Climate Change, Crop Yields and Mexico-U.S. Cross-border Migration

[Supporting Information]

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PART 1. Literature Review

Previous studies on environmental and climatic migration

A significant number of studies examine how climate and environmental factors affect general population growth patterns, and typically discern small effects. Rappaport (S1) regresses population growths in U.S. counties during 1970-2000 on indicators of weather and other controls. He finds that in general U.S. residents have been moving en masse to places with mild weather, characterized by warm winters, and cooler, less-humid summers. Similarly, Alvarez and Mossay (S2) analyze population data from the U.S. Census corresponding to the period 1790–1910, and find that population growth tends to be larger in zones with higher precipitation levels and higher temperatures. Deschenes and Moretti (S3) also find that the U.S. population has been moving from cold Northeastern states to the warmer Southwestern states. Further, the probability of moving to a state that has fewer days of extreme cold is higher for the age groups that are predicted to benefit more in terms of lower mortality compared to the age groups that are predicted to benefit less. Cheshire and Magrini (S4) investigate differences in the rate of growth of population across the large city-regions of the European Union (EU)-12 between 1980 and 2000. They found that cities with warmer weather within countries have systematically tended to gain population over the past 20 years. But there is no such effect for climate variables if expressed relative to the value of the EU-12 as a whole.

Other studies focus on how a given climatic event or process triggers out-migration. Boustan, Fishback and Kantor (S5) study the impact of internal migration in the United States on local labor markets during the period of Great Depression (1930s). They use extreme weather events and generosity in New Deal policies in sending areas to instrument for migration to receiving areas based on geographic proximity. They are able to calculate five-year migration rates at the city level, in terms of the number of migrants arriving in (or leaving) a city between 1935 and 1940 as a share of the existing population. In their first stage regression on determinants of migration, three weather variables are used: months of severe or extreme wetness during 1935-39, wet months, and average temperature during 1935-39. Several papers study how populations flee and return to hurricane-affected areas based on recent U.S. experiences (S6-S8).

There are also studies that focus on migration responses to climate and environmental factors in a rural developing country setting. Findley (S9) studies migration from rural Mali during the 1983 to 1985 drought using longitudinal data. She finds that long-distance migration decreased during drought periods, and suggests that this could be explained by the fact that food scarcity leads to increased prices, forcing people to spend more money on their basic needs rather than long-distance migration. However, short-distance migration to larger agglomerations increased during drought years as women and children left in search of work to contribute to household incomes. Meze-Hausken (S10) analyzes the adaptation capacity of subsistence farmers in Northern Ethiopia, and evaluates historical experiences gained from drought-induced migration. Through a survey of 104 peasants who had to migrate due to persistent drought, she shows that vulnerability to climate change is a complex issue, and depends on multiple factors that comprise the household environment. But to be vulnerable does not make someone a potential climate migrant, as people in marginal regions have developed a great variety of adaptation mechanisms. Henry, Schoumaker, and Beauchemin (S11) use event history analyses to investigate the impact of rainfall conditions on the risk of out-migration from Burkina Faso villages. They find that people from the drier regions are more likely than those from wetter areas to engage in both temporary and permanent migrations to other rural areas.

Saldaña-Zorrilla and Sandberg (S12) study Mexico for the period of 1990-2000 and find that numbers of climate-related disasters are positively associated with out-migration. They use data at the municipality level and control for spatial correlations among those municipalities. Because they have also controlled for other factors such as low income population share, access to credit, agricultural prices and education levels, their study shows that climate may have an independent role to play on migration. Their study, however, is subject to potential omitted variable bias problem as the data is cross-sectional.

Deshingkar and Grimm (S13) discuss voluntary internal migration patterns in the world. They claim that the “push” factors of out-migration are mostly related to declining opportunities in agriculture, such as drought, water-logging, land fragmentation and river-bank erosion. Nevertheless, there is very little empirical work on how changes in agricultural sector affect migration. O'Rourke (S14) studies the impact of Irish Famine of 1845-1849, and concludes that the famine played a significant role in unleashing the subsequent emigration.

Most existing forecasts regarding future environmental migrants in the world are based on some back-of-the-envelope calculations. For example, Myers (S15) claims that by 2050, up to 200 million people would be forced to migrate as a consequence of climate change, through effects such as rising sea levels, heavier floods, more severe storms, and more frequent and persistent droughts. See also Myers (S16, S17), Brown (S18) and the Stern Review (S19). According to Warner et. al. (S20), estimates of total number environmental migrants range from 25 to 50 million by the year 2010 to almost 700 million by 2050. To date, no study has explored the possible impact of future climate change on migration using a rigorous empirical framework.

Background on Mexico Emigration and Agriculture

With more than 10% of all Mexican-born people living in the United States, Mexico is one of the most significant emigration-source countries in the world (S21, S22). Studies show that Mexican emigration to the U.S. accelerated considerably after 1994, following the inception of North American Free Trade Agreement (NAFTA) and the Mexican Peso crisis, wherein the Peso depreciated considerably against the US dollar, doubling the real wage rate earned by emigrants. Despite intensified border enforcement in the United States following September 11, 2001, the rate of emigration continued to be high until the recession in 2008 (S23). Rather than curtailing migration pressures, intensified security mainly turned transitory migrants into permanent ones (S24, S25). The large-scale emigration was partly due to network effects (S26) - the presence of earlier cohorts of migrants allowed newcomers to assimilate more easily into the U.S. economy.

The agriculture sector plays a significant role in emigration from Mexico. For people in rural Mexico, especially marginalized areas, migration to urban areas and abroad has been traditionally a major "coping strategy" to maintain a certain standard of living (S12). When crop yield declines and rural livelihood becomes increasingly harsh, the alternative option of outmigration becomes more attractive, both due to the increased expected urban-rural income differential (S27) and from a risk management perspective (S28, S29).

Since the early 1990s, the reform of the land tenure system and the opening of Mexico's economy through liberalized trade and deregulation of markets have transformed the Mexican agriculture sector (S12, S30, S31). Small farmers and rural laborers were further impoverished from the recent changes, especially those who cultivated marginal and rain-fed lands (S32). Many subsistence farmers fled north due to increased importation of corn and other crops (S31, S33). We suspect that weather has always been an important factor in the agriculture-emigration relationship, as many of the migrant-sending regions of Mexico have extremely variable rainfall (S34). For example, the 1994-96 drought in northern Mexico led to widespread and significant crop failure and livestock losses, and was at least anecdotally associated with substantial out-migration (S35). Studies have also examined the effect of soil erosions and desertification in Mexico, which is closely related to changes in climate, on emigration, although no quantitative results are available due to lack of data (S36, S37). Alscher (S37) reviews many previous studies on environmentally induced migration in Mexico, and reports two case studies in Chiapas and Tlaxcala establishing a clear linkage between environmental degradation and migration.

The spatial structure of Mexico's agriculture sector also has important implications for the climate-emigration relationship. The northwest and portions of the central region of Mexico are characterized by large-scale competitive producers. On the other hand, intermediate producers and subsistence farmers are more concentrated in the southern and central states, places with strong outmigration traditions. Thus farmers from these areas have particular high sensitivity to migrate in response to adverse shocks including those associate with changes and variability in climate. This is especially so in the post-NAFTA era, when trade liberalization has disproportionate negative impacts on intermediate producers and small subsistence farmers, making rural people's livelihood increasingly difficulty by limiting their local off-farm work opportunities and dampening corn price (S31). See also Wilder and Whiteford (S38).

PART 2. Data

Emigration data

We derive Mexican emigration data from Mexican Census of 1995, 2000 and 2005. The data are downloaded from the website of Integrated Public Use Microdata Series – International (IPUMS) at https://international.ipums.org/international. Because the Mexican Census data contain information on people's whereabouts five years prior to the Census, we are able to take a residual approach to derive the number of emigrants for the two periods of 1995-2000 and 2000-05. The residual approach has been widely used in estimating undocumented immigrants in the literature (S39).

$$E_{it} = POP1_{it} - POP2_{it} - DOM\_OUT_{it} + IN\_MIG_{it} - DEATH_{it}$$

Where:

E_{it}: number of international migrants (aged between 15 to 65 at the beginning of t) from state i in period t (1995-2000 or 2000-05).

$POP1_{it}$: total population (15-65) in state i at the beginning of time period t.

$POP2_{it}$: total population (20-70) in state i at the end of time period t.

DOM_OUT_{it}: number of people who migrated from state i to other Mexican states during period t. Those people were aged 15-65 at the beginning of t but 20-70 at the end of t.

IN_MIG_{it}: number of people who migrated to state i from other states of Mexico or abroad in period t. Again, they were aged 15-65 at the beginning of t but 20-70 at the end of t.

$DEATH_{it}$: number of people who were (15-65) in state i at the beginning of period t but died in period t.

For the period 1995-2000 (2000-05), note that $POP1_{it}$ can be calculated from the 1995 (2000) Census, while $POP2_{it}$, DOM_OUT_{it}, and IN_MIG_{it} can be calculated from the 2000 (2005) Census. $DEATH_{it}$ is estimated using age and gender specific projected five-year mortality rates for 1995 (2000) based on $POP1_{it}$[*].

Using Mexico Census data, we derive the total number of Mexican emigrants to be 3.3 million (or 6.1% of the population in 1995) for the period of 1995-2000 and 2 million (or 3.4% of the population in 2000) for the period 2000-05. These numbers come quite close to estimates made using U.S. data. For example, using U.S. Census and Current Population Survey data, Passel (S22) estimate that on average there were about 500,000 people migrated from Mexico to U.S. per year during the decade from 1995 to 2005, including both legal and undocumented immigrants.

Nevertheless, for the period of 2000-05, we have four states with negative numbers of emigrants (Table S1), suggesting there were some inconsistencies among censuses. If inconsistencies among different census years are systematic across states, then our analyses, which only use *cross-state* variations in terms of *changes* in emigration, remain valid. Hanson and McIntosh (S40) use a similar method, although technically speaking, they only calculate rates of change in population numbers for different cohorts, as they do not correct for internal migration and mortality. They argue that heterogeneity in mortality is unlikely to be a serious concern. Meanwhile, no alternative statistics exist on emigration by states in Mexico. For example, U.S.-based data, such as U.S. Census and Current Population Surveys, do not contain information about the state within Mexico the immigrant came from. Other Mexican-

[*] Secretatia de Programación y Presupuesto, Coordinación General del Sistema Nacional de Información, 1978. Proyecciones de la población mexicana, 1970-2000: nivel nacional. Evaluación y analisis. Serie 3 ; no.8.

based data, such as Mexican Migration Project, do not allow for estimating number of emigrants for each state.

Although we also have census data for the year 1990, using the residual approach, we find that many emigration numbers derived for the period of 1990-1995 are negative. Thus there seem to be some inconsistencies between the 1990 and 1995 censuses. We decided not to use data for the period 1990-1995 out of concerns for data quality.

Crop data

Our crop data were downloaded from the website of SAGARPA (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación), the ministry of agriculture of Mexico.

The exact steps involved when downloading the data for corn is as follows (last accessed on October 22, 2009):

(1) Go to http://www.siap.gob.mx/index.php?idCat=107.
(2) Choose a crop type in the third paragraph of the main text and click. For corn, click on "Maíz Grano", this gets one to http://www.siap.gob.mx/ventanaIM.php?idCat=198&url=w4.siap.gob.mx/AppEstado/Monografias/Monografias2/maizgran.html.
(3) Click "Sistema Producto" in the right panel, which connects to http://www.maiz.gob.mx/index.php?portal=maiz.
(4) Click “Anuario” under “Producción”.

For each crop, the data includes state-level information on area planted, area harvested, productions, and prices for each year in 1980-2007. We then calculate crop yields through dividing production by area planted. In some of our analyses, we combine corn and wheat to form a measure of combined crop yields. When doing so, we convert wheat production into equivalent corn production units using their price ratios calculated from the national weighted average prices for a given year. For the period of 1995-2005, wheat production consists about 20% of the total when adjusted for price. In all our main analyses, we take five-year period average yields for each Mexican state.

Climate data

Our climate data includes monthly precipitation and average temperatures for each Mexico state for the period since 1971. These data are obtained directly from the Servicio Meteorológico Nacional (http://smn.cna.gob.mx/). Again, for our analysis we take five-year period averages for each state.

Table S1. Data for Each Mexican State

A. For the period of 1995-2000

Mexican State	Log Corn Yield	Log Yield of Corn Plus Wheat	Ratio of Emigrants	Annual Precipitation (m)	Annual Mean Temperature (^{o}C)	Summer Mean Temperature (^{o}C)
Aguascalientes	-0.020	-0.018	8.4%	0.37	17.52	21.12
Baja California	0.893	1.549	6.4%	0.21	18.84	22.07
Baja California Sur	1.465	1.472	4.0%	0.18	22.46	25.56
Campeche	0.182	0.182	5.0%	1.41	26.13	27.91
Chiapas	0.581	0.581	6.0%	1.77	23.84	25.01
Chihuahua	0.685	0.757	7.3%	0.35	17.53	23.77
Coahuila	-0.297	0.010	6.2%	0.35	19.95	25.87
Colima	0.837	0.837	4.4%	0.85	25.12	26.76
Distrito Federal	0.505	0.505	2.3%	0.76	15.85	17.80
Durango	0.115	0.179	10.1%	0.34	17.36	22.32
Guanajuato	0.612	0.928	10.1%	0.56	18.41	21.38
Guerrero	0.762	0.762	7.6%	0.91	25.12	26.43
Hidalgo	0.504	0.514	8.4%	0.68	16.41	18.69
Jalisco	1.191	1.207	8.0%	0.62	20.54	23.49
México	1.247	1.223	3.2%	0.57	14.47	16.45
Michoacán	0.796	0.891	11.5%	0.63	19.68	22.13
Morelos	0.750	0.755	8.1%	0.98	21.75	23.52
Nayarit	1.034	1.034	9.3%	1.21	25.11	27.81
Nuevo León	-0.452	-0.297	5.3%	0.48	20.31	25.28
Oaxaca	0.178	0.174	5.9%	1.66	21.83	23.37
Puebla	0.409	0.418	4.3%	1.84	17.45	19.47
Querétaro	0.424	0.457	7.1%	0.40	18.32	21.28
Quintana Roo	-0.764	-0.764	4.1%	1.42	25.72	27.54
San Luis Potosí	-0.503	-0.503	8.2%	0.76	21.07	24.76
Sinaloa	1.719	1.686	6.2%	0.60	25.13	29.10
Sonora	1.545	1.663	6.9%	0.33	22.39	27.81
Tabasco	0.173	0.173	3.6%	2.37	27.20	29.37
Tamaulipas	0.572	0.499	7.9%	0.68	23.62	28.14
Tlaxcala	0.514	0.586	6.8%	0.84	14.46	16.33
Veracruz	0.492	0.491	5.9%	1.60	23.01	25.82
Yucatán	-0.421	-0.421	4.4%	0.96	26.36	28.30
Zacatecas	-0.228	-0.213	12.0%	0.46	17.22	21.35

B. For the period of 2000-2005

Mexican State	Log Corn Yield	Log Yield of Corn Plus Wheat	Ratio of Emigrants	Annual Precipitation (m)	Annual Mean Temperature (^{o}C)	Summer Mean Temperature (^{o}C)
Aguascalientes	-0.204	-0.205	1.5%	0.54	17.62	20.78
Baja California	0.987	1.509	3.2%	0.19	18.76	22.74
Baja California Sur	1.631	1.647	-0.6%	0.18	22.20	25.28
Campeche	0.218	0.218	2.5%	1.48	25.96	28.05
Chiapas	0.627	0.627	2.5%	1.99	23.84	24.80
Chihuahua	0.944	0.974	5.5%	0.42	18.24	24.42
Coahuila	-0.209	-0.075	0.7%	0.44	20.80	26.49
Colima	0.910	0.910	5.0%	0.86	25.71	27.10
Distrito Federal	0.428	0.428	1.3%	0.77	15.95	17.31
Durango	0.324	0.333	4.7%	0.41	17.53	22.05
Guanajuato	1.044	1.125	5.1%	0.76	18.19	20.66
Guerrero	0.804	0.804	7.9%	1.00	25.03	26.10
Hidalgo	0.794	0.792	4.5%	0.62	16.62	18.59
Jalisco	1.474	1.474	3.5%	0.78	20.53	23.10
México	1.181	1.164	3.7%	0.71	14.37	15.90
Michoacán	0.960	1.011	9.1%	0.88	18.28	20.33
Morelos	0.855	0.859	6.0%	1.04	21.24	22.76
Nayarit	1.274	1.274	6.8%	1.14	24.93	27.61
Nuevo León	-0.187	0.118	0.9%	0.67	18.25	21.95
Oaxaca	0.198	0.190	6.1%	1.54	22.57	23.81
Puebla	0.448	0.448	3.6%	1.52	17.73	19.66
Querétaro	0.862	0.867	-0.03%	0.59	18.11	20.16
Quintana Roo	-0.951	-0.951	-4.9%	1.43	25.59	27.18
San Luis Potosí	-0.485	-0.484	4.5%	0.77	21.25	24.45
Sinaloa	1.972	1.923	3.6%	0.62	24.91	28.91
Sonora	1.436	1.590	1.0%	0.36	22.43	28.50
Tabasco	0.394	0.394	1.8%	2.28	26.59	28.57
Tamaulipas	0.665	0.663	1.6%	0.81	23.66	27.56
Tlaxcala	0.795	0.779	0.4%	0.65	14.45	16.01
Veracruz	0.587	0.586	3.2%	1.72	23.26	25.78
Yucatán	-0.426	-0.426	-1.4%	0.92	26.17	28.31
Zacatecas	0.113	0.113	7.2%	0.56	16.90	20.36

PART 3. Additional Results

Reduced form regression

We first regress emigration rate on key climate variables to test for a reduced form relationship between climate and migration. Table S2 presents the results. The dependent variable is percentage of the population that emigrated during a five-year period from a state. The independent variables are state-level five-year averages of annual precipitation, annual mean temperature, and summer mean temperature, as well as their quadratic terms. Column (1) reports Pooled Ordinary Least Squares (Pooled OLS) estimates and column (2) shows Random Effects (RE) estimates, both assuming that unobserved state effects are orthogonal to climate variables. Column (3) presents Fixed Effects (FE) estimates that include unrestricted state dummy variables. Note that Pooled OLS and RE estimates have unexpected signs and are statistically rejected when compared to FE estimates. The Hausman test rejects the RE model at the 1% level, suggesting that unobserved state effects are important and correlated with climate. For example, the number of emigrants from the same region in the past, which is highly correlated with climate, likely also contributes to current emigration through network effects.

Based on the FE results, less rainfall, lower annual temperature and hotter summer weather all lead to an increase in out-migration. Although the quadratic terms are all negative, the implied “turning point” values beyond which relationships change signs are relatively large. The “turning point” values are 3.1 meters for annual rainfall and 32°C for summer temperature, which are greater than the maximum values for all states, thus the effect of rainfall on out-migration is always negative and the effect of summer temperature is always positive. For annual mean temperature, the “turning point” value is 23.5°C. Thus, below 23.5°C, temperature increase reduces out-migration but above it, further temperature increase actually raises out-migration. The climate variables collectively are also highly significant, with a p-value of 0.0003. Thus our reduced form results suggest there is a significant relationship between climate and emigration from Mexico.

Table S2: Reduced-form Regressions: Emigration on Climate

	Pooled OLS (1)	RE (2)	FE (3)
Annual Precipitation (m)	0.042	0.036	-0.125
	(0.036)	(0.040)	(0.180)
Annual Precipitation Squared	-0.018	-0.016	0.020
	(0.014)	(0.015)	(0.054)
Annnual Average Temperature (°C)	-0.029	-0.035	-0.304**
	(0.030)	(0.034)	(0.112)
Annnual Average Temperature Squared /100	0.058	0.070	0.648**
	(0.068)	(0.076)	(0.249)
Summer Average Temperature (°C)	0.054**	0.058**	0.142
	(0.026)	(0.029)	(0.134)
Summer Average Temperature Squared /100	-0.110**	-0.115*	-0.222
	(0.053)	(0.060)	(0.275)
State Dummies	No	No	Yes
Number of observations	64	64	64
P-value for joint significance of climate variables	0.0464	0.1972	0.0003
F statistics (p-value): Pooled OLS vs. FE		1.76 (0.0718)	
Hausman Test Statistics (p-value): RE vs. FE		17.69 (0.0071)	

Note: The dependent variable is the ratio of emigration population for 1995-2000 and 2000-05 periods. Constant terms are included in all regressions. The numbers reported in parentheses are robust standard errors. **, and * stand for statistical significance at 5% and 10% level, respectively.

First stage regressions for FE-TSLS and FE-LIML

Table S3 presents the first stage results. The dependent variable is natural log of corn yields in column (1) and the log yields of corn and wheat combined in column

(2). The independent variables are the same as in Table S2. The regression equations also include state dummies and are estimated using the FE method. Although none of the individual climate variables are significant, they are collectively highly significant at even the 0.1% levels. This suggests that changes in climate have substantial power in explaining changes in crop yields, thus our instrumental variable approach is valid.

Table S3: First Stage Regressions: Crop Yields on Climate

	Corn (1)	Corn plus wheat (2)
Annual Precipitation (m)	0.307	0.014
	(0.889)	(0.672)
Annual Precipitation Squared	-0.105	-0.022
	(0.256)	(0.197)
Annnual Average Temperature (°C)	1.016	0.727
	(0.617)	(0.554)
Annnual Average Temperature Squared /100	-2.055	-1.404
	(1.342)	(1.237)
Summer Average Temperature (°C)	-0.552	-0.278
	(0.567)	(0.445)
Summer Average Temperature Squared /100	0.719	0.093
	(1.047)	(0.842)
Number of Observations	64	64
Adjusted R^2 (including state dummies)	0.9613	0.9722
F statistics (p-value) of climate variables	5.5 (0.0009)	9.18 (0.0000)

Note: The dependent variable is natural log of corn yields in column (1), and natural log of combined yields of corn and wheat in column (2) for each Mexican state. State dummies are included in both regressions. Wheat production has been transformed to equivalent corn production using national average price ratios between the two crops in Mexico for each year under study. All variables are five-year averages.

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