture corresponds to every 3 consecutive days. +, \* denote statistical significance at the 10% and 5% level, respectively.

Figure 5. Joint Effect of Climatic Stresses on Rural Migration Rate



Note: This figure plots the percentage change in the average rural migration rate after a joint increase of one period or interval in each two of our climatic variables (ten days for the case of heat), which are based on the estimation results reported in Appendix **Table A.2**. A period of drought and excessive rain corresponds to 5 consecutive days while one interval of low soil moisture corresponds to every 3 consecutive days. +, \* denote statistical significance at the 10% and 5% level, respectively.

## Appendix. Supplementary Tables

Table A.1. Effect of Climatic Stresses on Rural Migration Rate, Total and by Sex

Coefficients	(1) Migration Rate (Rural)	(2) Migration Rate (Rural Men)	(3) Migration Rate (Rural Women)
Lagged 5-day periods with rain less than 1 mm (Drought)	0.249* (0.142)	0.496** (0.229)	0.031 (0.078)
Lagged 5-day periods with rain more than 100 mm (Excessive Rain)	0.259 (0.181)	0.478 (0.299)	0.063 (0.090)
Lagged days with temperature above 86F/30C (Heat)	-0.068*** (0.018)	-0.112*** (0.029)	-0.029*** (0.010)
Lagged 3-day intervals of soil moisture below 10 mm (Low Soil Moisture)	-0.271*** (0.063)	-0.418*** (0.103)	-0.138*** (0.033)
Constant	6.247*** (1.676)	9.724*** (2.834)	3.054*** (0.845)
Observations	2,376	2,376	2,376
R-squared	0.224	0.206	0.201
Number of Municipalities	297	297	297
Time and Municipality FE	YES	YES	YES

Note: This table reports the coefficients of the fixed-effects (FE) regression model specified in equation (1) in the methodology section. All climatic variables are included in lags that correspond to the values of the previous year. Robust standard errors are reported in parentheses. \*, \*\*, \*\*\* denote statistical significance at the 10%, 5%, and 1% level, respectively. Mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.

Table A.2. Effect of Climatic Stresses and their Interactions on Rural Migration Rate, Total and by Sex

Coefficients	(1) Migration Rate (Rural)	(2) Migration Rate (Rural Men)	(3) Migration Rate (Rural Women)
Lagged 5-day periods with rain less than 1 mm (Drought)	0.105 (0.188)	0.271 (0.306)	-0.033 (0.098)
Lagged 5-day periods with rain more than 100 mm (Excessive Rain)	-0.229 (0.234)	-0.356 (0.390)	-0.120 (0.119)
Lagged days with temperature above 86F/30C (Excessive Heat)	-0.061*** (0.022)	-0.096*** (0.036)	-0.029** (0.012)
Lagged 3-day intervals of soil moisture below 10 mm (Low Soil Moisture)	-0.441*** (0.117)	-0.658*** (0.205)	-0.251*** (0.052)
Drought*Excessive Rain	0.050*** (0.017)	0.083*** (0.027)	0.019** (0.008)
Drought*Excessive Heat	0.000 (0.001)	0.000 (0.002)	0.000 (0.001)
Drought*Low Soil Moisture	0.016 (0.010)	0.023 (0.018)	0.011*** (0.004)
Excessive Rain*Excessive Heat	0.005*** (0.002)	0.009*** (0.003)	0.002* (0.001)
Excessive Rain*Low Soil Moisture	0.023** (0.010)	0.033* (0.018)	0.015*** (0.005)
Excessive Heat*Low Soil Moisture	-0.001 (0.001)	-0.002 (0.001)	-0.000 (0.000)
Constant	6.446*** (1.895)	9.873*** (3.190)	3.244*** (0.952)
Observations	2,376	2,376	2,376
R-squared	0.231	0.214	0.205
Number of Municipalities	297	297	297
Time and Municipality FE	YES	YES	YES

Note: This table reports the coefficients of the fixed-effects (FE) regression model specified in equation (1) in the methodology section where we added interaction terms between the climatic variables. All climatic variables are included in lags that correspond to the values of the previous year. Robust standard errors are reported in parentheses. \*, \*\*, \*\*\* denote statistical significance at the 10%, 5%, and 1% level, respectively. mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.

Table A.3. Effect of Climatic Stresses on Rural Migration Rate using Annual Population Projections and Alternative Climatic Indicators, Total and by Sex

Coefficients	(1) Migration Rate (Rural Projections)	(2) Migration Rate (Rural Men Projections)	(3) Migration Rate (Rural Women Projections)	(4) Migration Rate (Rural)	(5) Migration Rate (Rural Men)	(6) Migration Rate (Rural Women)
Lagged 5-day periods with rain less than 1 mm	0.240* (0.133)	0.477** (0.216)	0.030 (0.074)			
Lagged 5-day periods with rain more than 100 mm	0.327** (0.165)	0.581** (0.270)	0.099 (0.084)			
Lagged days with temperature above 86F/30C	-0.056*** (0.016)	-0.090*** (0.025)	-0.026*** (0.009)			
Lagged 3-day intervals of soil moisture below 10 mm	-0.224*** (0.057)	-0.352*** (0.095)	-0.108*** (0.028)			
Lagged 5-day consecutive periods with rain less than 1 mm				0.153 (0.130)	0.304 (0.211)	0.017 (0.074)
Lagged 5-day consecutive periods with rain more than 100 mm				-1.044** (0.455)	-1.574** (0.753)	-0.596** (0.231)
Lagged consecutive days with temperature above 86F/30C				-0.050*** (0.019)	-0.084*** (0.032)	-0.023** (0.010)
Lagged 3-day consecutive intervals of soil moisture below 10 mm				-6.918*** (1.625)	-10.757*** (2.654)	-3.423*** (0.848)
Constant	5.714*** (1.595)	8.930*** (2.699)	2.775*** (0.802)	8.065*** (1.039)	13.100*** (1.750)	3.555*** (0.546)
Observations	2,320	2,320	2,320	2,376	2,376	2,376
R-squared	0.230	0.211	0.198	0.222	0.203	0.202
Number of Municipalities	290	290	290	292	292	292
Time and Municipality FE	YES	YES	YES	YES	YES	YES

Note: This table reports the coefficients of the fixed-effects (FE) regression model specified in equation (1) in the methodology section where the dependent variable in the first three columns corresponds to migration rates per 10,000 rural inhabitants calculated as rural migrants divided by rural population projections for each year of the 2011-18 period (multiplied by 10,000) and the independent variables are the same as the ones defined in Appendix **Table A.1**. In the last three columns the dependent variable is similar to one defined in Appendix **Table A.1** but the climatic variables are alternative indicators; instead of using the number of periods (intervals) in a year that the climatic variable reached a critical threshold, we consider the maximum number of consecutive periods (intervals) when this variable was consistently above (below) the critical threshold. All climatic variables are included in lags that correspond to the values of the previous year. Robust standard errors are reported in parentheses. \*, \*\*, \*\*\* denote statistical significance at the 10%, 5%, and 1% level, respectively. mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.

Table A.4. Effect of Climatic Stresses on Rural Migration Rate Segmenting the Sample and adding Control Variables, Total and by Sex

Coefficients	(1) Migration Rate (Rural 2015- 2018)	(2) Migration Rate (Rural Men 2015-2018)	(3) Migration Rate (Rural Women 2015-2018)	(4) Migration Rate (Rural 2016- 2018)	(5) Migration Rate (Rural Men 2016-2018)	(6) Migration Rate (Rural Women 2016-2018)
Lagged 5-day periods with rain less than 1 mm	0.645*** (0.189)	1.022*** (0.305)	0.290** (0.133)	0.618*** (0.216)	0.972*** (0.361)	0.276** (0.139)
Lagged 5-day periods with rain more than 100 mm	0.108 (0.167)	0.197 (0.286)	0.026 (0.098)	0.737*** (0.243)	1.188*** (0.400)	0.315** (0.147)
Lagged days with temperature above 86F/30C	-0.026 (0.016)	-0.037 (0.026)	-0.018* (0.011)	-0.013 (0.016)	-0.011 (0.025)	-0.017 (0.012)
Lagged 3-day intervals of soil moisture below 10 mm	-0.168*** (0.043)	-0.253*** (0.077)	-0.093*** (0.025)	-0.101** (0.044)	-0.144* (0.080)	-0.063** (0.029)
Lagged extortions every 10,000 inhabitants				-0.149 (0.135)	-0.206 (0.231)	-0.098 (0.095)
Lagged homicides every 10,000 inhabitants				0.203 (0.277)	0.324 (0.448)	0.061 (0.160)
Lagged per capita GDP in US\$1,000				0.639 (0.388)	1.122* (0.638)	0.162 (0.191)
Constant	17.074*** (1.426)	28.366*** (2.326)	7.037*** (0.994)	18.093*** (2.714)	29.014*** (4.496)	8.738*** (1.604)
Observations	1,188	1,188	1,188	889	889	889
R-squared	0.074	0.063	0.064	0.070	0.064	0.040
Number of Municipalities	297	297	297	297	297	297
Time and Municipality FE	YES	YES	YES	YES	YES	YES

Note: This table reports the coefficients of the fixed-effects (FE) regression model specified in equation (1) in the methodology section where in the first three columns we segment the sample for the period 2015-18 and both the dependent and independent variables are the same as the ones defined in Appendix **Table A.1**. In the last three columns we alternatively augment equation (1) with time-varying municipal controls that include extortions, homicides, and Gross Domestic Product (GDP) for the year 2016-2018; while data on extortions and homicides is available from 2015 onwards, GDP data had to be extrapolated for some years as discussed in the main text. All climatic variables and controls are included in lags that correspond to the values of the previous year. Robust standard errors are reported in parentheses. \*, \*\*, \*\*\* denote statistical significance at the 10%, 5%, and 1% level, respectively. mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.

Table A.5. Effect of Climatic Stresses on Urban Migration Rate, Total and by Sex

Coefficients	(1) Migration Rate (Urban)	(2) Migration Rate (Urban Men)	(3) Migration Rate (Urban Women)	(4) Migration Rate (All Urban)	(5) Migration Rate (All Urban Men)	(6) Migration Rate (All Urban Women)
Lagged 5-day periods with rain less than 1 mm	0.033 (0.140)	0.087 (0.244)	-0.013 (0.093)	-0.056 (0.142)	-0.042 (0.231)	-0.067 (0.099)
Lagged 5-day periods with rain more than 100 mm	-0.064 (0.162)	-0.031 (0.257)	-0.095 (0.117)	-0.001 (0.315)	-0.057 (0.635)	0.030 (0.148)
Lagged days with temperature above 86F/30C	-0.072*** (0.016)	-0.109*** (0.026)	-0.039*** (0.013)	-0.001 (0.027)	-0.012 (0.051)	0.008 (0.015)
Lagged 3-day intervals of soil moisture below 10 mm	-0.230*** (0.058)	-0.363*** (0.093)	-0.114*** (0.041)	-0.001 (0.041)	-0.250 (0.198)	0.185 (0.165)
Constant	8.425*** (1.602)	13.004*** (2.648)	4.393*** (1.176)	5.420* (2.868)	9.290* (5.105)	2.218 (1.851)
Observations	2,560	2,560	2,560	184	184	184
R-squared	0.148	0.122	0.109	0.207	0.168	0.277
Number of Municipalities	320	320	320	23	23	23
Time and Municipality FE	YES	YES	YES	YES	YES	YES

Note: This table reports the coefficients of the fixed-effects (FE) regression model specified in equation (1) in the methodology section where the dependent variable across the six columns corresponds to urban migration rates per 10,000 urban inhabitants. This is calculated as the number of urban migrants every year divided by the 2018 urban population in the municipality multiplied by 10,000. In the first three columns, we consider all the municipalities that at least comprise an urban sector. In the last three columns, we only consider municipalities where the entire municipality comprises an urban area; these 23 municipalities include all those that are the capital of their corresponding department (except for the capitals of the department of Alta Verapaz and Zacapa), plus the municipalities of San Pablo La Laguna (department of Solola), San Pedro La Laguna (Solola), and Cajola (Quetzaltenango). The climatic variables are the same as the ones defined in Appendix **Table A.1** and all are included in lags that correspond to the values of the previous year. Robust standard errors are reported in parentheses. \*, \*\*, \*\*\* denote statistical significance at the 10%, 5%, and 1% level, respectively. mm = millimeters. 86F/30C = 86 degrees Fahrenheit / 30 degrees Celsius.